ICEE

9-10th May 2013
School of Economics and Management, University of Porto

Energy & Environment: bringing together Economics and Engineering

CONFERENCE PROCEEDINGS

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International Conference on Energy & Environment: bringing together Economics and Engineering. Proceedings

Isabel Soares and Paula Ferreira (Editors)

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COMPETE

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It is a great pleasure to welcome you to the 1st International Conference on Energy & Environment: bringing together Economics and Engineering, ICEE, in Porto, Portugal, May 9-10, 2013.

The conference is organized by FEP (School of Economics and Management, University of Porto), CEF.UP (Research Center on Economics and Finance, University of Porto) and the CGIT (Research Center on Industrial Management and Technology) of the School of Engineering, University of Minho.

ICEE brings together leading academic scientists, researchers and scholars from the energy and environment science community to interchange knowledge, to discuss and to disseminate new ideas towards a low-carbon, sustainable future.

Indeed, energy and environment transition issues require much more than pure technology knowledge. Instead, they involve processes of technological transfer where economics, social sciences, and even politics play decisive roles.

On behalf of the organising committee, I wish you a pleasant stay in Porto and I hope that the conference will be a rewarding and useful experience for all the participants!

Isabel Soares

General-chair of the 1st ICEE

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Venue

The Conference will take place at:

School of Economics of the University of Porto
(Faculdade de Economia da Universidade do Porto - FEP)
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4200-464 Porto
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Conference Topics

•Energy System Analysis

•Economic Growth and Sustainability

•Technological Change and the Environment

•Wealth Accounting and Valuation of Ecosystems

•Energy Markets

•Markets and Drivers of Renewable Energy

•Energy Modelling

•Energy Technology

•Energy Efficiency

•Energy Projects Analysis

•Environmental and Social Impact Assessment

•Carbon markets

Keynote Speakers

HENRIK LUND

M.Sc.Eng, PhD, Dr.Techn. Henrik Lund is Professor in Energy Planning at Aalborg University in Denmark and Editor-in-Chief of Elsevier international journal ENERGY. Prof. Lund was head of department from 1996 to 2002 and has served as head of several large research projects in Denmark as well as in Europe. Prof. Lund holds a PhD in "Implementation of sustainable energy systems" (1990) and a senior doctoral degree in "Choice Awareness and Renewable Energy Systems" (2009). Prof. Lund has more than 25 years of research experience and involvement in Danish Energy Planning and Policy making. Among others, Prof. Lund has been involved in the making of the Danish Society of Engineers' proposal for a future 100% Renewable Energy Plan for Denmark. Prof. Lund was awarded a gold medal by the International Energy Foundation (IEF) for "Best Research Paper Award" within the area "Energy Policies & Economics" in 1998. And Prof. Lund is the main developer of the energy system analysis model EnergyPLAN, which is used by various researchers and energy planners around the world. Prof. Lund has contributed to more than 200 books and articles and is the author of the book "Renewable Energy Systems - The Choice and Modeling of 100% Renewable Solutions." (Academic Press, Elsevier 2010).

THE ECONOMIC CRISIS AND SUSTAINABLE DEVELOPMENT

This presentation describes and promotes strategies for how to use the present economic crisis and investments in sustainable energy as a driver for job creation and industrial development and, thereby, economic growth.

The presentation takes a historical point of departure in the economic crisis of the 70s and 80s, in which countries like Denmark experienced massive unemployment in combination with severe balance of payments deficits. However, an active Danish energy policy with a focus on sustainable energy and employment did succeed in stabilising the primary energy supply while maintaining economic growth and developing growth in exports related to sustainable energy. The Danish policy was based on active strategies of job creation, technological innovation, and concerns for the balance of payment. Especially in the 80s, such strategies played an important role in the implementation of investments in green technologies such as CHP plants, wind turbines, and renovation of buildings. Both at the governmental as well as at the municipal level, methodologies of including job creation benefits in socio-economic feasibility studies were developed and applied when political decisions were made. Expenses related to fossil fuels import were partly replaced by salary costs in Denmark. Moreover, the Danish export of green energy technologies has increased year by year and is now a major factor in the Danish economy. From being a burden to the Danish economy, the energy sector today makes a positive contribution to the GDP.

From such historical point of departure, this presentation promotes the thesis that the same type of strategies may be applied again today in Denmark as well as in similar countries. The presentation puts forward the results of a recent study entitled "Heating Plan Denmark 2010", showing how, over the next 20 years, fossil fuels can be replaced with biomass, solar, wind and geothermal energy. Over the course of the next 20 years, Denmark will be able to heat its homes, institutions and commercial buildings without any CO2 impacts on the climate.The conversion to renewable energy sources is projected to cost around DKK 70 billion over 10 years, but more importantly, it will result in the creation of 7-8000 additional jobs in Denmark, and it is therefore expected to give positive returns on the governmental expenditures. Tools and methodologies to conduct such analyses are presented.

HENK G. SOL

Prof. Henk G. Sol, born in 1951, graduated in 1974 "cum laude" from the University of Groningen, The Netherlands, with a MSc in Operations Research and Information Systems. He obtained a Ph.D. "cum laude" from the University of Groningen on the subject of ‘Simulation in Information Systems Development’ in 1982.

Since 2008 he is Professor of Business Engineering and ICT at the Faculty of Economics and Business at the University of Groningen. Since 2009 he acts as advisory professor to the Expertise Centrum in the Hague. His research focuses on innovation and ICT, organizational development and decision enhancement services. He is involved with designing information-intensive, innovative organizations in the domains of health care, energy and mobility. He is a well-known author with hundreds of publications in these fields.

Prof. Sol organized numerous international conferences and workshops and gave a great many invited presentations. He served in (senior) editorial roles with journals as Decision Support Systems, Information Systems Research, Electronic Journal of E-commerce, Organizational Science, Communications of AIS and Information and Management. He is member of IFIP TC 8, W.G. 8.1, 8.2, 8.4 and various other professional organizations. He received the IFIP Outstanding Service Award as well as the IFIP Silver Core. He is also one of the founding fathers of AIS and one of its first vice-presidents. He is initiator of the Council of Engineering Systems Universities and of the Global Technology and Management Consortium.

Prof. Sol has acted as a management consultant for several governments and a large range of national and international organizations since 1972. He is chairman/ member of the (Supervisory) Board of Directors of several companies.

SMART CONVERSATIONS FOR SUSTAINABLE DEVELOPMENT

Sustainable development is a major challenge in our ambient society, amplified by issues like population growth and availability of scarce resources. This calls for sustainable innovations. Many examples provide evidence that governance is required to enhance the decisions that matter for sustainable development.

Smart conversations are evidently contributing to deal with diversity in a global arena of local realities, with international ambitions grounded in regional communities, with functional approaches to interdisciplinary themes, with networks of public and private actors. They are supported by services for scoping, and facilitation, as recipes for decision enhancement, packed in suites or decision apps with guidelines for conversational inquiry.

NILS-HENRIK VON DER FEHR

Nils-Henrik von der Fehr is Professor of Economics and Head of Department at the Department of Economics at the University of Oslo, Norway.

Professor von der Fehr specialises in auctions, industrial economics, energy and environmental economics, regulation and antitrust. He has published extensively in these fields in books and journals such as Economic Journal, The Energy Journal, European Economic Review, International Journal of Industrial Organization, Journal of Environmental Economics and Management, Journal of the European Economic Association, Journal of Political Economy, RAND Journal of Economics and Scandinavian Journal of Economics.

Nils-Henrik von der Fehr has wide experience as consultant and advisor to governments, organisations and private companies around the world. He has worked on regulatory and other issues in the electricity and other sectors in countries such as Australia, Austria, Brazil, Colombia, Denmark, Guatemala, Honduras, Iceland, Ireland, Italy, The Netherlands, New Zealand, Norway, Sweden and the UK, as well as for international organisations like the European Commission, Inter-American Development Bank and the World Bank. He was a member of the Dutch Electricity Market Surveillance Committee and has been a member of and/or chaired a number of government commissions in his native Norway.

COST BENEFIT ANALYSIS OF ELECTRICITY INFRASTRUCTURE PROJECTS

The European Commission (DG Energy) is currently developing a Cost Benefit Analysis (CBA) method for the evaluation and ranking of projects in relation to the Energy Infrastructure Package. I discuss how such an analysis should be undertaken - including its scope, calculation of net benefits and ranking of projects - based on work recently undertaken by THINK. Recommendations include (1) interaction between projects must to be taken into account in the project and baseline definition; (2) data consistency and quality should be ensured; (3) conventional time horizon should be 20 years; (4) CBA should concentrate on a reduced list of effects and those should be monetised; (5) distributional concerns should not be addressed in the calculation of net benefits; (6) infrastructure costs need to be disaggregated; (7) the model used to monetise production cost savings and gross consumer surplus needs to be explicitly stated; (8) a common discount factor should be used for all projects; (9) a stochastic approach that is consistent with the Energy Roadmap 2050 should be used to address uncertainty; and (10) the ranking should be primarily based on monetised net benefit, but adjustments might be needed for competitive projects and uncertainty.

ANIL MARKANDYA

Professor Markandya has worked in the field of resource and environmental economics for over forty years and was one of the group that helped set up the European Association of Environmental and Resource Economists. He graduated from the London School of Economics with a Master of Science in Econometrics in 1968 and was awarded his Ph.D. from the same institution on the Economics of the Environment in 1975. He has published widely in the areas of climate change, environmental valuation, biodiversity, environmental policy, energy and environment, green accounting, macroeconomics and trade. He has held academic positions at the universities of Princeton and Harvard in the US and at University College London and Bath University in the UK.

He was a lead author for Chapters of the 3rd and 4th IPCC Assessment Reports on Climate Change, which were awarded a share of the Nobel Peace in 2007. In 2008 he was nominated by Cambridge University as one of the top 50 contributors to thinking on sustainability in the world and he won 2nd Prize for a paper delivered to the World Energy Council (2008 Meetings). In 2011 he was nominated as a Lead Author for the 5th IPCC Assessment (WGII), starting in 2011. In the same year he was elected the President of the European Association of Environmental and Resource Economics and in 2013 he became a member of the Scientific Council of the European Environment Agency.

Professor Markandya has also acted as a consultant to a number of national and international organisations and served as Lead Economist at the World Bank working in energy and environmental issues from 2000 to 2005. Anil Markandya is honorary Professor of Economics at the University of Bath, UK, Director of the Basque Centre for Climate Change in the Basque Country, Spain as well as President of Metroeconomica.

RATIONAL AND NON-RATIONAL FACTORS DETERMINING DIETARY CHOICES: THEIR IMPACTS ON HEALTH AND ON CARBON

There is currently a lot of public discussion on diet and health. Growing obesity and type II diabetes is a matter of concern in most countries, including developing ones. Overlaying this discussion is the policy debate on how best to reduce greenhouse gases to meet the climate challenge. One pathway for doing this is to mitigate emissions from agriculture, particularly livestock. Doing so offers a possible double dividend: less methane emissions to benefit the environment and less consumption of red meat to benefit personal health (Friel et al., 2009). The aim of this paper is to both non-economic factors and economic factors which potentially influence dietary habits. This involves recognizing that individuals are potentially influenced by information about products including that provided by labels but they are also influenced by prices and their incomes. The latter can be affected by taxes and subsidies, but they are also influenced by technological changes. We examine the impacts of taxes on red meat and saturated fats as well as programs to encourage the consumption of green vegetables on health indicators as well as on emissions of greenhouse gases.

Programme

TIME	Thursday – 9 May 2013
8:30 - 9:30	Registration
9:30 - 10:00	Opening session
10:00 - 10:30	Keynote speech by Henrik Lund
10:30 - 11:00	Keynote speech by Henk G. Sol
11:00 - 11:15	Discussion
11:15 - 11:45	Coffee break
11:45 - 12:15	Keynote speech by Niels von der Fehr
12:15 - 12:45	Keynote speech by Anil Markandya
12:45 - 13:00	Discussion
13:00 - 14:30	Lunch
14:30 - 16:00	Parallel sessions
	Economic Growth and Sustainability 1
	Technological Change and Environment 1
	Energy Modelling 1
16:00 - 16:30	Coffee break
16:30 - 18:00	Parallel sessions
	Market Power and Regulation
	Energy System Analysis 1
	Wealth Accounting and Valuation of Ecosystems
	Energy Efficiency 1
20:00	Gala Dinner
TIME	**Friday – 10 May 2013**
9:30 - 11:00	Parallel sessions
	Energy System Analysis 2
	Energy Markets 1
	Environmental and Social Impact Assessment 1
	Energy Technology 1
11:00 - 11:30	Coffee break
11:30 - 13:00	Parallel sessions
	Markets and Drivers of Renewable Energy
	Energy Markets 2
	Technological Change and Environment 2
	Economic Growth and Sustainability 2
13:00 - 14:30	Lunch
14:30 - 16:00	Parallel sessions
	Energy Modelling 2
	Environmental and Social Impact Assessment 2
	Energy Efficiency 2
	Energy Technology 2
16:00 - 16:30	Coffee break
16:30 - 18:00	Parallel sessions
	Energy Modelling 3
	Energy Projects Analysis
	Environmental and Social Impact Assessment 3

Final Programme

DAY 9 - 9:30
Room 631 - Opening Session
Prof. João Proença - Dean of the School of Economics, University of Porto
Prof. Isabel Soares - General-Chair of ICEE, Full Professor, University of Porto
Prof. Paula Ferreira - Professor of the School of Engineering, University of Minho

DAY 9 - 10:00
Room 631 - Keynote Speakers Session
Prof. Henrik Lund - Aalborg University
Prof. Henrik G. Sol - University of Groningen
Prof. Niels von der Fehr - University of Oslo
Prof. Anil Markandaya - Director of the Basque Centre for Climate Change

DAY 9 - 14:30		
Room 626 - Technological Change and the Environment 1		
On the effects of environmental policy in an endogenous growth model with dirty versus ecological technology	Mónica Meireles[1]; Isabel Soares[2]; Óscar Afonso[2]	[1]ISCTE-IUL and BRU-IUL; [2]FEP and CEFUP
A critical analysis of the sustainable consumption of bitumen in hot mix asphalt made with recycled concrete aggregates	Ignacio Pérez Pérez[1]; Ana Rodríguez Pasandín[1]; Nuria Calvo[1]; Jacobo Feás[2]	[1]University of A Coruña; [2]University of Santiago de Compostela
The technological and environmental efficiency of EU-27 power mix: an evaluation through MPT	Fernando de Llano Paz[1]; Susana Iglesias Antelo[1]; Anxo Calvo Silvosa[1]; Isabel Soares[2]	[1]Faculty of Economics and Business (University of A Coruña); [2]School of Economics, University of Porto
Leapfroging agriculture as usual: The potential contribution and sustainabilty benefits of organic farming to carbon sequestration in Portugal	Manuela Castro e Silva[1]; Margarida Silva[2]	[1]Faculdade de Economia da Universidade do Porto; [2]CBQF/Escola Superior de Biotecnologia da Universidade Católica Portuguesa

Room 613 - Energy Modelling 1		
Electricity decarbonisation pathways for 2050: a TIMES based approach in closed versus open systems modelling	Filipa Amorim[1]; André Pina[1]; Hana Gerbelová[1]; Patrícia Pereira da Silva[2]; Jorge Vasconcelos[1]; Victor Martins[3]	[1]MIT Portugal Program - Sustainable Energy Systems, IN+, Inst Sup Tecn, Universidade Técnica de Lisboa; [2]MIT Portugal Program - Sustainable Energy Systems, FEUC, Universidade de Coimbra and INESCC; [3]MIT Portugal Program - Sustainable Energy Systems, ISEG, Universidade Técnica de Lisboa
A multi-objective interactive approach to assess economic-energy-environment trade-offs in Brazil	Ariovaldo Lopes de Carvalho[1]; Carlos Henggeler Antunes[1]; Fausto Freire[1]; Carla Oliveira Henriques[2]	[1]University of Coimbra; [2]Polytechnic Institute of Coimbra
Renewable energy scenarios in the portuguese electricity system	Liliana Fernandes[1]; Paula Ferreira[2]	[1]University of Minho; [2]University of Minho
Scaling Laws and Electricity Consumption in Cities: a sectoral view	Ana Gonçalves[1]; Tiago Domingos[1]	[1]Instituto Superior Técnico

Room 639 - Economic Growth and Sustainability 1		
Useful work accounting: Final exergy-to-useful work analysis in Mexico from 1971 to 2009	Zeus Guevara[1]; André Serrenho[1]; Tânia Sousa[1]; Tiago Domingos[1]	[1]Instituto Superior Técnico
Impact of Electricity Consumption on Output in Malaysian Manufacturing Sector	Dzul Hadzwan Husaini[1]; Lean Hooi Hooi[2]	[1]Faculty of Economics and Business, Universiti Malaysia Sarawak; [2]Economics Program, School of Social Sciences, Universiti Sains Malaysia
Fuel wood use and Economic Growth in Ghana: Implications for Climate Change Mitigation	Jonathan D. Quartey[1]	[1]Department of Economics, Kwame Nkrumah University of Science and Technology
Analysis of green net national income and genuine saving: Portugal, 1991 - 2005	Rui Mota[1]; Tiago Domingos[1]	[1]IST UNL

DAY 9 - 16:30		
Room 626 - Energy System Analysis 1		
Application of solar lighting energy system: Anadolu Airport in Turkey	Nilgun F. Bayraktar[1]; Emre Kiyak[1]	[1]Anadolu University
Exergy-to-useful work analysis in Brazil from 1971 to 2009	Francisco Vieira de Sá[1]; André Cabrera Serrenho[2]; Tânia Sousa[2]	[1]Instituto Superior Técnico; [2]Department of Mechanical Engineering and IN+, Instituto Superior Técnico
Measuring the Impact of Renewable Energy Sources on the Optimal Generation Mix: An Application to the Iberian Electricity Market	Carla Manuela Tavares Mendes[1]; Isabel Soares[1]	[1]School of Economics, University of Porto
Electricity cost optimization in a renewable energy system	Sérgio Pereira, Paula Ferreira, A.I. Vaz	Center for Industrial and Technology Management, Universidade do Minho

Room 642 - Energy Efficiency 1		
Efficiency of the introduction of electric buses in public transport fleet	Marko Slavulj[1]; Davor Brčić[1]; Ljupko Šimunović[1]	[1]Faculty of Transport and Traffic Sciences University of Zagreb
An Economic Model For Waste to Heat District Greenhouse Heating	Mehmet Basak[1]; Suleyman Hakan Sevilgen[1]	[1]Yildiz Technical University
Knowing electricity end-uses to successfully promote energy efficiency in buildings: a case study in low-income houses in Southern Brazil	Arthur Santos Silva[1]; Fernando Luiz[1]; Ana Carolina Mansur[1]; Abel Silva Vieira[1]; Aline Schaefer[1]; Enedir Ghisi[1]	[1]Federal University of Santa Catarina
Characterisation and Modelling of Energy Behaviours	Marta Lopes[1]; Carlos Henggeler Antunes[2]; Nelson Martins[3]; Maria São João Breda[4]; Paulo Peixoto[5]	[1]INESC Coimbra and ESAC; [2]INESC Coimbra and University of Coimbra; [3]University of Aveiro; [4]Institute of Cognitive Psychology, University of Coimbra; [5]Centre for Social Studies, University of Coimbra

Room 613 - Market Power and Regulation		
Regulating International Gas Transport: Welfare Effects of Postage Stamp and Entry-Exit Systems	António Brandão[1]; Isabel Soares[1]; Joana Resende[1]; Joana Pinho[2]; Paula Sarmento[1]	[1]CEF.UP and Faculty of Economics of University of Porto; [2]CEF.UP. RGEA and Faculdade de Económicas. Universidad de Vigo
The impact of regulation, privatization and competition in gas infrastructure investments	Tiago Andrade[1]	[1]REN - Redes Energéticas Nacionais
Trading a Pumped Storage Hydro in a Liberalized Electricity Market with Increasing Degrees of Market Power	Fábio Teixeira[1]; Jorge Sousa[2]; Sérgio Faias[2]	[1]ISEL; [2]ISEL and Cie3/IST
The “Smart Paradox”: Stimulate the deployment of Smart grids with effective regulatory instruments	Vítor Marques[1]; Nuno Bento[2]; Paulo Morais Costa[3]	[1]ERSE, Portugal; [2]DINÂMIA´CET-IUL, ISCTE, Portugal; [3]Instituto Politécnico de Viseu, Escola Superior de Tecnologia e Gestão; INESC TEC – INESC Technology and Science

Room 639 - Wealth Accounting and Valuation of Eco Systems		
Non-market valuation of environmental resources in Portugal	Paula Simões[1]; Luís Cruz[2]; Eduardo Barata[2]	[1]Polytechnic Institute of Leiria; [2]GEMF, Faculty of Economics, University of Coimbra
Transport infrastructure project evaluation using cost-benefit analysis: how are environmental impacts assessed?	Heather Jones[1]; Filipe Moura[1]; Tiago Domingo[1]	[1]Insituto Superior Técnico
The carbon responsibility of capital and labour	Alexandra Marques[1]; João Rodrigues[1]; Tiago Domingos[1]	[1]Instituto Superior Técnico, Universidade Técnica de Lisboa, Lisbon, Portugal
Public opinion on renewable energy technologies. The portuguese case.	Fernando Ribeiro; Paula Ferreira; Madalena Araújo; Ana Cristina Braga	Universidade do Minho

DAY 10 - 9:30		
Room 642 - Energy Technology 1		
The usage of BiogasWebPlanner® system for analysis of biogas market tendencies in Poland	Pablo Cesar Rodriguez Carmona, Krzysztof Pilarski, Tomasz Kluza, Jacek Dach, Piotr Boniecki, Wojciech Czekała, Andrzej Lewicki, Damian Janczak, Kamil Witaszek	Institute of Biosystems Engineering, Poznan University of Life Sciences, POLAND
Prospects on employing microalgae into the production of biofuels: outcomes from a Delphi study	Lauro André Ribeiro[1]; Patrícia Pereira da Silva[2]; Teresa Margarida Mata[3]; António Areosa Martins[4]	[1]Energy for Sustainability Initiative - Univ. Coimbra and INESCCoimbra; [2]Faculty of Economics - Univ. Coimbra, INESCCoimbra and Energy for Sustainability Initiative; [3]Faculty of Engineering - University of Porto; [4]Faculty of Natural Sciences, Engineering and Technology - Oporto Lusophone University
Low intensity pretreatment before anaerobic waste activated sludge anaerobic digestion	Klaudiusz Grubel[1]; Jan Suschka[1]; Bozena Mrowiec[1]	[1]University of Bielsko-Biala
Influence of sewage sludge content in the mixture with sawdust and maize straw on composting process dynamics	Wojciech Czekała[1*], Jacek Dach[1], Jacek Przybył[1], Krzysztof Pilarski[1], Damian Janczak[1], Andrzej Lewicki[1], Kamil Witaszek[1], Pablo César Rodríguez Carmona[1], Robert Mazur[2], Krystyna Malińska[3], Magdalena Myszura[2]	Institute of Biosystems Engineering, Poznan University of Life Sciences, POLAND
Analytical and Computational Studies of Utilising LSCs Luminescent Solar Concentrators Incorporated With Multi-Junction Photovoltaic Cells in the UAE	Hisham Mashmoushy	Beirut Arab University, Beirut, Lebanon

Room 613 - Environmental and Social Impact Assessment 1		
An integrated modeling approach for greening commuters' transportation and parking	Luis Cruz[1]; Fausto Freire[2]; João-Pedro Ferreira[1]; Eduardo Barata[1]	[1]GEMF, Faculty of Economics, University of Coimbra; [2]ADAI-LAETA, DEM, University of Coimbra
Reducing energy use by dialogue marketing. A combined approach for mobility and households' energy use	Reinhard Hössinger[1]; Christoph Link[1]; Ulrike Raich[1]; Wiebke Unbehaun[1]	[1]Institute for Transport Studies, Department of Landscape, Spatial and Infrastructure Sciences, University of Natural Resources and Life Sciences Vienna, Austria
Wind Energy and local community perceptions	Fátima Lima[1]; Paula Ferreira[1]; Filipa Vieira[1]	[1]University of Minho
Economic, social, energy and environmental assessment of inter municipality commuting	João-Pedro Ferreira[1]; Pedro Ramos[1]; Luis Cruz[1]; Eduardo Barata[1]	[1]GEMF, Faculty of Economics, University of Coimbra
Evaluation of Post-2012 carbon policies	Dr. Olga Diukanova[1]	[1]Foundation for the Development of Environmental and Energy Markets

Room 626 - Energy System Analysis 2		
Energy planning with electricity storage and sustainable mobility: the study of São Miguel island	Miguel Moreira da Silva[1]; Manuel António Matos[2]; João Abel Peças Lopes[2]	[1]Faculdade de Engenharia, Universidade do Porto; [2]Faculdade de Engenharia, Universidade do Porto / INESC Porto
Useful work transitions for Portugal from 1856 to 2009. Intensities and European patterns.	André Cabrera Serrenho[1]; Benjamin Warr[2]; Tânia Sousa[1]; Robert U. Ayres[2]; Tiago Domingos[1]	[1]Instituto Superior Técnico, Technical University of Lisbon; [2]INSEAD
The systems of data acquisition in bioreactor for modeling of biowaste composting	Damian Janczak; Jacek Dach; Krzysztof Pilarski; Piotr Boniecki; Jacek Przyby; Andrzej Lewicki; Wojciech Czekała; Kamil Witaszek; Pablo César Rodríguez Carmona; Marta Cieślik	Institute of Biosystems Engineering, Poznan University of Life Sciences, POLAND
Selection of portfolios of electricity generation projects: an exploratory study	Eduardo Matos, Paula Ferreira, Jorge Cunha	Center for Industrial and Technology Management, Universidade do Minho

Potential Role of Stationary Urban Distributed Storage on the Management of Power Systems	José Gonçalves[1,3], António Martins[1,3], Luís Neves[1,2,3]	[1]University of Coimbra, [2] Polytechnic Institute of Leiria, [3] INESC Coimbra

Room 639 - Energy Markets 1		
Drivers for household electricity prices in the EU: a system-GMM panel data approach	Patrícia Pereira da Silva[1]; Pedro Cerqueira[2]	[1]Faculty of Economics - Univ. Coimbra, INESCCoimbra and Energy for Sustainability Initiative; [2]Faculty of Economics - Univ. Coimbra and GEMF
Causes of the volatility of electricity spot price in Brazil	Nivalde José de Castro[1]; André Luis da Silva Leite[2]; Guilherme de Azevedo Dantas[1]; Roberto Brandão[1]	[1]Federal University of Rio de Janeiro UFRJ Brazil; [2]Federal University of Santa Catarina UFSC Brazil
The welfare cost of energy insecurity	Baltasar Manzano[1]; Luis Rey[2]	[1]Universidade de Vigo and Economics for Energy; [2]Economics for Energy
Explanatory variables on South-west spot electricity markets integration	Nuno Figueiredo[1]; P. Pereira da Silva[2]	[1]MIT-Portugal - Universidade de Coimbra; [2]Faculty of Economics, University of Coimbra

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Environmental and Socio-Economic impact assessment of the production of kenaf (HIBISCUS CANNABINUS L.) when irrigated with treated waste waters	Bruno Barbosa[1]; Ana Fernando[1]; Benilde Mendes[1]	[1]New University of Lisbon
Electro-coagulation of raw water in batch using aluminium and iron electrodes	BELHOUT Dalila[1]	[1]National Polytechnic School, Algiers, Algeria
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Impact of fossil fuel costs on electric power prices. Empirical evidence of the Spanish case	María Teresa García-Álvarez; Blanca Moreno	[1]Unviersity of Oviedo; [2]University of Coruna
The Impact of EU ETS on the Spanish Electricity Prices	Carlos Pereira Freitas[1]; Patrícia Pereira da Silva[2]	[1]Institute of Engineering, Polytechnic of Porto and Faculty of Economics, University of Coimbra; [2]Faculty of Economics, Univ. Coimbra, INESC Coimbra and Energy for Sustainability Initiative
Copulas and CoVaR, with applications for the energy market	Romain Decet[1]; and Thorsten Lehnerty[2]	[1]Risk & Credit Management, Enovos Luxembourg S.A., and Luxembourg School of Finance, University of Luxembourg; [2]Luxembourg School of Finance, University of Luxembourg

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Entry strategies in the face of incumbents dominant position: the case of advanced renewable energy technologies	Margarida Fontes[1]; Cristina Sousa[2]; Silvana Pimenta[3]	[1]LNEG - Laboratório Nacional de Energia e Geologia; [2]DINAMIA´CET and ISCTE-IUL; [3]ISCTE-IUL

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Fossil&Renewable Energy Consumption, GHGs and Economic Growth: Evidence from a Panel of European Union (EU) Countries	Gulden Boluk[1]; Mehmet Mert[1]	[1]Akdeniz University
Towards sustainable product development: an environmental and economic study	Carla L. Simões[1]; Lígia M. Costa Pinto[2]; C. A. Bernardo[1]	[1]Institute for Polymers and Composites – IPC/I3N, University of Minho; [2]Department of Economics/NIMA, University of Minho
A Macroeconomic Model For An Oil Scarcity Scenario	O. Carvalho, J. Magalhães, T. Sousa	Instituto Superior Técnico Department of Mechanical Engineering

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Comparative performance of alternative ready-to-use LCIA methods: The case-study of the pulp and paper industry	Margarida S. Gonçalves[1]; Tânia Pinto-Varela[2]; Ana Paula Barbosa-Póvoa[3]; Augusto Q. Novais[1]	[1]LNEG; [2]LNEG, IST; [3]IST
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Methodology to develop integrated scenarios for electricity demand, mix electricity supply, price and GDP	Mário Brito[1]; Tânia Sousa[1]	[1]Department of Mechanical Engineering and IN+, Instituto Superior Técnico
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Room 613 -Energy Technology 2

Photovoltaic power predict using neural network	Samir H.OUDJANA[1]	[1]URAER
Support of Electric Energy Requirement at Educational Institutions with Photovoltaic Systems Generating Electricty from Solar Radiation	Ali Vardar[1]; Atalay Çetin[2]	[1]Uludag University; [2]Aksaray University
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The application of low temperature anaerobic digestion for BTX removal	Bozena Mrowiec[1]; Mariusz Kuglarz[1]; Lucyna Przywara[1]	[1]University of Bielsko-Biala

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A prospective analysis of the employment impacts of energy efficiency retrofit investment in Portugal by 2020	Carla Oliveira Henriques[1]; Dulce Coelho[2]; Patrícia Pereira Silva[3]	[1]ISCAC, Polytechnique Institute of Coimbra and INESC Coimbra; [2]ISEC, Polytechnique Institute of Coimbra and INESC COimbra; [3]Faculty of Economics, University of Coimbra
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Energetic efficiency analysis of the agricultural biogas plant in 250 kWe experimental installation	Jacek Dach, Krzysztof Pilarski, Piotr Boniecki, Jacek Przybył, Damian Janczak, Andrzej Lewicki, Wojciech Czekała, Kamil Witaszek, Pablo César Rodríguez Carmona, Marta Cieślik	Institute of Biosystems Engineering, Poznan University of Life Sciences, POLAND
A comparative study of the evolution on energy efficiency between 1960 - 2009 across 4 European countries	João Catarino[1]; André Cabrera Serrenho[1]; Tânia Sousa[1]	[1]Instituto Superior Técnico, Technical University of Lisbon

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A risk analysis of small-hydro power (SHP) plants investment	Jorge Cunha, Paula Ferreira	Center for Industrial and Technology Management, Universidade do Minho
Domestic photovoltaic systems: a finance-based MCDA approach	Dulce Coelho[1]; Carla Oliveira Henriques[2]; Patrícia Pereira Silva[3]	[1]ISEC, Polytechnic Institute of Coimbra; [2]ISCAC, Polytechnic Institute of Coimbra; [3]Faculty of Economics, University of Coimbra
Deploying a Renewable Energy Project: An Equilibrium Analysis	Luciana Barbosa[1]; Alberto Sardinha[2]	[1]Instituto Superior Técnico, UTL; [2]INESC-ID and Instituto Superior Técnico, UTL

DAY 9 - 14:30		
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A critical analysis of the sustainable consumption of bitumen in hot mix asphalt made with recycled concrete aggregates	Ignacio Pérez Pérez[1]; Ana Rodríguez Pasandín[1]; Nuria Calvo[1]; Jacobo Feás[2]	[1]University of A Coruña; [2]University of Santiago de Compostela
The technological and environmental efficiency of EU-27 power mix: an evaluation through MPT	Fernando de Llano Paz[1]; Susana Iglesias Antelo[1]; Anxo Calvo Silvosa[1]; Isabel Soares[2]	[1]Faculty of Economics and Business (University of A Coruña); [2]School of Economics, University of Porto
Leapfroging agriculture as usual: The potential contribution and sustainabilty benefits of organic farming to carbon sequestration in Portugal	Manuela Castro e Silva[1]; Margarida Silva[2]	[1]Faculdade de Economia da Universidade do Porto; [2]CBQF/Escola Superior de Biotecnologia da Universidade Católica Portuguesa

On the effects of environmental policy in an endogenous growth model with dirty versus ecological technology

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Abstract

This paper develops a Schumpeterian R&D growth model with endogenous directed technological change. The aim is to study the contributions of both environmental policies and technological environment to the production of ecological goods, when consumers are indifferent between ecological and dirty goods. By solving the transitional dynamics numerically and by removing the scale effects, it is shown that when green firms and green research are supported by policy and/or dirty activities are taxed, technological progress leads to relatively more production of ecological goods and environmental quality improvements, through the price channel together with the technological-knowledge-absorption effect.

Keywords: endogenous growth, technological knowledge, environmental policy, environment.

JEL codes: C61; O13; Q55; Q58

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1. Introduction

The growing consumption of dirty goods has raised several environmental problems, namely the accumulation of pollution in the atmosphere. How do governmental policy might contribute to increase the production of ecological goods and, consequently, to decrease Greenhouse Gas Emissions (GHG)?

In the past four decades, many arguments have been raised about the relationship between economic growth and the environment. However, most of them have focused on economic growth models with exogenous technology, where environmental policy exerts only temporary effects on growth. Consequently, a suitable framework should include the endogenous response of technological change (Acemoglu et al., 2011).

Our work relates to papers that study environmental policy using endogenous growth models with focus on the direction of technological change (e.g., Acemoglu et al., 2002, 2011; Ricci, 2007; Smulders and De Nooij, 2003). But, in contrast to those studies, we stress the price channel role in directing innovation towards the higher priced good. We use a dynamic general equilibrium growth model, with endogenous skill-biased technological change, to analyse the contributions of environmental policies to the production of ecological goods, when consumers are indifferent between dirty and ecological goods. Three productive sectors are considered: the final goods (FGs), the intermediate goods (IGs) and the research and development (R&D). FGs can be produced either by ecological or dirty technology. Firms producing with ecological technology can only use non-polluting IGs and skilled-labour contributing to reduce pollution. Those producing with dirty technology can only use polluting IGs and unskilled-labour contributing to increase it. The quality of IGs is raised by R&D.

In line with this thought, Acemoglu et al. (2011) propose a simple two-sector model of directed technical change. The unique final good is produced by combining the inputs produced by these two sectors, where one of these sectors uses dirty machines and creates environmental degradation. The research is directed at improving the quality of machines in one or the other sector. Unlike our study, they assume that consumers have environmental preferences. Other authors as Peretto (2009), study the effects of a tax on energy use in a modern Schumpeterian growth model where, like in our model, no scale effect is exhibited. In turn, Hart (2008), Grimaud and Rougé (2008) and Bovenberg and De Mooij (1997) study the effects of taxing pollution in an endogenous growth model, while for instance, Fullerton and Kim (2008), address the public abatement spending rather than public policies for private abatement R&D.

The remainder of the paper is organised as it follows. Section 2 presents the model. Section 3 analyses the steady-state equilibrium. Section 4 studies the transitional dynamics and proceeds to some sensitive analysis. Section 5 concludes.

2. The Model

2.1. Overview

Following Acemoglu and Zilibotti (2001), Barro and Sala-i-Martin (2004, ch. 7) and Meireles et al. (2012), each perfectly competitive FG $n \in [0,1]$ production is given by:

$$Y_n(t) = \left\{ A_D \left[\int_0^J \left(q^{k(j,t)} x_n(k,j,t) \right)^{1-\alpha} dj \right] \left[(1-n)\, d\, D_n \right]^{\alpha} + A_E \left[\int_J^1 q^{k(j,t)} x_n(k,j,t)^{1-\alpha} dj \right] \left[n\, e\, E_n \right]^{\alpha} \right\}, \tag{1}$$

(i) A is the exogenous productivity level, reflecting the dirty technological environment (A_D) or the ecological technological environment (A_E); (ii) integrals denote the contributions of IG, $x_n(k,j,t)$, adjusted by the highest environmental quality, $q^{k(j,t)}$ with $q>1$, obtained with each successful R&D; (iii) $j \in [0, J]$ for dirty IGs (*D*-IGs) and $j \in]J,1]$ for ecological IGs (*E*-IGs); (iv) *E* and *D* mean, respectively, the skilled and the unskilled labour; (v) $\alpha \in]0,1[$ and (1-α) indicate, respectively, the labour and the IG shares; (vi) $e>d\geq 1$ guarantees an absolute productivity advantage of *E* over *D* and *n* and (1-*n*) assure that *E* is relatively more productive in FGs indexed by larger *n*. As it will be shown later, this implies that there will be an endogenous FG, $\bar{n}$, that represents a "proxy" measure of the environmental quality. The aggregate output, *Y*, is then:

$$Y(t) = \int_0^1 p_n(t) Y_n(t)\, dn \;=\; exp\, [ln 1]\; exp \left[\int_0^1 ln\, Y_n(t)\, dn \right] \;=\; exp \left[\int_0^1 ln\, Y_n(t)\, dn \right] \tag{2}$$

where, for simplicity, the price of *Y* is normalized to one. All resources, *Y*, can be consumed, *C*, used in the IGs production, *X*, or directed to R&D, *RS*:

$$Y(t) = X(t) + RS(t) + C(t) \tag{3}$$

IGs are provided by a monopolistic firm whose production requires a start-up cost of R&D that is recovered by a patent law. Since IGs employ *Y*, the marginal costs (*MC*) of both IGS and FGs are equal (*MC*=1) and the profit maximization price of the IGs is:

$$p(k,j,t) = p = \frac{1}{1-\alpha}, \tag{4}$$

The top environmental quality good is *q* units better than the following and is priced at $1/(1-\alpha)$. Following Grossman and Helpman (1991, chap.4), we consider that the limit price is used to capture the whole market:

$$p = q, \text{ where } 1<q\leq [1/(1-\alpha)] \tag{5}$$

Therefore, the equilibrium of *X* and *Y* is:

$$X = \exp(-1)\left[(1-\alpha)/q\right]^{1/\alpha} \left[\left(A_D^{1/\alpha} Q_D\, d\, D_n \right)^{1/2} + \left(A_E^{1/\alpha} Q_E\, e\, E_n \right)^{1/2} \right]^2 \tag{6}$$

$$Y = \left[(1-\alpha)/q\right]^{-1} X \tag{7}$$

2.2. The Environmental Quality Measure

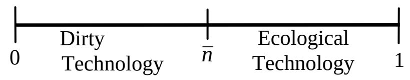
Following Meireles et al. (2012), in equilibrium, there will be a threshold FG $\bar{n} \in [0,1]$, such that only dirty (ecological) technology will be used to produce FGs indexed by $0 \leq n \leq \bar{n}$ ($\bar{n} < n \leq 1$). Given the labour supply and the TK, this $\bar{n}$ arises from the profit maximization of both perfect competitive FGs producers and monopolist IGs firms together with the full employment equilibrium in factor markets:

$$\bar{n} = \left\{ \left[\left(\frac{A_E}{A_D} \right)^{1/\alpha} \frac{e}{d} \, \frac{E}{D} \, \frac{Q_E}{Q_D} \right]^{1/2} + 1 \right\}^{-1} \tag{8}$$

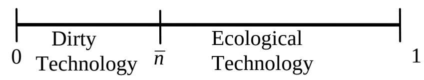
$$Q_D(t) \equiv \int_0^J q^{k(j,t)(1-\alpha)/\alpha} \, dj \ \text{ and } \ Q_E(t) \equiv \int_J^1 q^{k(j,t)(1-\alpha)/\alpha} \, dj \, , \tag{9}$$

Eq. (9) are aggregate quality indexes that evaluate the technological knowledge (TK) in each range of IGs and the ratio $Q_E / Q_D \equiv B$ measures the (ecological) TK bias:

(i) When $Q_E = Q_D$:



(ii) When $B \uparrow$:



Eq. (8) is a measure of the environmental quality in our model, indicating that the switch from dirty to ecological technology is advantageous. Small $\bar{n}$ means a relatively higher level of ecological goods production and thus, a better environmental quality and vice-versa. The price indexes ratio of ecological and dirty FGs is:

$$p(t) = p_E(t)/p_D(t) = \left[\bar{n}(t)/(1-\bar{n}(t))\right]^{\alpha}, \text{ where } \begin{cases} p_D = p_n (1-n)^{\alpha} = \exp(-\alpha)\,\bar{n}^{-\alpha} \\ p_E = p_n \, n^{\alpha} = \exp(-\alpha)(1-\bar{n})^{-\alpha} \end{cases} \tag{10}$$

Small $\bar{n}$ implies a small relative price of FGs produced with ecological technology. Hence, the demand for *E*-IGs is low, discouraging R&D that improves their environmental quality. Thus, labour and environmental quality levels affect the R&D direction through the FG price channel (e.g., Acemoglu, 2002).

The incentive to support R&D relies on the expected present value of profits flow:

$$V(k, j, t) = \Pi(k, j, t) / \left[r(t) + pb(j, k, t)\right] \tag{11}$$

The denominator is the interest rate plus the Schumpeter's creative destruction rate. R&D improves IGs and, hence, the quality indexes (9), while creatively destroying the previous profits. Following Aghion and Howitt (1992), innovations arrive with a Poisson probability distribution with an arrival rate $pb(k, j, t)$. Thus, the instantaneous probability of a successful innovation is given by:

$$pb(k, j, t) = rs(k, j, t)\, \beta\, q^{k(j,t)}\, \xi^{-1} q^{-(1/\alpha)\, k(j,t)} M^{-1}\, h(j) \tag{12}$$

(i) $rs(k, j, t)$ is the flow of *Y* devoted to R&D in *j*; (ii) $\beta\, q^{k(j,t)}$, $\beta>0$, is the positive learning effect of accumulated TK from past R&D in *j*; (iii) $\xi^{-1} q^{-(1/\alpha)\, k(j,t)}$, $\xi>0$, is the adverse effect caused by the increasing complexity of quality improvements in *j*; (iv) M^{-1}, with $M=D$ if $0\leq j\leq J$ and $M=E$ if $J<j\leq 1$, is the adverse effect of market size;[1] (v) $h(j)$ is the TK absorption effect that captures the absolute advantage of less over more polluted environment in implementing advanced TK (cleaner air improves health and workers productivity, and thus their capacity to adapt to new TK). Its proposed specification is:

$$h(j) = \begin{cases} 1 & , \, if \;\; 0 \leq j \leq J \\ \left[1 + A_E/(A_E + A_D)\right]^{\sigma} & , \, if \;\; J < j \leq 1 \end{cases} \qquad \text{where: } \sigma = 1 + A_E/A_D \tag{13}$$

Profits for a *j* firm, using a successful R&D of quality *k*, taking over the leadership are:

$$\Pi(k, j, t) = m\; M\,(q-1)\; \left[p_M\; A_M\; (1-\alpha)/q\right]^{1/\alpha}\, q^{k(j,t)\,(1-\alpha)/\alpha} \tag{14}$$

where $m=e$ for $M=E$ and $m=d$ for $M=D$.

Under free entry R&D equilibrium, the expected returns must equal the spent resources:

$$pb(j, k, t)\, V(k+1, j, t) = rs(k, j, t) \tag{15}$$

Thus, the TK growth rate equilibrium, Q_M, can be translated into the following TK path:

$$E(\Delta Q_M/Q_M) = \dot{Q}_M/Q_M = \underbrace{\left[\frac{\beta}{\xi}\frac{(q-1)}{q}\; (p_M\; A_M\; (1-\alpha))^{1/\alpha}\, m\; h(j) - r(t)\right]}_{pb_M} \left[q^{(1-\alpha)/\alpha} - 1\right], \tag{16}$$

where $[q^{((1-\alpha)/\alpha)}-1]$ is the effect of each successful R&D on TK and pb_M is the equilibrium probability of successful R&D. From (16) and computing pb_E-pb_D there is a dynamic price effect, indicating that there are stronger incentives to enhance TK embodied in high-priced goods.

We consider a time invariant number of heterogeneous individuals, $a \in [0, 1]$, who decide between working with ecological or dirty technology and between consumption and savings. For simplicity, individuals with higher ability $a>\bar{a}$ are assumed to be skilled and to perform better using ecological technology. Conversely, those with lower ability $a\leq\bar{a}$ are considered to be unskilled and to perform better using dirty technology. Each individual solves the Hamiltonian optimal control maximization problem of the following utility, subject to the intertemporal budget constraint:

[1] The difficulty in introducing new environmental quality adjusted IGs and replacing old ones is proportional to the market size (measured by labour), due to coordination among agents together with informational, organizational, transportation and marketing costs (Dinopoulos and Thompson, 1999).

$$U(a,t) = \int_0^\infty \left[\frac{c(a,t)^{1-\theta} - 1}{1-\theta} \right] \exp(-\rho t)\, dt \quad (17)$$

$c(a,t)$ is the consumption of *Y* by *a*, at *t*; $\rho > 0$ is the homogeneous subjective discount rate and $\theta > 0$ is the inverse of the intertemporal elasticity of substitution.

The solution for the individual's consumption path is the standard Euler equation:

$$\dot{c}(a,t)/c(a,t) = \dot{c}(t)/c(t) = \dot{C}(t)/C(t) = (1/\theta)\,[r(t) - \rho\,] \quad (18)$$

where $\dot{c}(t)/c(t)$ yields the growth rate of consumption.

2.3. Government Intervention

Since we assume that consumers are indifferent between ecological or dirty goods consumption, firms will not receive the incentives to produce relatively more ecological goods. Hence, they will produce according to their maximum profits and the environmental quality may fall below a critical threshold. In this context, the environmental policy should act to induce relatively more ecological goods production to decrease GHGs emissions. In the literature, there is a conventional wisdom that, from an efficiency perspective, market-based instruments are preferred over command-and-control instruments, since they equalize marginal abatement costs across firms, yielding statically efficient outcomes (Baumol and Oates 1994). Furthermore, market-based instruments are believed to be more effective in inducing technological change as they offer a permanent incentive to use lesser environmental commodities. Thus, we consider the market-based instruments as government policy, in our model.

Assuming, then, that government can subsidise the *E*-IG by paying an ad-valorem fraction, s_x, of each firm's cost and that it can tax the *D*-IG by charging an ad-valorem fraction, τ_x, of each firm's cost, the after subsidy or tax *MC* of producing *j* is ($MC+\varphi_x$), where φ_x denotes subsidies ($-s_x$) or taxes (τ_x). Thus, with government intervention the profit maximization price of the monopolistic IG firms (4), now yields $p=(1+\varphi_x)/(1-\alpha)$ and the limit pricing used to capture the whole market becomes:

$$p = q(1+\varphi_x), \text{ where } (1+\varphi_x)<q(1+\varphi_x)\leq[(1+\varphi_x)/(1-\alpha)] \quad (19)$$

With public policy the aggregate equilibrium of IG (6) and FG (7) is replaced by:

$$X \;=\; \exp\,(-1)[(1-\alpha)/q(1+\varphi_x)]^{1/\alpha}\left[\left(A_D^{1/\alpha}\, Q_D\; d\; D_n\right)^{1/2} + \left(A_E^{1/\alpha}\, Q_E\; e\; E_n\right)^{1/2}\right]^2 \quad (20)$$

$$Y = [(1-\alpha)/q(1+\varphi_x)]^{-1}\, X \quad (21)$$

In the same way, under free entry R&D equilibrium, the expected reward for pursuing the $(k+1)^{th}$ successful research, must equal the after subsidy cost of research:

$$pb(j,k,t)\,V(k+1,j,t)=(1-s_r)\,rs(k,j,t) \tag{22}$$

s_r is an ad-valorem subsidy to R&D that results in a R&D costs reduction and can be specific to ecological or dirty R&D. With public policy, the TK path is now:

$$E(\Delta Q_M/Q_M)=\dot{Q}_M/Q_M=\underbrace{\left[\frac{\beta}{\xi}\frac{(1+\varphi_{x,M})}{(1-s_{r,M})}\frac{(q-1)}{q}\left(\frac{p_M\,A_M\,(1-\alpha)}{(1+\varphi_{x,M})}\right)^{1/\alpha} m\,h(j)-r(t)\right]}_{pb_M}\left[q^{(1-\alpha)/\alpha}-1\right] \tag{23}$$

From (23), it is clear that R&D equilibrium rates reply negatively to the interest rate and to a raise in the exogenous tax rate of dirty-IGs, $\tau_{x,D}$ and positively to increase in the exogenous subsidy rates of both *M*-R&D, $s_{r,M}$, and ecological-IGs, $s_{x,E}$. Thus, the direction of the TK is driven by the price channel and can be affected by government.

The government budget is assumed to be balanced at each time:

$$\tau_k r(t)\int_0^1 K(a,t)da+\tau_M w_M(t)\int_0^1[u_w(a,t)M(a,t)]da+\tau_{x,D}X(t)=s_{x,E}X(t)+s_{r,M}RS(t) \tag{24}$$

The left-hand side of (24) is government tax revenue from assets income, $\tau_k r(t)K(t)$, from labour income, $\tau_M\,[w_E(t)E(t)+w_D(t)D(t)]$, and from an environmental tax on IGs that use *D*-technology, $\tau_{x,D}X(t)$. The right-hand side is government expenditures on environmental subsidies for *E*-IGs used by *E*-technology, $s_{x,E}X(t)$, and for R&D to enhance the environmental quality of both *E*- and *D*-specific IGs, $s_{r,M}RS(t)$.

Finally, the new solution for the individual's consumption path is:

$$\dot{c}(a,t)/c(a,t)=\dot{c}(t)/c(t)=\dot{C}(t)/C(t)=(1/\theta)\,[(1-\tau_k)\,r(t)-\rho\,] \tag{25}$$

where $\dot{c}(t)/c(t)$ yields the growth rate of consumption for all individuals.

3. The Steady State Equilibrium

In steady-state agents can maximize utility or profits and all markets clear. The dynamic equilibrium can be described by Q_E and Q_D paths. Since, in equilibrium *Y*, *X*, *RS* and *C* are all constant multiples of Q_E and Q_D, the stable and unique steady-state endogenous growth rate, $g^*(\equiv g_D^*\equiv g_E^*)$, is:

$$g^*=\left(\frac{\dot{Y}}{Y}\right)^*=\left(\frac{\dot{X}}{X}\right)^*=\left(\frac{\dot{RS}}{RS}\right)^*=\left(\frac{\dot{Q}_D}{Q_D}\right)^*=\left(\frac{\dot{Q}_E}{Q_E}\right)^*=\left(\frac{\dot{C}}{C}\right)^*=\left(\frac{\dot{c}}{c}\right)^*=\frac{1}{\theta}[(1-\tau_K)r^*-\rho]\Rightarrow\left(\frac{\dot{p}_E}{p_E}\right)^*=\left(\frac{\dot{p}_D}{p_D}\right)^*=\left(\frac{\dot{\bar{n}}}{\bar{n}}\right)^*=0 \tag{26}$$

Eq. (26) implies a constant steady-state interest rate, $r^*(\equiv r_D^*\equiv r_E^*)$, obtained by setting the consumption growth rate (25) equal to TK growth rate (23). g^* arises from plugging r^* into

(25). From (26), the steady-state TK bias B^*, remains stable. Equalising the steady-state growth rates of Q_E and Q_D, $\left(\dot{Q}_D/Q_D\right)^* = \left(\dot{Q}_E/Q_E\right)^*$, it can also be found p_M^* and $\overline{n}^*$.

By $s_{x,E}$ and $s_{r,M}$ government intervention positively affects r^* and hence g^*. Indeed, $s_{x,E}$ by increasing monopolistic profits, encourages R&D and $s_{r,M}$ by reducing R&D costs also stimulates R&D. Conversely, by $\tau_{x,D}$ and τ_K, government intervention negatively affects r^* and thus g^*. $\tau_{x,D}$ discourages R&D by decreasing the monopolistic profits and τ_K decreases investment in R&D, due to the smaller expected marginal benefit. Since τ_w is absent in equilibrium conditions, it does not directly affect g^*.

4. Transitional Dynamics and Sensitivity Analysis

We solve the model numerically to illustrate the effect of both government intervention and a positive change in the green technological environment, on both TK bias and on $\overline{n}$. From (23) and since r is unique, the stability of B is:

$$\frac{\dot{B}}{B} = \frac{\dot{Q}_E}{Q_E} - \frac{\dot{Q}_D}{Q_D} = \frac{\beta}{\xi}\left(\frac{q-1}{q}\right)(1-\alpha)^{1/\alpha}\exp(-\alpha)\left\{ e\left(1+\frac{A_E}{A_E+A_D}\right)^{\sigma}\left(\frac{1-s_{x,E}}{1-s_{r,E}}\right)\left(\frac{A_E}{1-s_{x.E}}\right)^{1/\alpha}\left[1+\left(\frac{Q_E}{Q_D}\frac{e}{d}\frac{E}{D}\right)^{-1/2}\right]^{\alpha} - d\left(\frac{1+\tau_{x,D}}{1-s_{r,D}}\right)\left(\frac{A_D}{1+\tau_{x.D}}\right)^{1/\alpha}\left[1+\left(\frac{Q_E}{Q_D}\frac{e}{d}\frac{E}{D}\right)^{1/2}\right]^{\alpha}\right\} \tag{27}$$

Table 1. Baseline parameter values

Parameter	Value	Parameter	Value
A_E	1.50	α	0.70
A_D	1.00	β	1.60
e	1.20	θ	1.50
d	1.00	ρ	0.02
E	0.70	σ	2.00
D	1.00	ξ	4.00
q	3.33	$s_{x,E}$, $s_{r,E}$, $s_{r,D}$ $\tau_{x,D}$	0.00

Source: Authors' assumptions based on theoretical framework and on the literature.

Considering the baseline values in Table 1, the paths of B and $\overline{n}$ are displayed in Fig.1(*a*-*f*) and Fig. 2(*a*-*f*), respectively.[2]

Figure 1*a*

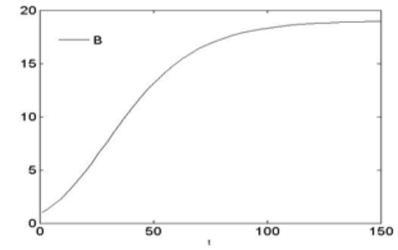


Figure 1*b*

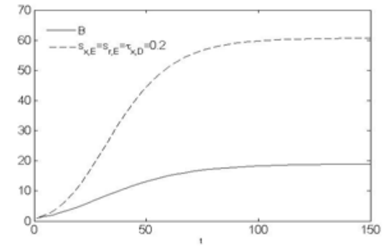


Figure 1*c*

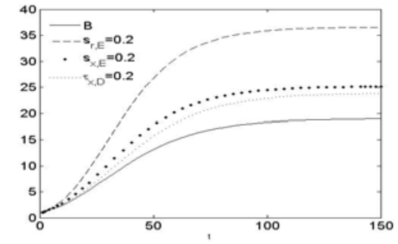


Figure 1*d*

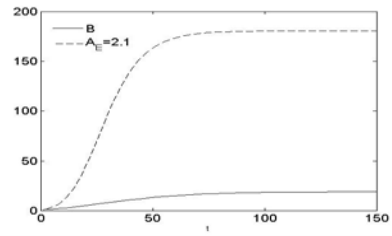


Figure 1*e*

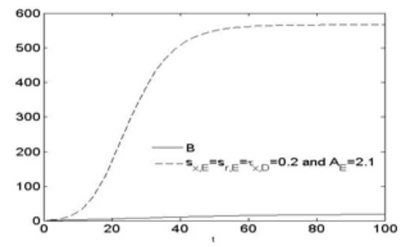


Figure 1*f*

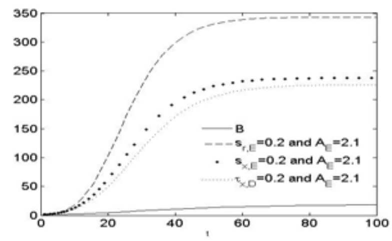


Figure 2*a*

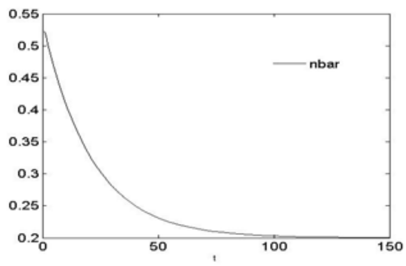
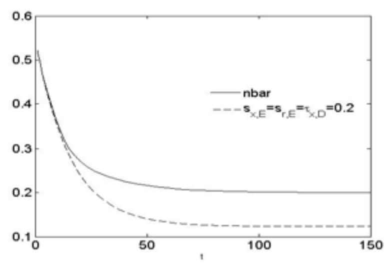


Figure 2*b*



[2] Parameter calibration is based on empirical literature and on theoretical specifications. q=(1/(1-α)), the mark-up ratio, is set in line with the mark-up estimates of Kwan and Lai (2003). θ is in accordance with previous calibrations of growth models, assumed to exceed one – e.g., Jones et al. (1993) and ρ follows from previous works on growth – e.g., Dinopoulos and Thompson (1999). The remaining parameters have been calibrated taking into account our theoretical assumptions and considering a steady-state growth rate of 2%, the average *per capita* growth rate of the USA in the post-war period.

Figure 2*c*

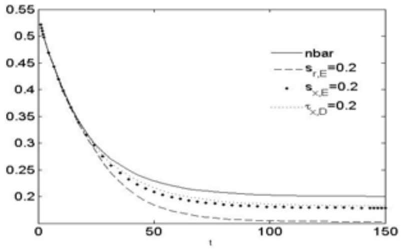


Figure 2*d*

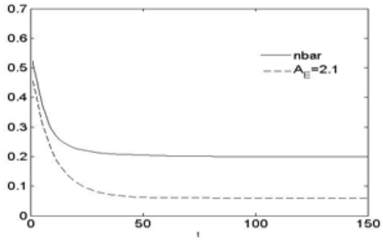


Figure 2*e*

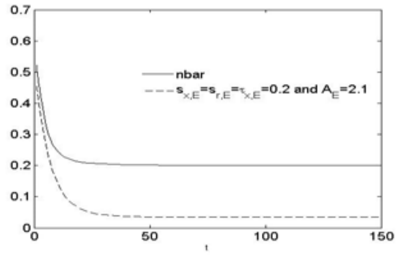
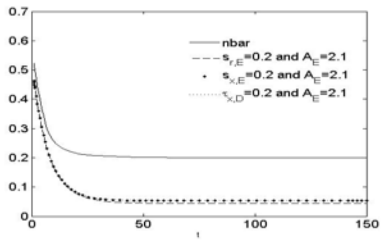


Figure 2*f*



Note: Transitional dynamics of:

Fig.1(*a-c*) TK bias, *B*, without exogenous increase in A_E and Fig.1(*d-f*) TK bias with increase in A_E.

Fig.2(*a-c*) the environmental quality measure, $\overline{n}$, without exogenous increase in A_E and Fig.2(*d-f*) the environmental quality measure with increase in A_E.

Fig. 1*a* and Fig. 2*a* show the baseline steady-state values of, respectively, *B* and $\overline{n}$, under no government intervention and with no positive change in the green technological environment. In turn, Fig. 1*b* and Fig. 2*b* show that the introduction of $s_{x,E}$ together with $s_{r,E}$ and $\tau_{x,D}$, at *t*=0, accentuates, respectively the TK bias and the final good sector bias, $\overline{n}$. Indeed, $s_{x,E}$ increases the profits of *E*-IGs producers, whereas $s_{r,E}$ reduces *E*-R&D costs, stimulating investment in *E*-R&D and, hence, increasing the ecological TK growth rate. Conversely, $\tau_{x,D}$ discourages investment in *D*-R&D in favour of *E*-R&D by decreasing the profits of *D*-IG producers. Hence, the production of ecological IG raises, increasing the number of ecological FGs, whose relative prices decrease continuously towards the new-steady-state. As a result, $\overline{n}$ decreases, illustrating an improvement of the environmental quality, see (8). Thus, *B* is increasing, but at a falling rate until it reaches its new higher steady-state, B^*=60.64 (from $B^*_{Baseline}$=*B*(*t*=0)=18.86), and $\overline{n}$ is decreasing, but at a falling rate until it reaches its new lower steady-state, $\overline{n}^*$=0.12 (from $\overline{n}^*_{Baseline}$=$\overline{n}$ (*t*=0)=0.20).

Fig. 1*c* and 2*c* compare the baseline steady-state values of *B* and $\overline{n}$, respectively, with the raise of each type of subsidies and tax ($s_{x,E}$, $s_{r,E}$ and $\tau_{x,D}$). It is clear that $s_{r,E}$ is the most contributor to heighten *B* and $\overline{n}$. By contrary, $\tau_{x,D}$, is the lesser contributor.

Fig. 1*d* shows that an increase in A_E, clearly heightens *B* in favour of *E*-IGs, the least polluting goods. That increase re-directs R&D towards improvement of ecological IGs and increases the TK absorption effect. In (13), *h*(*j*) jumps immediately from 2.25 to 3.01 as a result of a move from A_E=1.50 to A_E=2.10. Hence, as with government intervention only, though now with stronger magnitude, the production of *E*-IGs raises, increasing the number of *E*-FGs whose relative prices decrease continuously towards the stable new steady-state, Thus, B is growing, but at a falling rate until it reaches its new higher steady-state, B^* = 180.37.

In turn, Fig. 2*d* shows that an increase in A_E heightens $\overline{n}$ in favour of *E*-FGs. Notwithstanding, at *t*=0, it also causes an instantly drop in $\overline{n}_{\text{Baseline}}$= 0.52 to $\overline{n}$ =0.46, due to the rise in A_E without change in B. The increase in *E*-FGs ($\overline{n}$ falls) diminishes their relative prices, discouraging ecological TK, which implies that $\overline{n}$ is decreasing, but at a falling rate until its new lower steady-state, $\overline{n}^*$=0.06 (see Table 2). Once in steady-state, with a constant B, $\overline{n}^*$ remains constant. With a sufficiently TK absorption effect, $\overline{n}^*$ is smaller than under the baseline scenario, with no increase in A_E, $\overline{n}^*$=0.06<$\overline{n}^*_{\text{Baseline}}$=0.20.

Fig. 1(*e-f*) and Fig. 2(*e-f*) present the same behaviour as Fig. 1(*b-c*) and Fig. 2(*b-c*), respectively, but with notably stronger magnitude.

As a result of the price channel, the paths of B and $\overline{n}$ in Fig. 1(*a-c)* and Fig. 2(*a-c*), respectively, are strongly smoothed compared to the path of B and $\overline{n}$ in Fig. 1(*d-f*) and Fig. 2(*d-f*). In fact, *ceteris paribus*, the increase of A_E immediately increases the profits of the monopolistic producers of ecological IGs and, thus, the demand for *E*-R&D.

5. Conclusion

This paper presents a dynamic general equilibrium growth model with endogenous skill-biased technological change. It analyses the contributions of both environmental policies and technological environment to the ecological goods production, when consumers are indifferent between ecological and dirty goods. A measure of the environmental quality is also provided, expressed by the FGs sector bias, $\overline{n}$.

We found that technological progress leads to relatively more production of ecological goods and environmental quality improvements when green firms and green research are supported by policy and/or dirty activities are taxed. This result is in line with, for instance, Ricci (2007). In the same way, a positive change in the green technological environment strongly fosters R&D towards quality improvement of green IGs, increasing their production. Notwithstanding, the raise in the number of ecological FG reduces their relative prices, discouraging ecological TK and ecological production. Consequently, through the price channel, ecological TK bias and ecological FG sector bias increases at a falling rate until they reach their new steady-state.

For future research, it would be interesting to develop an endogenous multi-country growth model with different environmental endowments to discuss issues of global policy coordination and to verify whether, with international trade, environmental regulation would be sufficient to encourage both the development of clean technologies and the production of ecological goods.

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A critical analysis of the sustainable consumption of bitumen in hot mix asphalt made with recycled concrete aggregates

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Abstract

The frequent construction and demolition of buildings and civil works cause huge amounts of the waste of energy and other natural resources. It is generally accepted that hot mix asphalt (HMA) made with recycled concrete aggregate (RCA) promotes sustainable construction. However, our analysis identifies an environmental downside: increased consumption of bitumen from these mixtures and therefore increased consumption of fossil fuels. Technical solutions as to limit RCA content in mixtures, control their impurities, control the fraction in which it is used and the application of pretreatments are emerging as potential tools to limit the consumption of bitumen by HMA made with RCA. From the management point of view, we also propose as policy a revision of the technical specifications to adapt the technical standards to the particularities of RCA. This paper makes a contribution in joining both engineering and economic approaches, in order to make proposals for construction management only using recycled materials economically feasible.

Keywords: sustainable management, recycled concrete aggregate, bitumen, environment impact assessment, strategic management

JEL Codes: Q32, Q55, Q58

1. Introduction

The construction sector, both buildings and civil works, consumes a huge amount of energy and natural resources (Fu et al., 2012), which highlights its importance as a strong candidate when using waste as raw materials. This is particularly important in road building. Since the road network is characterized by its large size and because they were scattered over the entire surface, offers great potential for the use of waste. Especially considering that the industry road building is the largest consumer of aggregates at European level (Symonds et al., 1999).

Recycling is a key activity for sustainable construction. As world economies are heavily dependent on natural resources, both production and sustainable consumption of these are critical to achieving long-term and worldwide economic well-being. One way to do this is to reduce the dependence of such resources by reusing waste in order to prolong the life cycle of natural resources continuously.

The government of the most developed countries has strengthened from the 90's different options for management of construction and demolition waste (C&D) and his reuse in construction projects. Among the different options for management this type of waste, recycling is the preferred option. However, the greater part of the fractions contained in the C&D need of previous treatments to obtain products of quality that can use again (Government of Vasque Country, Spain).

Fractions of this type of waste that are object of special attention as a material to be recycled are the formed by concrete, bricks, tiles, stones, ceramics or asphalt, that represent around the 70-80% of total C & D and they are primarily used to produce recycled aggregate.

Preliminary analysis identifies a number of environmental benefits from the use of RCA in manufacturing hot mix asphalt (Symonds et al, 1999; Pérez et al., 2007; Federal Highway Administration (FHWA), 2004):

- Reduce environmental impacts of the extraction of natural aggregates such as noise, dust, vibration, visual and landscape conditions.
- Mitigate the depletion of natural resources and, therefore, contribute to sustainable development in the medium term.
- Preventing the proliferation of abandoned quarries and reduce their environmental and landscape impact.
- Avoid strong socio-environmental impact caused by the dumping of RCAs and the waste of spaces that could be given other uses.
- Avoid rejection of raw materials which if properly treated may be recycled.

- Avoid pollution of soils and aquifers that can arise when C & D are not separated properly in origin, or deposited in uncontrolled landfills. Many countries are witnessing this kind of uncontrolled dumping. For example, in Kuwait, 33% of the waste produced is illegally discharged [29]. In Spain, despite efforts to eradicate this type of discharge, the National Integrated Waste Plan (PNIR) estimates that from the total C & D produced, a 50% has been uncontrolled discharge (Ministry of Development of Environment, Rural and Marine, 2009).

Once detected the problem to be analyzed and its relevance, this paper therefore seeks as objective the technical-economic analysis of the use of RCAs in manufacture of bituminous mixtures, and the proposal of measures to allow a greater use of this material in the road construction.

After this introduction, the paper is structured as follows: firstly describes the environmental problem that limits the use of RCA in HMA, given the increased demand of binder for this type of aggregates, and presents a causal analysis that relates, from a conceptual point of view, the consumption of aggregates with their environmental cost. The following describes the experimental design based on research conducted in the laboratory of the School of Civil Engineering of the University of A Coruña (Spain). Finally, we present the results of the research and proposed solutions, some of them raised as a starting point for new research.

2. Description of the environmental problem: the demand for bitumen in HMA made with RCA

To facilitate the understanding of the environmental problem object of our study, we identified a number of relevant variables and we have related them through two loops with dynamic behavior, following the methodology of causal analysis of system dynamics (Stearman, 2000). This analysis is a starting point that allows to intuitively understanding how the stimulus to the use of construction waste need not necessarily contributes to reducing the environmental impact.

To this end, we have identified the following variables:

- Pressure to encourage sustainable construction: determines the economic value of the incentives offered by the government to encourage the consumption of construction waste
- RCA consumption: describes the volume of recycled aggregates used in road construction
- Natural aggregates consumption: describes the volume of natural aggregates used in road construction
- Environmental impact: assesses the overall environmental impact in road construction

- Bitumen demand: determines the required quantity of bitumen in road construction
- Fossil fuel consumption: indicates the volume of fossil fuels (petroleum) required in the construction of roads

The relationships between variables, according to the standards of the methodology chosen, reflect direct relationships (positive sign) or reverse (negative) set to dynamic variations of the elements related.

From a conceptual point of view, we can say that the use of waste as construction material components is part of the concept of sustainable construction (Kibert, 2007), since it allows performing more efficient management of resources and thus reducing the environmental impact of the management and treatment of waste.

In addition, by recycling in construction and the consumption of recycled aggregates a number of benefits can be achieved such as, for example, reducing the need for energy and natural resources (natural aggregates) and optimizing the use of landfills.

The above increases social pressure from the Government, who will provide incentives to sustainable construction that seeks the increased consumption of RCA in civil engineering construction. In the stimulation loop described below (Figure 1), this reflects a dynamic behavior. Increased incentives for sustainable building (pressure to encourage sustainable construction) will increase the consumption of residues as components of the mixture in road construction (RCA consumption), reducing the consumption of natural aggregates (natural aggregates consumption). The reduction in consumption of these aggregates reduces total environmental cost (direct). And this will also reduce the volume of government incentives to this end, having fulfilled the goal.

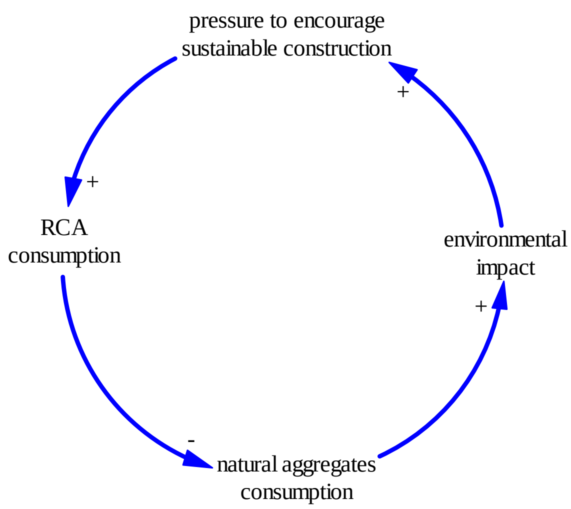

Figure 1: Loop to encourage the consumption of RCA.

The simplified analysis of this fact could lead us to say that a policy of incentives temporary use of RCAs in road construction will help reduce the environmental cost would solve a major problem for the Administration.

However, this reality is more complex than it seems, and this requires a more comprehensive technical analysis. The use of RCA in HMA has an environmental problem that cannot be ignored, which is the increased demand for binder (bitumen) of such aggregates (Anon, 1984; FHWA, 2004) compared to that of natural ones. As shown in Figure 2, the hot mix asphalt, manufactured in part with RCA from waste from construction and demolition (C&D), show optimum contents of binder higher than conventional mixtures (Shen & Du, 2004; 2005; Pérez et al., 2007; Pérez et al., 2010; Bhushal et al., 2011; Pérez et al., 2012), i.e., those with a 0% RCA. This is most pronounced when the replacement of natural aggregate is performed by RCA in the fine fraction (Rafi et al., 2010). Furthermore, as shown in Figure 2, the consumption increases with increasing binder content in the mixture RCA.

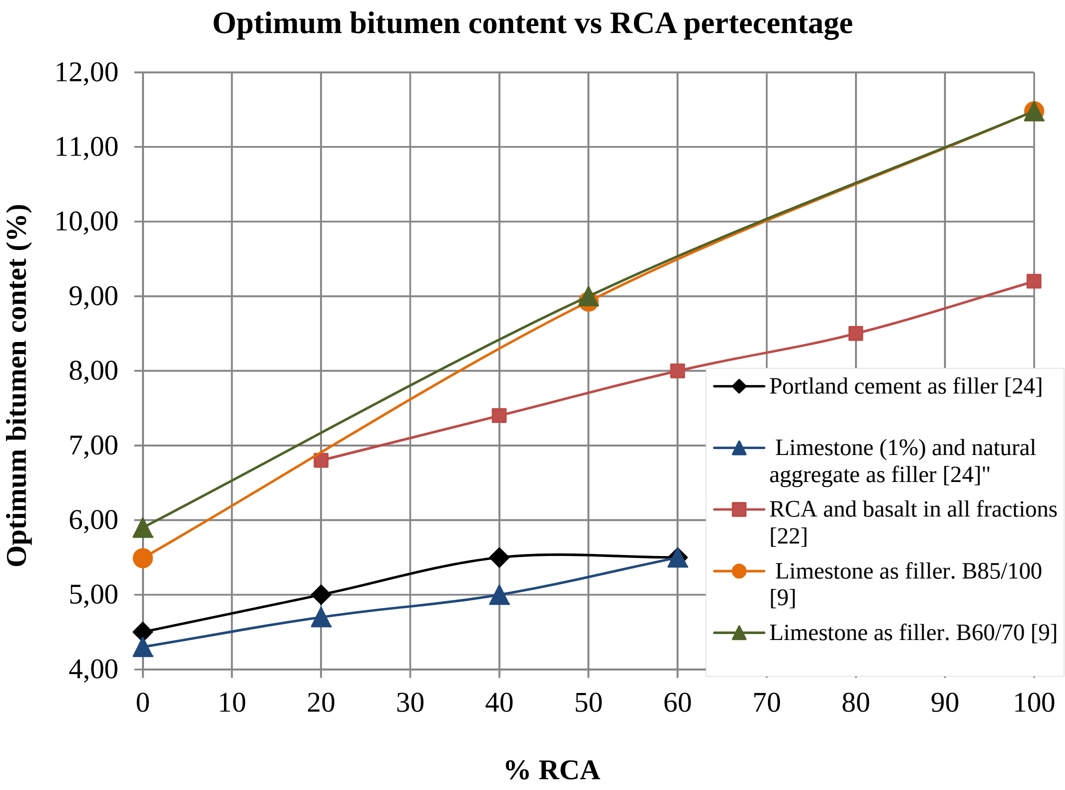

Figure2: Variation of optimum binder content based on the percentage of RCA.

From an environmental perspective, it has to be taken into account that the asphalt bitumen or penetration bitumen is a petroleum product, and therefore, a higher consumption of bitumen means more oil consumption. Thus, as reflected in Figure 3, an increase in consumption demand of RCA increase the bitumen blends (direct connection), and this would increase the consumption of fossil fuels, leading to greater environmental impact, in against the target set initially in all policy incentives to recycle and reuse these materials.

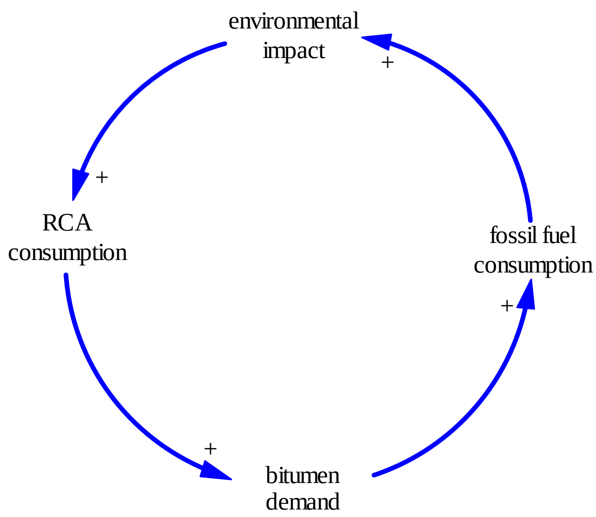

Figure 3: Loop of disincentive to RCA consumption.

The conceptual analysis performed allows us to have an idea of the complexity of the problem and the difficulty of tracking detailed economic and environmental impact of the use of various materials, components and procedures and their alternatives (Bon et al., 2000).

In order to go further with the analysis of the relationship between some of the variables involved, an experimental design aimed to estimate parameters of consumption of bitumen in HMA mixtures made with RCA is presented in this paper.

3. Experimental design

A research carried out in the Laboratory of Highway at the School of Civil Engineering of the University of A Coruña (UDC) suggest do not exceed 30% of RCA in manufacturing HMA type AC 22 base G . Figure 4 shows the granulometric curve selected for this bituminous mixture. The production of hot-mix asphalt base layer used two types of aggregate: natural aggregate and RCA. As natural aggregate has been used cornubianite. The RCA comes from construction and demolition waste from residential buildings of various origins and was supplied by a recycling plant of construction and demolition waste from Madrid (Spain). The asphalt mix was manufactured with RCA percentages of 0%, 5%, 10%, 20% and 30% in fraction 8/16 mm and 4/8 mm (the latter only for 30% of RCA). In all cases has been used as filler and gray Portland cement as binder penetration bitumen B50/70 from Venezuela. The optimum binder content was carried out for each of the selected percentages by performing RCA Marshall test (Ministry of Public Works and Transport, 1992) on cylindrical samples of 101.6 mm diameter and 63.5 mm height compacted with 75 blows per face with Marshall mace.

This limit of 30% is given for two main reasons:

- The possible reduction in mechanical properties of the mixtures made with higher percentages.
- Grading instability posed by RCA. It has been shown that RCA fragments during mixing operations and compaction of asphalt mixtures in which intervenes, which makes this type of mixtures present granulometric instability. This phenomenon also occurs in conventional mixtures lesser extent. It should be noted that other researchers (Paranavithana et al., 2006; Gul, 2008) have also noted the change in the size distribution of the HMA made with RCA after mixing and compacting them, attributing this to the weak cement mortar attached. Figure 4 shows the variation in the grading of AC 22 asphalt mix made with a base G 4% B50/70 and RCA percentages of 0%, 5%, 10%, 20% and 30% in fractions 8 / 16 mm and / or 4/8 mm. After the recovery of the aggregate (Ministry of Public Works and Transport, 1992) it can be seen that the mixing with 30% of RCA goes slightly out of the spindle considered by Spanish specifications after mixing and compacting and how it differs from the initially selected granulometry.

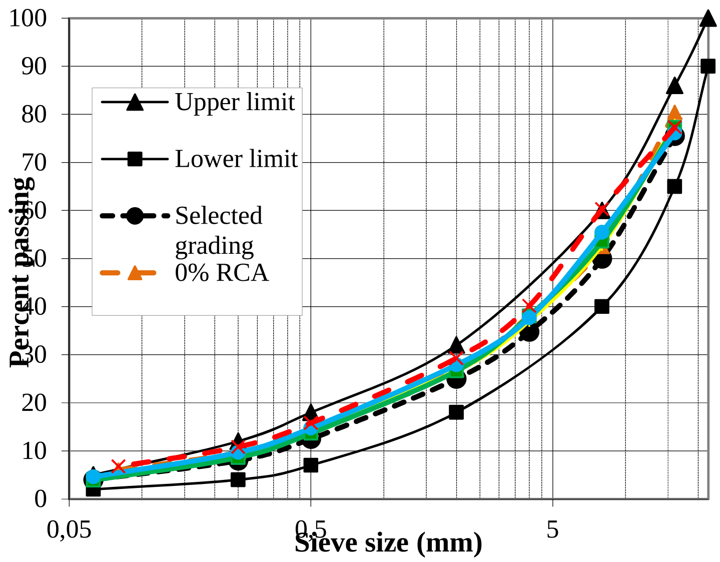

Figure 4 : Selected granulometry and granulometry from bituminous mixes produced with RCA after mixing and compacting (obtained from recovered aggregates).

Accepting the limit of 30% of RCA in the manufacture of HMA, and taking into account the data of Figure 2, it can be seen that increasing the binder content between a mixture and a mixture with conventional RCA will reach a maximum of 2% (limestone as filler with B85/100 and B60/70). The limit of the mixing set to 30% requires further study, since the properties of mixtures made with RCA will depend both on the type of RCA used in their manufacture and the properties of natural aggregate, being particularly important its affinity with the binder and its resistance to fragmentation.

The experiment was carried out with a dosage of such mixtures by using the Marshall method, according to standard NLT (Ministry of Public Works and Transport, 1992). The results are attached in Figure 5. As can it can be seen in this case, increasing the optimal bitumen content (Bo) between 0% and 30% RCA would be much lower, only 0.3%.

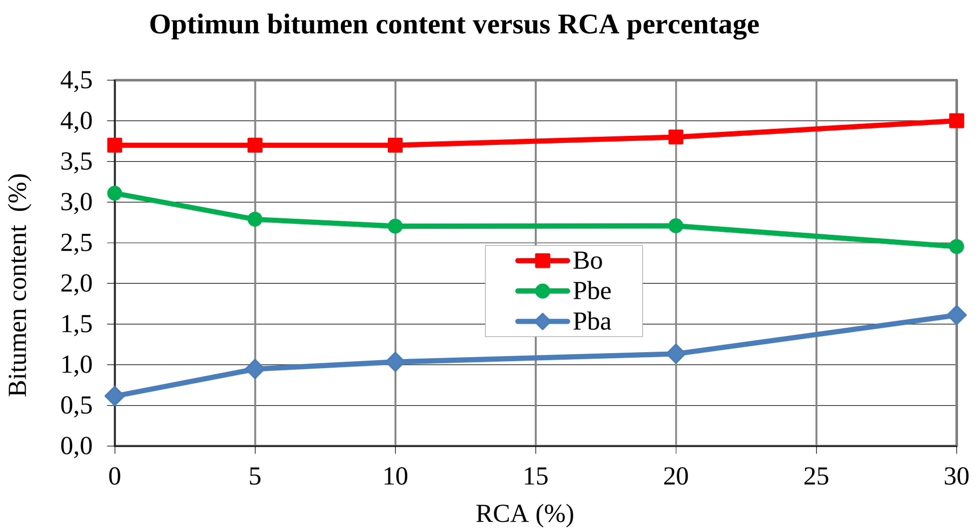

Figure 5: Optimum binder content, effective binder content and binder content absorbed by the percentage of RCA.

As shown, there are strong differences between consumption of binder shown in Figure 2 and those shown in Figure 5. These differences in the increase of optimum bitumen content proposed by other researchers might be for several reasons: a) the type of RCA employed in the manufacture of mixtures, b) the fractions used in the RCA and c) particular technical specifications of each country. The following sections examine the reasons and indicate possible ways to reduce their effect on the optimum binder content:

a) The type of RCA employed in the manufacture of mixtures

Difference: As for the type of RCA employee, it is noteworthy that Jimenez et al., 2011, based on a study of three types of RCA from construction and demolition (C & D), concluded that they are fairly homogeneous, because over 96% of the particles are made of concrete (between 71% and 76% are natural aggregates with adhered mortar and between 20% and 25% are natural aggregates without adhered mortar). The remaining components may be considered as impurities. Thus there would be between 1.6% and 3.5% of ceramic material, between 0% and 0.3% asphalt, between 0% and 0.1% gypsum and insignificant amounts of wood, glass, plastic, metal, natural soil and light particles. Some of the impurities present in the RCA can cause an increased demand for binder materials because facing the making of HMA they have lower quality than the concrete, except asphalt.

Proposal: to limit the consumption of bitumen, a prior removal of impurities would be required, in particular removal of ceramic material and the gypsum.

b) The fractions used in the RCA

Difference: in order to see the influence in the consumption of bitumen of the fractions in which RCA is used, it should be noted that, as seen in Figure 6, the RCA from C & D differs mainly from conventional aggregates having mortar attached to its surface (Sánchez de Juan & Alaejos Gutiérrez, 2009).

The attached mortar is the primarily responsible for the binder increased absorption of RCA than a conventional aggregate (Bhusal et al., 2011). Since the fine fraction has a higher mortar content than the coarse (Sanchez de Juan & Alajeos Gutiérrez, 2009), it also has a higher absorption than the coarse fraction. In this sense Bushal et al., 2011 propose that, for economic reasons, that RCA substitution should take place in the coarse fraction, to avoid greater optimum binder content.

Proposal: from the research, it is recommended that, for mixtures of maximum aggregate size of 22 mm, the substitution should made in fractions of 8/16 mm and 4/8 mm. Using RCA in thicker fractions would introduce excessive heterogeneities in the mixture.

Therefore to reduce the consumption of bitumen of HMA made with RCA, the use of RCA should be limited to the coarse fractions, while keeping in mind that too thick fractions (greater to 16 mm) might introduce excessive heterogeneities in the mixture.

c) Technical specifications of each country

Difference: Finally it has been seen that the technical specifications may also influence the amount of binder. As is well known, in each country the technical specifications of the hot mix asphalt can be very different. In Spain the General Technical Specification for Road and Bridge Works, PG-3 (Ministry of Development, 2008) requires a minimum binder content of 3.5% while for example the Florida Department of Transportation (FDOT) requires a minimum 5% effective binder content (Jajliardo, 2003). The effective binder content (Pbe) is the percentage of binder is not absorbed by the aggregate. Although most aggregates have certain absorption of binder, in the case of RCA, absorption (Pba) adopts a high value. In this regard, it is interesting that some researches (Paranavithana et al., 2006; Mills-Beale & You, 2009) indicate that the effective binder content of bituminous mixes made with RCA is lower than conventional mixtures, due to the high absorption of binder by RCA. As seen, the main responsible of this feature is the absorbent nature of the cement mortar on the surface of the RCA, so that the larger the RCA content greater the absorption of binder (Bushal et al., 2011). As shown in Figure 5, the tests performed in this study confirmed these results: with increasing the percentage of RCA the Pba and Bo increases and Pbe decreases slightly.

Proposal: to ensure sustainable consumption of bitumen in bituminous mixes made with RCA it would be appropriate to review the rules of each state or country and adapt the specifications to the peculiarities of the RCA. Specifically, given the absorbent nature of the RCA seems inappropriate to specify a minimum amount of effective binder.

Finally, the results of this research allow advance in new technical solutions aimed at reducing consumption of bitumen by the HMA made with RCA. The embodiment of any "coating" of RCA with lime or bitumen emulsion to partially seal the pores of the aggregate could reduce absorption binder. This research is currently open in the University of A Coruña (Spain), and we hope it will be the starting point for further analysis.

4. Conclusions

From the experiment we can be concluded that the HMA made from RCA consume a greater amount of bitumen and therefore a greater amount of oil. Thus, it calls in question the ultimate goal of sustainable construction going against the principles of reducing consumption of natural resources and thus their impact on the environment. It would be necessary to determine whether the reuse of RCA could environmentally compensate an increased consumption of bitumen as binder.

More research is needed to make the HMA made with RCA, an effective sustainable building material with a binder content similar to those used in conventional mixtures. To contribute to the reduction of the binder content of such mixtures, the following measures can be taken:

- Limit RCA content of the mixture. 30% seems to be the most appropriate value. Higher limits may be inadmissible due to unstable particle size having such mixtures.
- Adapting the specifications and technical standards to the particularities of the RCA. In particular, since the RCA has a greater absorption than conventional bitumen aggregates, it seems not appropriate to set a lower limit of absorbed binder content.
- Remove RCA impurities before its use in the manufacture of HMA, particularly gypsum and ceramic materials. These materials, besides being highly absorbent, have a lower quality that may result in higher consumption of bitumen.

- Limit the use of RCA to coarse fractions, since the finer fractions contain a greater percentage of mortar, highly absorbent. In any case it is not convenient to use fractions over 16 mm because they may introduce excessive heterogeneities in the mix.

- Perform a RCA pretreatment to partially seal the pores and thus reduce the absorption of binder. Conducting a “coating” of the RCA with lime or bitumen emulsion are research topics currently followed at the UDC.

On the other hand, if the use of RCA in the manufacture of HMA is generalized, local waste could be used closer to the production of asphalt, thus saving on transport costs, particularly of fossil fuels.

The analysis presented in this paper is a new addition to the environmental impact assessment of sustainable construction from a technical-economic perspective, which seeks to improve the understanding among the stakeholders (administrations, producers and consumers of aggregates, society) in order to assess the complex systemic implications of their actions. Academically, this research opens new alternatives of analysis in a research topic currently very active.

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The technological and environmental efficiency of eu-27 power mix: an evaluation through mpt.

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ABSTRACT

Portfolio theory can result in a valid and contrasted methodology for evaluating real assets and electricity production portfolios, inside energy planning problem. It results a more complete alternative to the least-cost perspective. In the proposed model all of technologies production costs are considered, including the different components of externalities (and not only CO2 costs). This tries to correct the possible Market failure, due to imperfect costs allocation. Besides the model measurement of technological risk is based on the non-weighted addition of variances. This proposal can be a more robust calculation to obtain risks values. The model presents a risk minimization objective function and a cost-risk efficient frontier. Two different cases are proposed: "Pure Markowitz" (with only simple portfolio approach constraints) and "Technological Limitation" (considering participation portfolio limits for technologies). It allows to analyse the efficiency of IEA.EU-27 portfolios for 2009-10, 2020 and 2030 horizon from a portfolio theory perspective. The results show the inefficiency of IEA.EU-27 portfolios and how the "efficient path" (economical and environmental) for EU-27 power generation portfolio is based on Renewable sources.

KEYWORDS: Portfolio theory, Electricity generation, Externalities, Energy policy.

JEL CODES: G110; Q470; Q530

1. Introduction

The solution for the energy problem of a territory should conciliate security of supply, sustainability and competitiveness. The technologies portfolio design employed to produce electricity is of special transcendence. In addition to costs of production, the portfolio has social and environmental impacts. The factors that condition its design are diverse. The characteristics of the sector and of the generated output[1] meet a type of market with an oligopolistic tendency, conditioned by regulatory policies. Moreover, a high level of uncertainty (technological, economic, regulatory and/or environmental) complicates even more decision making.

The energy planning, seen as a selection of investments issue (Awerbuch, 2004), facilitates the portfolio design for a long-term perspective. The application of the portfolio theory[2] (Markowitz, 1952) allows to evaluate the set of available technologies from a return-risk perspective. The limited approach of the minimum stand-alone generating cost is abandoned and replaced for the portfolio cost concept. Analysis is enriched via inclusion of risk. This way, not only the individual variability of elements (cost components, fuels and technologies) is incorporated but also the several relations between them (correlations). The search for the portfolio efficiency is favoured by an effect of potential diversification of the portfolio. The total risk can be decreased in relation to the several degrees of correlation between the elements.

The present work tackles the issue of definition of efficient portfolios for electricity production assets from the postulates formulated by the portfolio theory. It pretends to evaluate the electricity generation portfolios proposed by the World Energy Outlook-International Energy Agency (2011 and 2012) for the horizon 2020 and 2030 for the EU-27. The analysis perspective in the energy field is in the medium-long term (10-20 years), longer than the ones of the financial perspective. It pursues the *social aim* of generation of electricity on a long-term basis in an efficient form. It looks for a generation portfolio that leads to the lowest social cost, with an acceptable level of risk for the society and respect for environmental conditions (Jansen *et al.*, 2006:10). For this, in the second section, the most notable contributions collected in the bibliography are examined. Right afterwards, the designed model is presented in the third section, based on the cost of the portfolio through the expected average value and the associated risk. In the fourth section obtained results are commented. Finally, conclusions are drawn and lines for future investigation are proposed in the fifth section.

2. Application of MPT to the electricity generation mix

[1] Among others: non storage capacity, need of a supply and distribution network or capital intensive investments.
[2] The financial assets replacement by real ones needs the non-strict assumption of the efficiency hypotheses for the portfolio theory in financial markets (Awerbuch and Berger, 2003).

The application of the porfolio theory to the energy planning has had wide acceptance, being numerous the studies that confirm it. From the first study made by Bar-Lev and Katz in 1976, Awerbuch stands out as one of the most referenced authors in latter studies. The bibliography examination shows that there is not just an approach to define the type of the efficient frontier line. Studies based on economic and electricity production criteria can be found. The economic ones present many return-risk frontiers, as well as cost-risk frontiers. Definition of return is diverse: as reverse of the cost of generation (kWh/cent$) (Awerbuch and Berger, 2003), as Net Present Value (NPV) for technology of generation (Roques *et al.*, 2008; Westner and Madlener 2009), as Internal Rate of Return (IRR) (Muñoz *et al.*, 2009), or as relative measure of profitability (Gökgöz and Atmaca, 2011). On the other hand, those based on production criteria (Roques *et al.,* 2010) have as a reference the expected value of the average production.

The models include diverse optimization functions and constraints, and the majority of them consider several horizons and regions (Table 1).

<table>
<tr><th>Author/s</th><th>Objective functions</th><th>Constraints</th><th>Horizons</th><th>Territory</th></tr>
<tr><td>Awerbuch and Berger (2003)</td><td rowspan="6">Performance maximization</td><td rowspan="3">Technology limits shares</td><td>2000 & 2010</td><td>Europe</td></tr>
<tr><td>Kienzle (2007)</td><td>2007</td><td>BKW Company (Switzerland)</td></tr>
<tr><td>Rodolius (2010)</td><td>2010</td><td>Cyprus</td></tr>
<tr><td>Arnesano et al. (2012)</td><td>Inexistent</td><td>2009 & 2020 & 2030</td><td>Italy</td></tr>
<tr><td>De Jonghe et al. (2011)</td><td>Technology
Production
Ramp rates</td><td colspan="2">Simulation Example</td></tr>
<tr><td>Roques et al. (2010)</td><td>National wind resource potential and transmission</td><td>2020</td><td>Austria, Denmark, France, Germany & Spain</td></tr>
<tr><td>Zhu and Fan (2010)</td><td rowspan="3">Risk minimization</td><td rowspan="2">Technology limits shares</td><td>2005 & 2020</td><td>China</td></tr>
<tr><td>Bhattacharya and Kojima (2010)</td><td>Simulation Example</td><td>Japan</td></tr>
<tr><td>Delarue et al. (2011)</td><td>Technology
Production
Ramp rates</td><td colspan="2">Simulation Example</td></tr>
<tr><td>White et al. (2007)</td><td rowspan="4">Cost minimization</td><td rowspan="4">Technology limits shares</td><td rowspan="3">2020</td><td>California</td></tr>
<tr><td>Awerbuch and Yang (2007)</td><td>EU-27</td></tr>
<tr><td>Allan et al. (2010)</td><td>Scotland</td></tr>
<tr><td>Jansen et al. (2006)</td><td>2030</td><td>The Netherlands</td></tr>
<tr><td>Huang and Wu (2008)</td><td>Cost minimization balanced by</td><td>Installed capacity related to</td><td>2006-2025</td><td>Taiwan</td></tr>
</table>

	risk	demand side		
Roques *et al.* (2008)	Utility maximization	Inexistent	Simulation Example (Liberalized Power Markets)	
Gökgöz and Atmaca (2012)		Investment capacity in spot market	Current case	Turkey
Muñoz *et al.* (2009)	Sharpe Index maximization	Inexistent	2005-2010	Spain
Rombauts *et al* (2011)	Return maximization & Risk minimization	Cross-border transmission & capacity	Simulation Example	

Table 1.- Literature Survey about Type of Objective Functions, Constraints, Horizons and Regions analyzed. Source: Own authors´ elaboration.

The origin of the managed data is diverse. Some of them use values that come from international entities and organisms (IEA, European Commission, Energy Information Administration of the USA...). Others come from technical studies, projects or investigation programs. The difficult availability of data not linked to each cost component by production technology (investment, O&M[3], fuel...) forces to opt for simulation, data of other studies or proxy variables in order to obtain these.

Some critics to the portfolio theory application to generation of electricity assets can be found in the bibliography. Hanser and Grave (2007) criticise the portfolio theory being applied to such diverse assets (financial and energetic). Their line of thought is that the portfolio approach does not include the totality of the elements that are being analysed in a real asset (that these go beyond the correlations between assets). Among them would be the security of supply or the reliability of the system facing peaks of demand. However a precise definition of restrictions and objective functions in the model can resolve partly this problem. Other authors, such as Hickey *et al.* (2010), Kruyt *et al.* (2009) and Stirling (1998) centre its questioning in the high level of ignorance that characterises the energy context. Thus employing only historical data (generation costs) is limiting and can only result in obtaining non reliable results.

The application of the portfolio theory to the issue of energy planning of territories is presented as a contrasted methodology. However the characterisation of the technologies takes into account only the production cost and the CO2 emission, with some cases of global externalities cost (Arnesano et al., 2012; Krey and Zweifel, 2006). It seems necessary to deepen in the environmental and social appearance of the portfolio through the inclusion of the different externalities in the model. To the extent they consider the totality of the costs (included externalities), will they attain a realistic allocation of the resources. Thus, initially advantageous technologies in terms of production costs are no longer positive due to the high environmental costs in which they incur.

[3] Operation and maintenance.

3. Definition of the model.

The model proposed here has an optimisation structure with restrictions. It is an approach to the portfolio theory with an objective function for minimisation of risk, subject to any given level of portfolio cost. It is based on the generation technological costs and the risk of costs (standard deviations and correlations between the several costs components).

3.1. Origin of the selected data

The model is framed in the context of social welfare maximisation (Awerbuch and Berger, 2003; Jansen et al., 2006). The cost and the risk of the technologies and of the portfolios are defined in terms of production (€/MWh). The portfolios IEA.UE-27 of electricity generation are analysed (2009-10; 2020 and 2030). The IEA (2011 and 2012) presents three scenarios 2020 and 2030: Current Policies[4], New Policies[5] and scenario 450[6].

The consulted data for the calculation of the technological structure costs of the model come from several sources of international relevance and recent publication. The calculation of the production costs is based on levelised costs of electricity by technology of several sources (IEA-ETSAP, 2010; IEA, 2010; IRENA, 2012; Eurelectric, 2011; De Jager, 2011; IPCC, 2005a,b). Complementary production costs are calculated in accordance to data in IEA-ETSAP (2010) for the nuclear energy and Carbon Capture and Storage (CCS from now on), and according to data from Awerbuch and Yang (2007), Jansen et al. (2006) and EWEA (2005) for wind (on-shore and off-shore) and solar photovoltaic energies. For the calculation of external costs, European Commission programs for externalities calculations are consulted, such as NEEDS[7] –in the frame of ExternE (EC, 2005)- or CASES[8], as well as referential studies in Europe that work with this data (Bennink et al., 2010; Markandya; 2011; Rafaj and Kypreos, 2007; Porchia and Bigano; 2008; Porchia et al., 2008). The selection process of the sources has had three criteria as basis: the level of detail of provided information, the adequacy of information to the studied region (EU-27), and the coherence of each structure cost by technology and source, with the totality of other technological structure costs.

According to the different temporal reference of the levelised cost and due to the difference of temporal range of the considered intervals, it is decided not to capitalize or to discount data. Applying circumstantial and non-specific variations in energy field happened in the last four years (between 2007 and 2011) to the levelised costs (calculated for periods between 20 and 30 years) should be avoided. The average of the monthly averages of the exchange rate Euro-Dollar for the period 2005-2012 ($1.27€) has been taken into account for the adaptation to Euros. The

[4] Considering continuity in governmental and EU policies carried out until 2011-2012.
[5] Applying legal framework in order to improve energy security to and fight against Global Climate Change.
[6] Assuming a temperature average growth within Global Warming over pre-industrial levels of 2ºC.
[7] New Energy Externalities Developments for Sustainability.
[8] Cost Assessment for Sustainable Energy Systems.

no-variability of data and structure costs is assumed from 2010 to 2030. Although some authors (Moselle, 2011) and organisms (IEA-ETSAP, 2010; IRENA, 2012; Eurelectric, 2011) present projections of total costs for the studied horizons, its difficult allocation in a non-separated way to the different cost components of the model leads to its no consideration.

3.2. Definition of technologies.

The technological map employed for electricity production in EU-27 is wide, diverse and dependent on each state. The group (T) of technologies (t) considered in the study sum up to a total of 12, including the most employed ones[9]. These are: Coal[10], Coal with CCS, Natural Gas[11], Natural Gas with CCS, Oil, Nuclear, Large Hydro, Small Hydro, On-shore Wind, Off-shore Wind, Solar Photovoltaic and Biomass. The study opts for defining each technology by designation of the type of fuel employed, with a permanent character, referring not to its engineering designation (that may vary).

3.2.1. Power Generation Technology Cost.

The costs of electricity production by technology are given, following Jansen's et al. (2006) proposal, in the shape of variable costs (dependent on the production; $\mathrm{m.u.}12/\mathrm{MWh}13$). Transformation of the fixed costs in variable ones (annualized) is obtained by weighting these by the annual number of operating hours (load factor):

$$C_{F,t\left(m.u./_{MW}\right)} \times \frac{1}{ANOH_t} = C_{v\left(\frac{m.u.}{MWh}\right)}$$

Equation 1.- Transformation of the fixed costs in variable ones

Where $\mathrm{C}_{\mathrm{F,t}\left(\mathrm{u.m.}/_{\mathrm{MW}}\right)}$ the fixed cost (investment or O&M) of the technology t, $\mathrm{ANOH_t}$ the annual number of operating hours (h) by medium term of the technology t. These can be obtained from the load factor[14] of each technology:

$$ANOH_t = 8760\ hours \times CF_t.$$

Equation 2.- Annual number of operating hours (h) ***by medium term of the technology*** t

[9] Other renewable energies (geothermal, tidal...) have not been taken into account due to their marginal contribution to the present production.
[10] Super Critical Pulverized Coal Technology (SCPC).
[11] Combined-Cycle Gas Turbine.
[12] Monetary unit or monetary value.
[13] Megawatts per hour.
[14] Relation between real energy generated in a period of time, and maximum energy capable of being produced by its installed capacity (and working at the highest power).

with
$t \in T =$
$\{Coal\ , Coal\ with\ CCS, Natural\ Gas\ , Natural\ Gas\ with\ CCS, Oil, Nuclear, Large\ Hydro,$
$Small\ Hydro, On-shore\ Wind, Off-shore\ Wind, Solar\ Photovoltaic\ and\ Biomass\}$
and $\mathrm{CF_t}$ the technology t Capacity (load) Factor.

The Total Generation Cost by technology ($\mathrm{TGC_t}$) is obtained by the addition of the two great concepts, Production Costs ($\mathrm{PC_t}$) and Externalities Costs ($\mathrm{EC_t}$):

$$TGC_t\ \left(\frac{m.u.}{MWh}\right) = PC_t + EC_t$$

Equation 3.- Total Technology Generation Cost

In this one, Production Cost ($\mathrm{PC_t}$) by technology (t) would be obtained by the addition of Investment, O&M, Fuel and Complementary costs:

$$PC_t\left(\frac{u.m.}{MWh}\right)\ = Inv_t + O\&M_t + Fuel_t + Compl_t$$

Equation 4.- Technology Production Cost

For Renewable Energy Sources (RES from now on), except Biomass, $\mathrm{Fuel\ Cost_{V,t}}$ ($\mathrm{Fuel_t}$) is considered to be none[15]. The $\mathrm{Complementary\ Production\ Cost_{\ V,t}}$ ($\mathrm{Compl_t}$) responds to: decommissioning and management of waste for Nuclear, intermittency[16] for Wind and Solar Photovoltaic, and the CO2 transport and storage for CCS technologies. All the costs of production, except the investment one[17] ($\mathrm{Inv_t}$), are in terms of production ($\mathrm{m.u./MWh}$).

Externalities Cost ($\mathrm{EC_t}$) derived from electricity production presents a high potential damage on the ecosystems and the society. The environment and the Society assume the costs[18] which must be taken into by the generation companies (and consumers) (Eyre, 1997). This produces a "Market Failure". The market does not assign resources in an efficient and optimum way due to under-valuation in prices. In the study, some costs will be "internalized" (Wesselink et al., 2010; IPCC, 2005b):

a) Climate Change and Global Warming cost ($CO2_t$ emission),
b) Soil acidification and negative impact on ecosystems and public health ($SO2_t$ and NOX_t emissions),
c) Negative impact on human health and welfare-quality of life conditions (Particulates Matter -PM_t- emission),
d) Potential accidents in power plants (Acc_t),
e) Negative impact associated with extraction of raw materials (land use for Biomass $-Land_t-$)
f) Radioactivity caused by electricity production by Nuclear energy (Rad_t).

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[15] For depending on non-controllable and of free disposition natural resources. (Awerbuch and Yang, 2007).
[16] Related to system flexibility and its capacity to integrate the non-manageable RES electricity.
[17] It is expressed in terms of installed capacity.
[18] Except for the CO2 ones, these costs are generally not included.

The expression used for the calculation would be:

$$EC_t\left(\frac{m.u.}{MWh}\right) = CO2_t + SO2_t + NOx_t + PM_t + Rad_t + Land_t + Acc_t$$

Equation 5.- Technology Extternalities Cost.

3.2.2. Portfolio Electricity Generation Cost.

Portfolio theory establishes the expected technologies portfolio cost through the addition of every one of the expected generating costs of each technology weighted by their fractional share (in percentage) in the portfolio.

$$E(C_p) = \sum_T x_t E(TGC_t)$$

Equation 6.- Portfolio Electricity Generation Cost.

Where $\mathrm{C_p}$ is the Portfolio Cost (m.u./MWh), $\mathrm{x_t}$ is the individual share of technology t in the Portfolio p, and $\mathrm{TGC_t}$ is the Total Generation Cost of technology t (m.u./MWh). In the model approach, the $\mathrm{x_t}$ are the unknown quantities. The addition of the portfolio share of each one of the 12 technologies will result in the total share (100%). Technologies that incorporate CCS for Coal and Natural Gas are considered as having invalid participations for the years 2009 and 2020, and with possible participation in the 2030 portfolio in the model.

3.3. Power Generation Risk.

3.3.1. Technology Risk Estimates.

Portfolio theory assumes the past volatility as guide for the future. Thus the risk by technology is obtained from data on the variability of the different cost components. The risk is formed by the standard deviations and the possible relations between the elements (correlations). The consulted sources do not offer series of historical data for the production costs. It is solved by the assumption of risk data from Awerbuch and Yang (2007)[19]. The process is the same as in the last published works (Allan *et al.*, 2010; Delarue *et al.*, 2011; Arnesano *et al.*, 2012). For all other costs risks, their standard deviations are calculated employing the data collected in the mentioned bibliography.

[19] In the proposed model, in order to save the absence of monetary dimension of the standard deviation of the relative measure of HPR´s –Holding Period Returns $= \left(\frac{Cost_x - Cost_{x-1} + CF_x}{Cost_{x-1}}\right)$ –, the data of Awerbuch and Yang (2007) is multiplied by the costs of each concept of the study (resulting in €/MWh).

In the literature the risk calculation by technology assumes the absence of correlation hypothesis between the different cost components for the same technology (Jansen *et al.*, 2006; Allan *et al.*, 2010; Delarue *et al.,* 2011 and Arnesano *et al.*, 2012). Nevertheless, and due to the existence of correlation between fuel cost and CO2 emission cost is considered in the literature, purely the no correlation hypothesis would be assumed for the rest of components. Therefore the technology risk is obtained from the addition of variances for the several types of cost considered and the covariance of the fuel cost with CO2 emission cost:

$$\sigma_t = \left(\sum \sigma_{PC_t}^2 + \sum \sigma_{EC_t}^2 + 2\sigma_{Fuel_t}\sigma_{Co2_t}\rho_{Fuel_t\&Co2_t}\right)^{\frac{1}{2}}$$

$$\sigma_t = \left(\sigma_{Inv_t}^2 + \sigma_{O\&M_t}^2 + \sigma_{Fuel_t}^2 + \sigma_{Compl_t}^2 + \sigma_{CO2_t}^2 + \sigma_{SO2_t}^2 + \sigma_{NOX_t}^2 + \sigma_{PM_t}^2 + \sigma_{Rad_t}^2 + \sigma_{Land_t}^2 + \sigma_{Acc_t}^2 + 2\sigma_{Fuel_t}\sigma_{Co2_t}\rho_{Fuel_t\&Co2_t}\right)^{\frac{1}{2}}$$

Equation 7.- Technology Risk (Standard Deviation).

This technology risk calculation approach differs from previous studies (Awerbuch and Berger, 2003; White *et al*., 2007; Awerbuch and Yang, 2007; Awerbuch *et al*., 2008; Allan *et al*., 2011 or Arnesano *et al.*, 2012). The proposed calculation of technology risk derives from the non-weighted addition of the variances and (null) covariances. Jansen *et al.* (2006:58,65) outline the adequacy of this approach based on the measure of the total technology cost: that is determined by the non-weighted addition of the different cost streams. This non-weighted option (in Delarue *et al.*, 2011) seeks to reduce possible errors on Technology risks estimates.

The study proposes Awerbuch and Yang (2007) and Allan *et al.* (2010) approaches regarding the risks for fuel costs and for CO2 in the RES. The authors assume that these risks are zero (invalid), based in the assumption of the absence of consumption of fuel and CO2 emission for RES (except Biomass). Arnesano *et al.* (2012), however, considers that fuel risk (with an equal value to the standard deviation of the capacity factor) and CO2 cost risk (equal to that of the rest of technologies) exist.

3.3.2. Portfolio Risk.

The portfolio risk (σ_p) works regarding individual technologies risks (formed at the same time by several costs components) and its interaction between each pair of elements:

$$\sigma_p = \left\{\sum_{t=1}^{12} x_t^2\,\sigma_t^2 + \sum_{t_1=1}^{12}\sum_{t_2=1,t_1\neq t_2}^{12}\left(\sum_{\forall C_1}\sum_{\forall C_2}\sigma_{C_1t_1}\sigma_{C_2t_2}\rho_{C_1t_1,C_2t_2}\right)x_{t_1}x_{t_2}\right\}^{1/2}$$

Equation 8.- Portfolio Risk –General expression- (Standard deviation).

Where x_t represents technology share t as parts per unit in the portfolio p, σ_t is the standard deviation of the technology t cost stream and $C_k t_i$ is cost component k of technology i. This general Equation 8 can be expressed as in Equation 9. This is due to the null value assumption of the most of the possible cost components correlations of the different technologies.

$$\sigma_p = \left\{ \sum_{t=1}^{12} x_t^2 \left(\sigma_{Inv_t}^2 + \sigma_{O\&M_t}^2 + \sigma_{Fuel_t}^2 + \cdots + \sigma_{Acc_t}^2 + 2\sigma_{Fuel_{t_1}} \sigma_{CO2_t} \rho_{Fuel_t, CO2_t} \right) + \sum_{t_1=1}^{12} \sum_{,t_2=1, t_1 \neq t_2}^{12} \left(2\sigma_{O\&M_{t_1}} \sigma_{O\&M_{t_2}} \rho_{O\&M_{t_1}, O\&M_{t_2}} x_{t_1} x_{t_2} + 2\sigma_{Fuel_{t_1}} \sigma_{Fuel_{t_2}} \rho_{Fuel_{t_1}, Fuel_{t_2}} x_{t_1} x_{t_2} \right) \right\}^{1/2}$$

Equation 9.- Portfolio Risk (Standard deviation).

Where

$C_{1,} C_2 \in C_{c,t} =$
$\{Inv_t; O\&M_t;\ Fuel_t;\ Compl_t;\ CO2_t;\ SO2_t;\ NOX_t;\ PM_t;\ Rad_t;\ Land_t;\ Acc_t\}$

In the present study the same proposal of Allan et al. (2010) or Arnesano et al. (2012) about the existence of correlation between two technologies is followed. Both of them, due to the difficulty in finding available data, assume Awerbuch and Yang's (2007) correlation coefficients between O&M costs. In addition the correlation between several fuels and CO2 prices is considered. Many authors use their own historical price series to calculate them. In the study annual data is taken from several sources for the different types of prices (BP, 2011; SENDECO2, 2012 and Uranium Miners[20]).

3.4. The model

The model approach is based on the minimisation of the generation portfolio risk forcing the cost to be equal to a determinate value. For each one of the horizons the initial cost established for the portfolio will be that of IEA.EU-27 (2011; 2012). Its mathematical expression is the following:

[20] Data on the uranium price available at: http://www.uraniumminer.net/market_price.htm

$$Min\{\sigma_p\} = Min \left\{\sum_{t=1}^{12} x_t^2\,\sigma_t^2 + \sum_{t_1=1}^{12}\sum_{t_2=1,t_1\neq t_2}^{12}\left(\sum_{\forall C_1}\sum_{\forall C_2}\sigma_{C_1t_1}\sigma_{C_2t_2}\rho_{C_1t_1,C_2t_2}\right)x_{t_1}x_{t_2}\right\}^{\frac{1}{2}}$$

$$= \left\{\sum_{t=1}^{12} x_t^2\left(\sigma_{Inv_t}^2 + \sigma_{O\&M_t}^2 + \sigma_{Fuel_t}^2 + \sigma_{Compl_t}^2 + \sigma_{CO2_t}^2 + \sigma_{SO2_t}^2 + \sigma_{NOX_t}^2\right.\right.$$
$$\left. + \sigma_{PM_t}^2 + \sigma_{Rad_t}^2 + \sigma_{Land_t}^2 + \sigma_{Acc_t}^2 + 2\sigma_{Fuel_t}\sigma_{CO2_t}\rho_{Fuel_t,CO2_t}\right)$$
$$+ \sum_{t_1=1}^{12}\sum_{t_2=1,t_1\neq t_2}^{12}\left(\sigma_{O\&M_{t_1}}\sigma_{O\&M_{t_2}}\rho_{O\&M_{t_1},O\&M_{t_2}}\,x_{t_1}x_{t_2}\right.$$
$$\left.\left. + \sigma_{Fuel_{t_1}}\sigma_{Fuel_{t_2}}\rho_{Fuel_{t_1,}Fuel_{t2}}\,x_{t_1}x_{t_2}\right)\right\}^{\frac{1}{2}}$$

$Subject\ to$:

$$E(C_p) = \sum_T x_t E(TGC_t) = \sum_T x_t(PC_t + EC_t)$$
$$= \sum_T x_t\,[Inv_t + O\&M_t + Fuel_t + Compl_t)$$
$$+ (CO2_t + SO2_t + NOX_t + PM_t + Rad_t + Land_t + Acc_t)]$$
$$= C_{Portfolio\ IEA.EU-27}$$
$$\sum_T x_t = 1$$
$$\forall t \in T: x_t \geq 0$$

Equation 10.- Mathematical Expression of the Model.

For each one of the three considered horizons (2009-10, 2020 and 2030) two cases of study are proposed. The first of them is named “Pure Markowitz”. For this case only the two constraints which define the original portfolio approach are considered. The second case, designated “Technological Limitation”, incorporates also for each technology one constraint which limits its portfolio share. These approaches make room for two different models which are exposed as followed.

3.5. “Pure Markowitz” Case

This approach incorporates the Markowitz constraints. Total flexibility for investment and disinvestment (decommission) in the several generation assets is granted. Non-existence of transaction costs in relation with the modification of the portfolio is also granted.

3.6. “Technological Limitation” Case

This model incorporates upper bound constraints by technology share. Depending on the considered horizon, limits of technology participation change. The calculation of these share limits for each technology and horizon (2009-10; 2020 and 2030) are based on the data of the different scenarios of the sources consulted for the EU-27 (IEA, 2011 and 2012; Russ et al., 2009). Although in Table 2 minimum and maximum limits of participation are shown, only those related to maximum shares will be incorporated. CCS technology for Coal and Natural Gas only participate in the portfolio from the 2030 horizon, with an established limit related to that proposed by the IPTS (Russ et al., 2009). Each technology constraint would be:

$$x_t \leq Maximum\ share\ of\ technology\ t$$

Equation 11.- Technological limit constraint.

Region	Mix EU-27 Power Generation			
Cases	"Pure Markowitz"	"Technological Limitation (2009-10)"	"Technological Limitation (2020)"	"Technological Limitation (2030)"
Technologies	**Limits (%)**			
Coal	-	23.5-26.8	15.9-23.8	7.1-23.4
Coal & CCS	-	Do not participate	Do not participate	Together with Natural Gas&CCS they cannot exceed 18% of the total share of Fossil fuel technologies. Together with Coal they cannot exceed 23.4%
Natural Gas	-	17-23	20.9-25.7	15.1-27.6
Natural Gas & CCS	-	Do not participate	Do not participate	Together with Coal&CCS they cannot exceed 18% of the total share of Fossil fuel technologies. Together with Natural Gas they cannot exceed 27.6%
Oil	-	2.6-3.0	1.1-1.4	0.6-0.8
Nuclear	-	25.1-28.3	20.5-26.0	19.3-29.8
Hydro	-	10.4-11.7	9.7-11.5	8.3-12.3
Large Hydro	-	9.1-10.3	8.5-10.1	7.3-10.8

Small Hydro	-	1.2-1.4	1.2-1.4	1-1.5
Biomass	-	3.9-4.3	5.2-6.4	5.9-8.5
Solar PV	-	0.4-0.7	2.3-3.8	3.0-5.5
Wind		4.2-4.5	10.3-14.0	13.4-22.3
On-shore Wind	-	3.8-4.1	9.4-12.7	12.2-20.3
Off-shore Wind	-	0.4-0.4	0.9-1.3	1.2-2.0

Table 2.- Minimum and maximum technologies portfolio shares. Source: Own authors´ calculation since data collected in IEA (2011 and 2012) and IPTS (Russ* et al.*, 2009).

4. Results

The electricity generation portfolio analysis proposed by the IEA for the EU-27 and for the different horizons concludes that these are not efficient. This means that it is possible to find another efficient alternative combination with the same cost and a lower risk. Or alternatively with the same risk it is possible to find another efficient alternative combination with a lower cost. The final efficient selection depends on the risk aversion level of the decision making subject. Examples of this can be seen in Table 3. It should be emphasised that the situation of the alternative efficient portfolios to IEA proposals is under the cost of that of the absolute minimum risk portfolio of those of the frontier portfolios curve. For this reason, the comparison will be with efficient portfolios[21]. Depending on the case ("Pure Markowitz" or "Technological Limitation") some of them bring closer to the minimum risk portfolio.

4.1. Year 2009-2010

In "Pure Markowitz" Case the model provides some relevant information about two absolute portfolios: minimum cost and minimum risk. The absolute minimum cost portfolio is the same combination for the three analysed horizons (2009-10; 2020 and 2030), and it would be entirely composed by Large Hydro (Figure 1). Alternately, absolute minimum risk portfolio 2009-10 would be participated for all of available technologies. Those that stand up are Small Hydro, On-shore and Off-shore Wind and Natural Gas.

[21] The efficient frontier is formed by the combinations of the frontier portfolios curve situated from the absolute minimum risk portfolio to the absolute minimum cost portfolio. Those combinations with a greater cost will be refused for being inefficient.

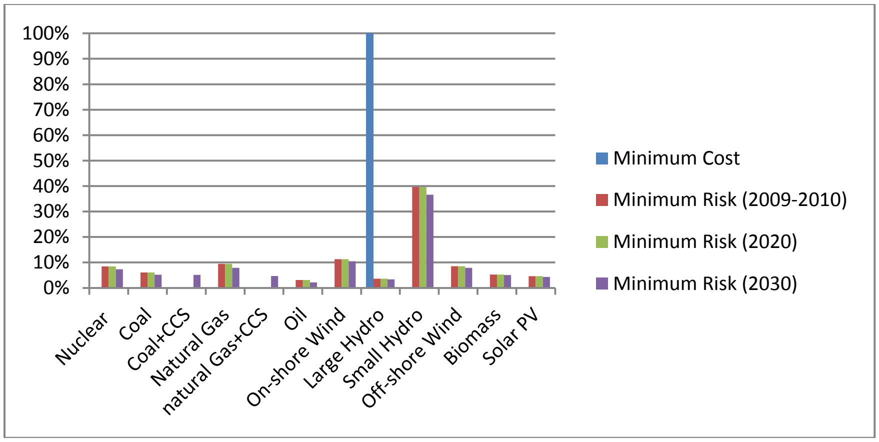

Figure 1.-Absolute Minimum Risk & Absolute Minimum Cost Portfolios Composition. "Pure Markowitz" Case. Source: Own authors´ calculation.

In Figure 2 efficient combinations for the model are collected (lower cost for an equal risk, or a lower risk for an equal cost). The IEA.EU-27 portfolios for this horizon assume a greater risk for the same cost. For this reason they are situated to the right of the curve and under the absolute minimum risk portfolio.

Year 2009	Risk	Cost	Year 2010	Risk	Cost
EU-27. IEA-2009	3.998	55.10	EU-27. IEA-2010	3.932	55.41
Same cost, lower risk	2.364	55.10	Same cost, lower risk	2.360	55.41
Same risk, lower cost	3.998	41.34	Same risk, lower cost	3.932	41.39
Absolute Minimum Risk	2.322	62.46			
Absolute Minimum Cost	10.285	38.84			

Table 3.- IEA.UE-27 Portfolios (2009-2010) and efficient and optimal model portfolios. Source: Own authors´ calculation.

Leaving from IEA Portfolios and in order to reach the absolute minimum risk, it would be necessary to increase the participation of Wind (on-shore and off-shore), Small Hydro and Solar PV (Figure 3). On the contrary, Nuclear (from 26% to 8%), Coal, Natural Gas, Oil and Large Hydro should be reduced. Besides if the efficient portfolios and IEA.UE-27 are compared in terms of proportion "Fossil-RES" it is observed how they change from 52%-20% (IEA), to 20%-70% (minimum risk). Fossil and Nuclear costs increase due to the consideration of externalities in the model (in addition to incorporating a high risk due to correlations). The efficient "path" requires reducing Fossil technologies and increasing RES shares.

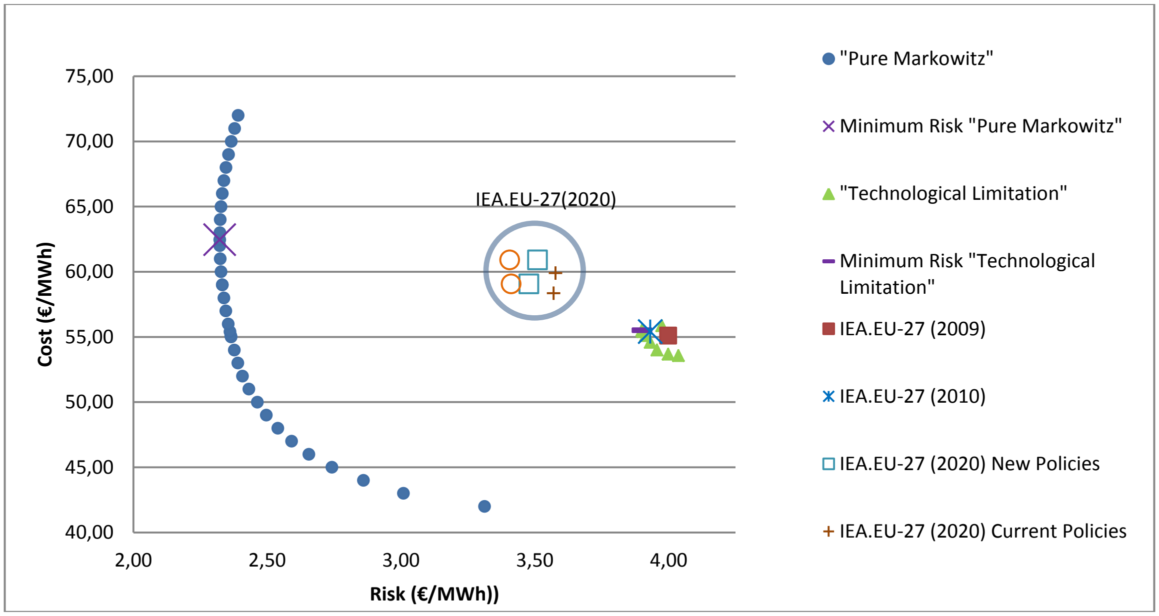

Figure 2.- Frontier Portfolios Curve, IE.EU-27 portfolios and Absolute Minimum Risk Portfolios. "Pure Markowitz" and "Technological Limitation" Cases (2009-2010). Source: Own authors´ calculation.

However the composition of the absolute minimum risk or lower cost portfolios here commented cannot exist. There are some proposed participations that are not possible to reach in fact (Small Hydro, Off-shore Wind or Solar PV) (Figure 3). Each technology share depends on the installed capacity in the analysed period. Thus it is necessary to limit the maximum participation depending on the projections of individual technology development and its portfolio participation. The case of "Technological Limitation" incorporates to the model these constraints. The result is the shifting rightwards and upwards of the frontier portfolios curve (Figure 2). They increase the cost as much as the risk.

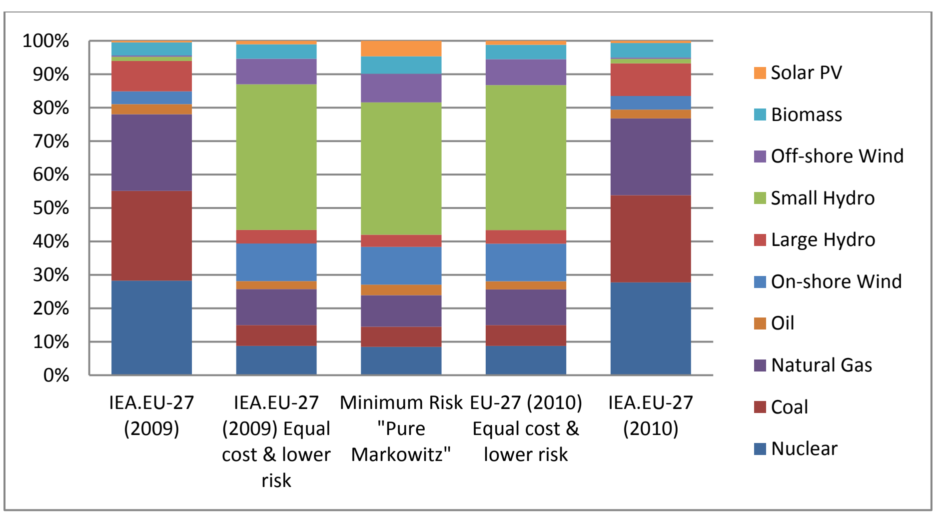

Figure 3.- IEA.EU-27, Absolute Minimum Risk & Efficient Portfolios Composition. "Pure Markowitz" Case (2009-2010). Source: Own authors' calculation.

IEA.EU-27 Portfolios are close to the efficient portfolios proposed in the "Technological Limitation" Case. IEA.EU-27 (2010) Portfolio is very close to the absolute minimum risk one. In Figure 4 the portfolio efficient frontier can be observed for "Technological Limitation" Case (it is an enlarge representation of that one of Figure 2). This allows to conclude that the way of producing electricity in the EU-27 in 2010 was very close to efficiency. It would need to increase lightly Large Hydro, Nuclear and Oil (+0.5%) and reduce coal (-1%). It must be noted that the incorporation of the maximum share limits has a high restrictive impact on the model. The real solution is being guided to these limits (similar to the IEA participations).

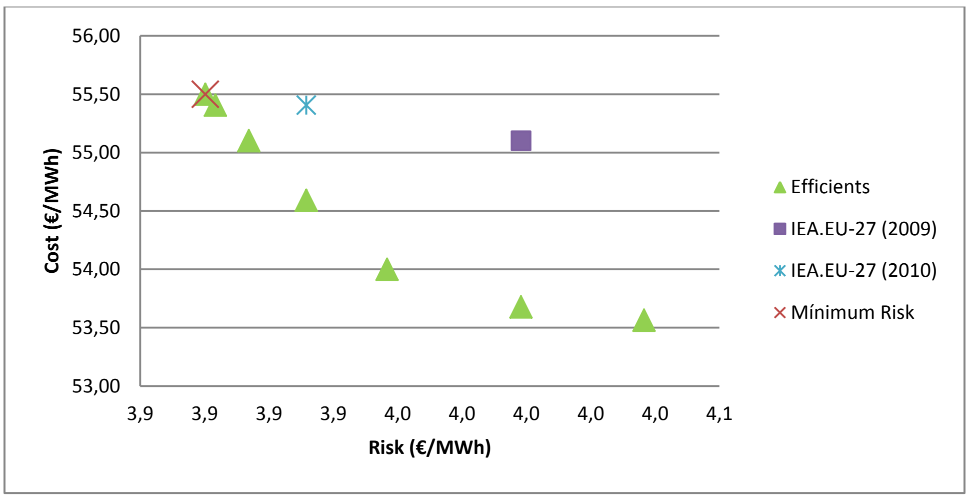

Figure 4.- Efficient Portfolios Curve and IEA.EU-27 Portfolios. "Technological Limitation" Case (2009-2010). Source: Own authors´ calculation.

4.2. 2020 Horizon

The frontier portfolios curve (and therefore absolute minimum risk and minimum cost portfolios) for "Pure Markowitz" 2020 Case is the same as that one for 2009-2010. The available technologies and its costs are the same. Even the establishment of the "Technological Limitation" for 2020 produces the commented shifting rightwards and upwards of the solutions curve in 2009-10 horizon. The cost and the risk increase. The efficient portfolios curve approaches to IEA.EU-27 (2020) Portfolios. Analysing the IEA.EU-27 (2020) Portfolio proximity to the frontier portfolios curve it can be observed how the nearest is the 450 Portfolio (IEA, 2012) (Figure 5). The most IEA´s sensitive environmental portfolio is the one which approximates the most to efficiency in terms of minimum risk. The difference between IEA.EU-27 and 450 can be found in a lower participation of Natural Gas and On-shore Wind and greater for Coal and Nuclear in the 450 Portfolio.

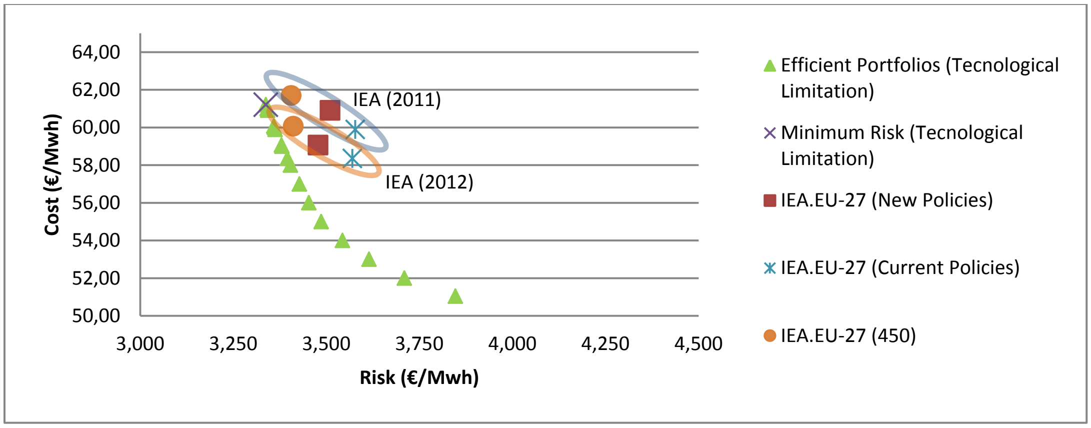

Figure 5.- Efficient Portfolios Curve and IEA.EU-27 (2020) Portfolios. "Technological Limitation" Case. Source: Own authors´ calculation.

If absolute minimum cost and absolute minimum risk portfolios are compared, several conclusions can be drawn (Figure 6). There are some technologies that participate in both of them to the limit (Small Hydro, Large Hydro, On-shore Wind and Natural Gas). If the objective is minimizing cost the portfolio will reduce the most expensive technologies: Solar PV, Biomass and Off-shore Wind. The most economic ones, not having still reached the limit, as Nuclear and Coal, gain relevance.

The absolute minimum risk portfolio is more diversified, participating in it all available technologies. The decrease of Coal benefits the portfolio risk. The reason is its high correlation with the rest of Fossils costs components. Contrary to Biomass, which participation increases. The negative values of Biomass correlation coefficients reduce the risk. In addition it has been observed that Solar PV is now part of the portfolio. This is due to its negative correlation between O&M costs and the absence of correlation, both in reference to fuels and despite its very high cost. This fact is common to the other RES technologies.

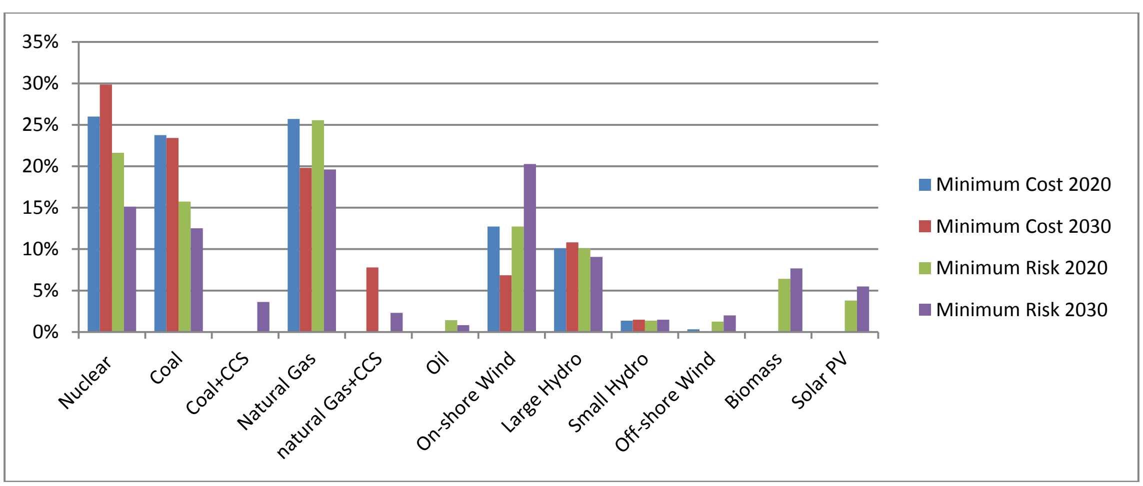

Figure 6.- Absolute Minimum Cost and Absolute Minimum Risk Composition. "Technological Limitation" (2020) & (2030). Source: Own authors´ calculation.

4.3. 2030 Horizon

In 2030 CCS technology will be in the portfolio, for Coal as much for Natural Gas. The increase of possible technologies has a positive repercussion in the frontier portfolios curve ("Pure Markowitz" 2020 and 2030), moving to the left (Figure 7). The portfolio would be benefiting from the positive effect of the diversification, due to the increase of the number of possible technologies, along with the several correlations between technologies and costs components. Under "Pure Markowitz" Case, alternative combinations to those of the IEA[22] would exist. Therefore it will be possible to reduce the existing cost or risk.

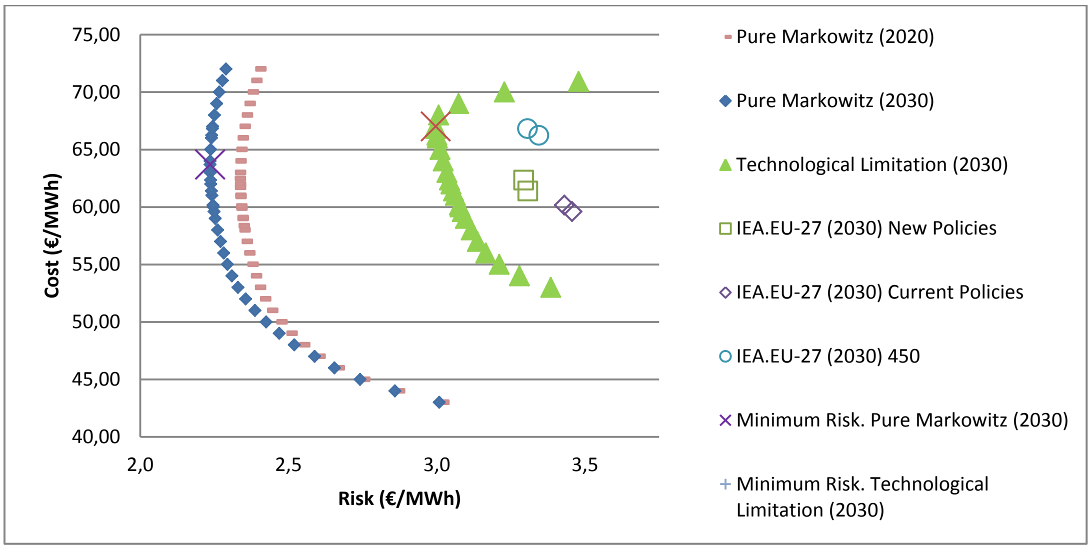

Figure 7.- IEA.EU-27 (2030) Portfolios, Frontier Portfolios Curves and Absolute Minimum Risk Portfolios. "Pure Markowitz" (2020) & (2030) and "Technological Limitation" (2030) Cases. Source: Own authors´ calculation.

In "Technological Limitation" Case (2009-10; 2020; 2030) the frontier portfolios curve shifts leftwards and upwards (Figure 8). For this reason, increasing RES technological limits and reducing Fossil technological shares (apart from Natural Gas) according to the horizon, guides portfolio risk to be lower and portfolio cost to be larger.

[22] These portfolios do not present separated costs components data for CCS technologies. This fact conditions their characterization in the model. As a result data given by the portfolios IEA.EU-27 (2030) present a greater cost and risk than those that consider CCS technologies.

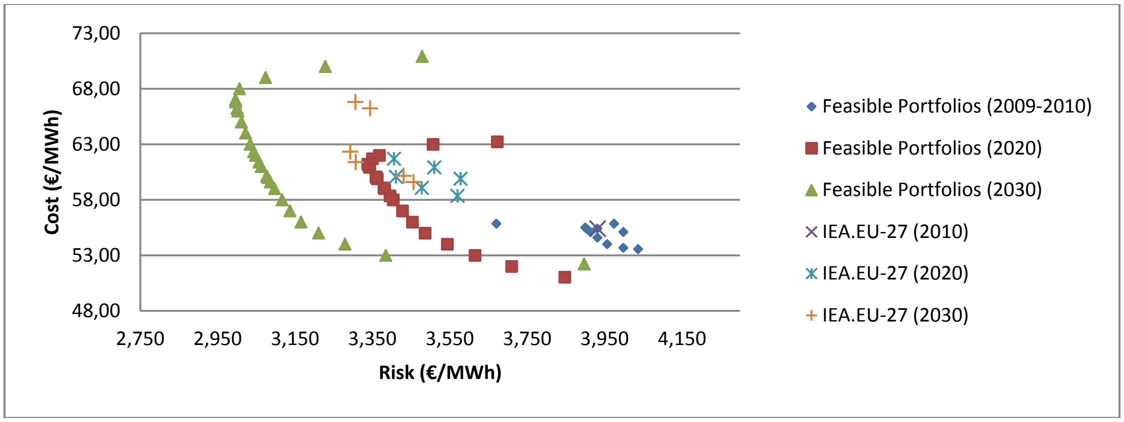

Figure 8.- Frontier Portfolios Curve evolution in "Technological Limitation" Cases (2010, 2020 & 2030) & IEA.EU-27 Portfolios. Source: Own authors´ calculation.

In 2030 opting for an absolute minimum cost combination leads to considering 7 of the 12 possible technologies (Figure 6). It is based on Nuclear (29%), Coal (24%), Natural Gas (20%), Gas with CCS (8%) and Large Hydro (11%). Alternatively, the absolute minimum risk one is led by the On-shore Wind (20%), Natural Gas (20%), Nuclear (15%) and Coal (13%), considering all of them (12 technologies).

Focusing the analysis on the IEA.EU-27 (2030) Portfolios efficiency, it can be concluded that they are not efficient. From the point of view of risk minimization the combination that approximates the most to efficiency is again 450 Portfolio (IEA, 2012) (IEA, 2012). As long as the EU-27 produces electricity in the proportions that this portfolio shows, it will be approaching environmental and economic efficiency.

5. Conclusions

Portfolio theory can result in a valid and contrasted methodology for evaluating real assets and electricity production portfolios. Proposing the analysis from the simultaneous conceptual consideration of the cost and the risk confers the approach a greater capacity and conceptual wealth than that of the simple least-cost individual generating technology perspective.

The objective of this methodological approach is the generation of efficient portfolios. The model solution portfolios make up a curve that marks off from the left to the feasible or possible joint portfolios. Therefore frontier portfolios are named. Among those efficient ones would be only some of them; in particular, those minimise the cost, for a certain level of risk, or minimise the risk, for a fixed level of cost.

With this approach is possible to analyse the efficiency of a specific portfolio (IEA.EU-27) through its comparison with efficient their own (equal risk or equal cost). Besides in each efficient portfolios curve two possible optimal portfolios can be found: the absolute minimum cost or the absolute minimum risk portfolios among efficient ones.

Different from most of the models revised in the bibliography, the suggested model of this study is based on the inclusion of the totality of the costs (externalities, and not only production and CO2 emission) tries to correct the possible existent market failure market in the electricity generation. Another new proposal consists of the measurement of each technology risk through the non-weighted addition of Total Generation Cost components variances and standard deviations (following Jansen et al., 2006 and Delarue et al., 2011). Therefore the variability of the different costs components and, especially, the existent correlations between them are considered.

The first consequence of this methodological option is the increase of the Total Generation Costs of all the pollutant technologies. Also due to considering risks, the model produces efficient portfolios for the two studied cases ("Pure Markowitz" and "Technological Limitation"). These efficient combinations penalize the generation based on Fossil fuels consumption and on Nuclear technology and give preference to RES. Operating with the non-weighted addition for the risk calculation leads to higher and methodologically more robust values for the risk than the weighted addition perspective.

Likewise the model confirms the positive effect of the application of portfolio theory over RES technologies, from the risk minimization perspective. As a result in case of absence of any technological limitation constraints ("Pure Markowitz"), absolute minimum risk portfolio (2009-2010) and (2020) would present the following composition: 73% RES; 18% Fossil fuels and 8% Nuclear. In 2030 the entrance of Carbon Capture and Storage technologies shifts leftwards (lower risk) and upwards (longer cost) the frontier portfolios curve. Consequently RES share is reduced (67%), Fossil technologies participation is slightly increased (25%) and Nuclear remains in a 7% of the total portfolio. Alternately, if the minimization cost viewpoint would be adopted, the possible optimal portfolio (absolute minimum cost) would be completely consist of Large Hydro for the three considered horizons (2009-10, 2020 and 2030).

The "Technological Limitation" in the shape of maximum participation constraints rise cost and risk of frontier portfolios curve. Therefore the technological shares are modified and lead to a realistic perspective. Efficient portfolios curves go towards IEA.UE-27 graph situation. In 2030 Carbon Capture and Storage technology availability shifts the frontier portfolios curve from lower levels of risks and longer levels of costs. Risk reduction is favored by the number of available technologies. In 2020 the absolute minimum cost portfolio is differentiated from that one of absolute minimum risk in the absence of the participation of the most expensive technologies (Oil, Solar PV, Biomass and Off-shore Wind) and in the longer share of Nuclear and Coal. For its part, the absolute minimum risk portfolio mixes in all of the available technologies, benefiting from the major level of diversification. In 2030 in the absolute minimum risk portfolio joined CCS technologies, the Nuclear share is decreased (down to 15%) and all RES participation is increased (except Large Hydro). In this case RES technologies suppose a share of 36% of the mix in 2020, and a share of 46% in 2030. In 2030 the absolute minimum cost portfolio is defined by an important share of Nuclear (30%), the shifting of a part of the Natural Gas share to Natural Gas with CCS, and the reduction to half the On-shore Wind participation, both of them in reference with absolute minimum cost portfolio 2020.

Inside Technological Limitation Case, minimizing cost leads to one lower diversified portfolio and with important Fossil technologies (50%) and Nuclear shares (26-30%). If the aim was minimising risk, the possible optimal portfolio (absolute minimum risk) tends to reduce the Fossil and Nuclear participations, favouring the increase of RES ones (On-shore Wind, Large Hydro, Biomass and Solar PV). Portfolio theory approach to the determination of power mix turns into RES technologies, characterized by high production costs and limited externality costs, in efficient and competitive alternatives in the case of choosing to minimize risk.

As previously cited about, the model allows to assess IEA.EU-27 portfolios for 2009-10, 2020 and 2030 horizons. In 2010 the IEA.EU-27 power portfolio had a similar composition to that of the model absolute minimum risk portfolio. Consequently it would be concluding that the EU-27 produced electricity in a near efficient way. In 2020 and 2030 the portfolio that approximates the most to efficiency is the IEA.UE-27 450 (the portfolio which looks like the most environmentally sensitive). Deciding on one similar portfolio to the IEA New Policies or IEA Current Policies, would lead to a distance from efficiency, as in this study is shown. As long as the European portfolio would brought to it, the EU-27 will be producing electricity in an efficient way (minimizing risk), from an environmental and economic point of view.

In relation with this last comment, one of the lines for future research will be the deepening in the environmental question restrictions, trough the inclusion of specific constraints (polluting gases emissions, for example) in the model for the considered horizons. Another line of interest will be the definition of one measure that informs about the distance between the institutional proposed portfolios and the efficient portfolios resulting by the application of portfolio theory.

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Leapfrogging agriculture as usual:

The potential contribution and sustainability benefits of organic farming to carbon sequestration in Portugal

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Abstract

This analysis attempts to unfold the potential climate change benefits of a large scale conversion to organic farming using Portugal as a model. The additional carbon capture entailed in organic practices is estimated and a theoretical carbon emission reduction potential is calculated. The carbon benefits translate into a carbon market value which does not provide the necessary economic enticement for the transition to happen. However, when the corresponding ecosystem services are taken into account, the resulting value could turn into the necessary motivation. A suggestion is made on a possible solution to finance such massive payments.

Keywords: climate change, sustainability, carbon markets, soil carbon sequestration, organic agriculture transition, Portugal

JEL Classification: Q01, Q15, Q18

Introduction

Society is currently experiencing both the dwindling of the global resource base and the finiteness of the planet's life supporting services, climate change being an example in point. The latter has attracted a considerable amount of research (e.g. McKibbin and Wilcoxen, 2002; Stern, 2006; Nordhaus, 2007; Feehan, et al., 2009; Del Grosso and Cavigelli, 2012), which consistently shows the risk of crossing critical environmental thresholds, leading to irreversible natural damage (Solomon et al., 2009).

How to react to impending climate change has been the subject of numerous analyses (e.g. Stern, 2006; Nordhaus, 2007; Bell, 2006; Rogelj et al., 2013), and the role of agriculture has also been examined (e.g. Fleming, and Vanclay, 2009; Snyder et al., 2009). However, a literature review has not evidenced any studies looking at a massive reorientation of farming policy based on ecosystem services provided and accompanying carbon sequestration potential. Portugal, being the European Union member state with the highest percentage of emission increase allowance (EEA, 2011), represents an obvious target for such an analysis.

In this article a preliminary attempt is made at evaluating the extent to which a large scale transition to a more sustainable agriculture in Portugal would significantly contribute toward meeting the challenge of reducing climate significant emissions and how such a system could theoretically be paid for. The study is structured as follows. The first section reviews climate change objectives and obligations at the European Union and national levels. Afterwards the double role of farming in increasing and offsetting emissions is evaluated based on published literature. Finally, two major alternatives to inducing appropriate agricultural conversion are evaluated.

Section I - Climate and Sustainability

THE CLIMATE CHANGE CHALLENGE

Among atmospheric scientists there is agreement that cumulative anthropogenic emissions are increasing the atmospheric greenhouse gas (GHG) concentration as terrestrial and oceanic sinks are insufficient to reabsorb the additional fossil fuel derived carbon at a sufficient rate (Wheeler, 2010), emissions essentially originate from fossil fuel combustion (over 75%) and land use change (the remaining balance) (Snyder 2009). This has not always been this way, however, as until about 40 years ago all of agriculture combined had resulted in higher CO2 equivalent emissions than fossil fuel use (Desjardins et al., 2005).

This reality entails a high urgency challenge as, according to Hansen et al. (2006), an average temperature increase above 1ºC (from 2000 levels, which translates into roughly 1,7ºC from pre-industrial time) already carries a "dangerous" evolution in climate patterns. One of the reasons is that climate systems involve non linear response curves with thresholds which, when crossed, lead to new steady states that directly threaten humanity's survival (Rockström et al., 2009).

As such, atmospheric carbon must be reduced down to below 350 ppm from its current 394 ppm value in order to minimize the harshest implications from human interference with atmospheric homeostasis (Hansen 2008; Mauna Loa Observatory, 2012). This means a severe reduction in net emissions that must happen on a time scale of at most 20-30 years, except this is not the future where business as usual is headed (Hansen, 2008; Smith 2004).

THE KYOTO OBJECTIVES FOR THE EU AND PORTUGAL

The Kyoto Protocol, which entered into force on 2005, created binding GHG emissions targets for signatory countries during the 2008-2012 period. At the European Union (EU) level (with 15 member states at the time) this translated into an 8% reduction target commitment relative to the 1990 reference year (EEA, 2011). Within this collective goal, however, Portugal was allowed a 27% emission increase limit – the largest of all EU member states.

The 2012 Doha climate talks agreed on an extension of the Kyoto Protocol to 2020, with the EU-27 unilaterally committing to a minimum GHG emission reduction of 20% and keeping open the option of reaching 30% if other major countries agree to follow suit (Lesser, 2013; EEA, 2011). During this period Portugal has been allowed a 30% increase over 1990 levels, that is, about 3% over 2008-2012 emissions (APA, 2012).

Section II - Agriculture as Friend and Foe

AGRICULTURE'S DOUBLE ROLE

Agriculture represents one of the main contributors to climate change, as pointed out by Snyder et al. (2009). In 2009 agriculture accounted for 10.3% of the total GHG emissions in the EU, that number reaching 10.5% as regards Portugal (INE, 2012). It is interesting to note, however, that the overall emissions associated with cradle to grave food production reach an estimate of 32% if fuel use, fertiliser production and agriculturally induced land use change emissions are accounted for (Bellarby et al., 2008). On the other hand, there is potential for agriculture to act as a carbon sink, the exact worth of which varies greatly depending on the management practices involved (Smith 2001). This can be translated into economic value, as recognised in the Kyoto Protocol which states, under article 3.4, that carbon sinks in agriculture may be included when calculating overall country performance.

In the EU in particular, a high potential has been estimated relative to current agricultural practices. In Smith (2004) the realistic soil carbon sequestration potential of organic farming in the EU is calculated to reach 3.9 Mt C y-1, the largest amount for all cropland practices analysed, albeit with a significant degree of uncertainty involved.

A COMPARISON BETWEEN ORGANIC AND CONVENTIONAL FARMING

According to the definition put forward by the International Federation of Organic Agriculture Movements (IFOAM), organic agriculture is a socially, environmentally and financially balanced approach to food production (IFOAM, 2005). This holistic view is based, still according to IFOAM, on four main principles (fairness, care, health and ecology) and results in increased sustainability of the food supply (Seyfang, 2006). The differential performance of organic and conventional farming has been extensively studied.

Soil organic matter (SOM – of which at least half is pure carbon) is not evenly distributed: in a meta-analysis, Mondelaers et al. (2009) demonstrated (with a 95% confidence interval) that SOM concentration in organic farming is significantly higher – averaging 12% – over what can be found in conventional farming (even though not all studies find significative variation between these two forms of agriculture).

A detailed revision of comparative studies has calculated organically farmed soil consistently presents even higher carbon contents: 20% when Europe, the US and Australasia are combined; 28% if focusing on Northern Europe alone; and 33% when only UK studies are included (Gundula, 2009).

This large divergence between farming practices can be explained by differences in levels of composted animal waste use, leguminous cover crops and crop residue recycling, which all tend to be higher in organic agriculture (Hansen, 2001).

THE CARBON BENEFITS OF ADOPTING ORGANIC FARMING

An important feature of the soil carbon increase associated with organic farming is that the rate of sequestration is highest during the first 20 years (where about half the increase happens) and then tapers off until at about 100 years the system has reached its new equilibrium (for the new farming regime) and the net carbon accumulation is zero (Bhogal 2009). This in fact means that the conversion to organic farming brings with it large and immediate benefits, something which has a direct bearing on climate policy.

In practice SOM sequestration through the conversion to organic farming approach provides a much needed high return mitigation option which should be explored while longer term measures are still being put into place and hence not giving results (Smith, 2004).

CARBON SEQUESTRATION IN THE ORGANIC TRANSITION

A report by the european research project PICCMAT calculates that a switch to organic agriculture beget an additional 400 kg per ha per year of SOM. (Frelih-Larsen et al., 2008).

One of the longest running and most studied systems, the Rodale farming systems trial, present an even better outlook. Data collected with a 20 year interval show an annual soil carbon increase of 981 kg per ha per year in organic production with animal manure inputs, as compared to only 293 kg per ha per year in the conventional system (Pimentel, et al., 2005). This translates into an additional 688 kg of soil carbon per ha per year benefit obtained through organic farming practices.

THE PORTUGUESE REALITY AND POTENTIAL PROSPECTS

Portuguese agriculture (including forestry and fisheries) is responsible for about 10% of the national carbon emissions (Alves et al., 2011). The total agricultural area currently in use is 3.7 * 106 ha with an additional 128 000 ha available, but not in production (INE, 2011; INE, 2009a). Overall, only about 121 000 ha are under organic management (MADRP, 2004). Theoretically, if all in use conventional agricultural area were to be brought under organic production, 3.55 * 106 ha would be making the transition. That a country could plan on turning farming 100% organic may be seen as farfetched but has in fact already happened in 2012, when Bhutan announced such a plan at the Rio+20 Conference on Sustainable Development (Barclay, 2012).

Using the Rodale measured benefit of 688 kg C per ha per year, this newly converted organic production area in Portugal would potentially bring in 48 million tonnes of additional soil carbon over the course of 20 years (at a yearly rate of 2.44 million tonnes of additional soil carbon). Considering that the Portuguese agriculture emits 7.8 million tonnes of carbon per year (INE, 2009b) the transition could offset 31.3% of all Portuguese agriculture's estimated emissions for a minimum of a 20 year period. This largely overshoots the reductions officially targeted for this period. But how can the odds be stacked in favor of such a large scale conversion?

Section III - Two paths, one way to a double win

CARBON CREDIT POLICIES

The EU agreed a carbon market can efficiently and economically reduce GHG emissions within the block (Art. 1, Directive EC/87/2003), a decision implemented through the EU Emission Trading Scheme (ETS). The ETS works on the 'cap and trade' principle (EU, 2012), whereby economic agents can define their own most effective approach to emissions reductions.

Currently about 45% of all EU emissions are covered through this approach, encompassing the largest industries, power plants and some flight routes (EU, 2012). Some emitters not included in the ETS include transportation, domestic use, the third sector and agriculture, although they may come to be included in the future (Ellerman, 2008). The ETS, the world's largest, has resulted in a solid carbon administration infrastructure and a uniform carbon price across all 31 participating countries. It has also put a number on the price tag of fossil fuel burning, which effectively defines the market value of carbon sequestration (Ellerman, 2008).

CARBON PRICE EVOLUTION

The average carbon price has risen from €17 in 2006, to €20–25 in 2007, to €27 (US$42) in 2008 (Maraseni, 2009). It took a plunge to an average price of €14 in 2009 (World Bank, 2010), with little variation in 2010 and 2011 (14.56 € in 2010 dropping slightly to 13.93 € in 2011 (World Bank, 2012). In 2012, however, carbon prices had dropped to about €6.5 per ton of carbon at the end of the year (Santos, 2013).

The latter trend is expected to reduce the attractiveness of investment in low carbon technologies and in more efficient and best management practices (Verdonk and Vollebergh, 2012), prompting the European Commission to put forward a number of carbon market stimulation measures which include extending the ETS to additional sectors, among others (COM, 2012).

That current prices are undervalued has also been defended by Creti et al. (2011), who consider the carbon market is bound to increase prices in order to regain equilibrium. French investment bank analyst Paolo Coghe estimates that, whatever measures the European Commission does implement, prices will increase to €9.3 in 2013 all the way to €14 in 2020 (Ferdinand, 2013).

AN ETS BASED INCENTIVE FOR CARBON SEQUESTRATION IN FARMING?

When the higher predicted value of €14 per ton of captured carbon is considered, and taking the above mentioned 981 kg per ha per year overall carbon sequestration ability of organic production, the estimated market value for this societal service is €13.7 per ha per year (or €48.6 Million when the full Portuguese to be converted agricultural area is considered).

By itself, a market incentive this low is not likely to induce a large scale transition to organic farming in Portugal. In fact, it has been estimated that a payment of €500 for five years would not act as enough of a motivator to tilt farmer behaviour in such a direction (O'Riordan and Cobb, 2001). Hence, a complementary approach is necessary if this useful change is to happen at all.

THE MARKET VALUE OF ORGANIC FARMING SUSTAINABILITY

An organic approach to farming has been found to offer improved sustainability over conventional production, with increased biodiversity and lower energy consumption [(Maeder et al., 2002), higher soil quality and overall lower environmental impact [(Reganold et al., 2001) and, by definition, much reduced pesticide use with corresponding benefits regarding water quality (COM, 2004), a benefit compounded by organic's lower nitrate to water leaching rates (Hansen et al., 2001).

When organic farming is compared to the conventional reference as regards the non-market value of these ecosystem services (excluding carbon sequestration), the estimated difference is €310 per hectare per year in favor of the organic method (using the lower, most conservative estimates) (Sandhu et al., 2008). Being of societal benefit, it can be argued that such services justify payment.

A MODEL FOR SOIL CARBON SEQUESTRATION

According to Daugbjerg et al. (2011), Danish policies introducing direct organic farmer payments (starting at €412 per ha the first year and decreasing slowly from there) have been successful in promoting the conversion to organic farming. Assuming farmer dynamics in the two countries are comparable, that amount should be enough to spur the necessary conversion interest in Portugal as well.

However, Denmark has 37% higher consumer prices when compared to Portugal (Numbeo, n.d.), which effectively means that such a payment is equivalent to €301 in Portugal. Hence, if direct farmer payments of €310 per ha were to be introduced in Portugal for those taking up organic farming it is reasonable to assume they would be at least as motivational as the danish. This amount in fact increases to €323.7 when the €13.7 per ha ETS carbon payment is included.

The €310 per ha ecological services subsidy translates into a yearly €1100 Million for a national 100% organic conversion considering the 3.55 * 106 ha of agricultural land in use mentioned above. This funding could be covered to 100% through the €1,335 Million in annual farm subsidies that Portugal receives under the current Common Agricultural Policy (Farm Subsidy Network, 2008).

Conclusion

The evaluation of agriculture's contribution to climate change in Portugal points to the conclusion that carbon markets do not provide enough of a financial incentive to effectively promote large scale carbon sequestration. However, a profound shift in the way farm subsidies are assigned could fund all additional ecosystem services as provided by organic farming, thus triggering a massive carbon sequestration program for the next 20 to 30 year horizon where, climatologists warn, lies the danger of irreversible climatic destabilization. Such a program would inevitably involve a steep learning curve, but could represent a win-win situation as regards overall land use and national sustainability. Data used in this study are preliminary and depend on many assumptions. A more detailed and precise analysis should be undertaken given the urgency of the climatic threat.

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DAY 9 - 14:30		
Room 613 - Energy Modelling 1		
Electricity decarbonisation pathways for 2050: a TIMES based approach in closed versus open systems modelling	Filipa Amorim[1]; André Pina[1]; Hana Gerbelová[1]; Patrícia Pereira da Silva[2]; Jorge Vasconcelos[1]; Victor Martins[3]	[1]MIT Portugal Program - Sustainable Energy Systems, IN+, Inst Sup Tecn, Universidade Técnica de Lisboa; [2]MIT Portugal Program - Sustainable Energy Systems, FEUC, Universidade de Coimbra and INESCC; [3]MIT Portugal Program - Sustainable Energy Systems, ISEG, Universidade Técnica de Lisboa
A multi-objective interactive approach to assess economic-energy-environment trade-offs in Brazil	Ariovaldo Lopes de Carvalho[1]; Carlos Henggeler Antunes[1]; Fausto Freire[1]; Carla Oliveira Henriques[2]	[1]University of Coimbra; [2]Polytechnic Institute of Coimbra
Renewable energy scenarios in the portuguese electricity system	Liliana Fernandes[1]; Paula Ferreira[2]	[1]University of Minho; [2]University of Minho
Scaling Laws and Electricity Consumption in Cities: a sectoral view	Ana Gonçalves[1]; Tiago Domingos[1]	[1]Instituto Superior Técnico

Electricity decarbonisation pathways for 2050:

a TIMES based approach in closed versus open systems modelling

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ABSTRACT

The goal of this research is to analyze the cost-effective opportunities in continental Portugal to achieve full decarbonization of the electricity generation sector by 2050. Since interconnection with neighboring Spain may be one of the key drivers to achieve a cost-effective low carbon pathway, combined with new generating technologies, we evaluate its importance by modeling the Portuguese system either as an isolated or as part of an integrated Iberian system.

To design the low carbon roadmap for 2050 in Portugal, TIMES - The Integrated Markal-Efom System was used. It is an optimization partial equilibrium bottom-up model generator that finds the minimal cost solution for an energy system over a certain time period. Our approach accounts for the short term dynamics of supply and demand to enable a better match and optimize resources complementarities.

The results show that modeling Portugal as an isolated system can lead to underinvestment and underuse of the country's endowment of renewable energy sources in the longer term, which reduces the efficiency of investment. The modeling of Portugal as an interconnected energy system can therefore have a significant impact on the design of a sustainable electricity system and lead to improved investment efficiency.

KEYWORDS: Iberian electricity market (MIBEL), The Integrated Markal-Efom System (TIMES), Roadmap 2050, renewable electricity (RE), hourly dynamics.

JEL CODES: C61, Q28, Q48; L97

1. Introduction

Mostly due to the diversity and increasing of renewable electricity generation technologies, especially those with variable output, energy systems planning models nowadays tend to be more realistic and complex than ever before. Also, the liberalization trend of electricity markets and the increasing decentralization of electricity production systems create additional needs relative to traditional planning models. In the last few decades a large number of energy tools have appeared (Connolly et al. 2010), with a wide variety of possible applications. Pina et al. (2013) have critically reviewed some of these models and developed high temporal resolution TIMES model for long-term policy analysis. Following Pina's work, this paper presents a modelling exercise to optimize the investment in new generation capacity in the long-term with the goal of achieving significant CO_2 emissions reductions, taking into account the hourly dynamics of electricity supply and demand, to which we have added another important model development, the interplay between adjacent systems.

The main objective of the paper is, therefore, to highlight the significance of considering open systems in energy systems modeling analysis. To that end, the modeling implementation was conducted to mainland Portugal for the time period of 2005-2050, under the constraint of full CO_2 emissions reduction by 2050, and two scenarios - one in which Portugal is seen as an isolated system and another in which exchanges with neighboring Spain are included.

To design the low carbon technological roadmap for 2050 in Portugal, TIMES - The Integrated Markal-Efom System model was used (ETSAP, 2007). TIMES is a tool developed within the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency. It is an optimization partial equilibrium bottom-up model generator that minimizes the total cost of an energy system over a certain time period. The model is based on detailed and explicit information about available energy technologies (e.g. production capacity, efficiency and operation costs) and the description of end-use consumption of different sectors and types of energy. It is usually applied to the analysis of the entire energy sector, but may also be applied to study in detail single sectors (e.g. the electricity and district heat sector) (Loulou et al., 2005).

Analyses looking into the planning of Portuguese low carbon energy systems up to 2050 have been developed, either concerning the whole energy sector (Fortes et al., 2012; Seixas et al. 2012) or the electricity sector alone (Gerbelová et al., 2013; Pina et al., 2013). None of these, however, include the increasingly relevant interactions with the Spanish electricity system, ignoring the deepening integration under MIBEL, which our approach considers.

The remaining of this paper is structured as follows. Section 2 describes in more detail the framework of the developed PT/SP TIMES model. Sections 3 and 4 characterize the analyzed and adjacent electricity systems, Portugal and Spain, respectively. Section 5 reviews the modeling scenarios and assumptions used in the analysis. Section 6 presents the results and, finally, section 7 concludes.

2. The PT/SP TIMES model

The Integrated MARKAL-EFOM System (TIMES) was introduced in 1999 as the latest development of the MARKAL framework maintained by the IEA's Energy Technology System Analysis Program (IEA, 2009; Loulou et al., 2008). It is being developed by several people related to ETSAP such as Gary Goldstein, Amit Kanudia, Richard Loulou, Uwe Remme and Giancarlo Tosato. The model is built through a detailed description of technologies and commodities that characterize the energy system.

The main advantage of TIMES is its flexibility, which allows integrating more than one interacting regions and to sub-divide the year in several time periods with different lengths (defined by the user). A typical TIMES model for the evolution of an electricity system can be represented as shown in Figure 1. Additional inputs and outputs are represented in the dashed lines to account for exchanges between 2 adjacent systems and to increase time resolution (adapted from Pina et al., 2011).

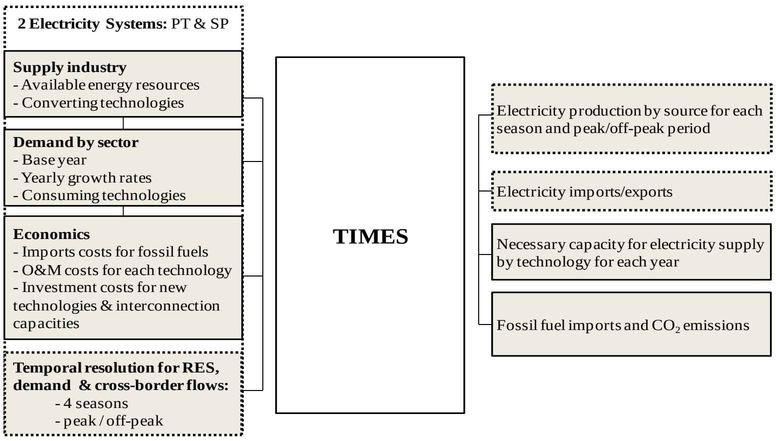


Figure 1 – Main inputs and outputs of a typical TIMES model for electricity systems

The PT/SP TIMES model considers the interconnection between 2 adjacent systems. The direction, intensity and time-dynamics of the interconnection's use varies along with time (year/season/hours) as it may be expected due to, for instance, time-zone differences and each region typical consumption profiles or the relative competitive advantage of electricity at certain time-periods in result of the different availability of resources in each system.

The model considers 288 time periods each year: 4 Seasons, 3 typical days per Season and 24h per day are considered. The typical days considered in the model are 1 Weekday, 1 Saturday and 1 Sunday. This division of the year enables the modelling of several different supply and demand dynamics, as pointed by Pina et al. (2013). The data required to allow for this higher resolution was based on information made available by REN and REE (REN, 2012b; REE, 2012a; REE, 2012b). In the case of a system with high penetration from renewable energies, this fine time resolution enables the analysis of possible advantages of using/building interconnections to import from or to export to the neighboring country. Historically, interconnection capacity was built based in principles of energy security; more recently, these worries have been overlaid by cost-competitiveness principles.

3. The Portuguese electricity system

Last decades transformations in the Portuguese electricity system highlight the efforts to transform it and cope with the goals of European Climate/Energy Policy: the transition to a decarbonised electricity system in parallel to the full integration of *competitive* European electricity markets (Amorim et al. 2013). To this end, we have assisted to the substitution of more polluting fossil fuelled generation by less polluting and diversified sources of fuel, such as endogenous renewable energy sources and natural gas, along with investments in new and upgraded grids, both for internal use and for exchanges with the neighbouring system. This has contributed to the reduction of the external fuel dependence and import costs. Tables 1 and 2 express the evolution of the Portuguese electricity from 2005 to 2010 (REN, 2005-2012). Table 1 shows total installed capacity while Table 2 shows the interconnection available.

MW	**2005**		**2006**		**2007**		**2008**		**2009**		**2010**	
Total	**12.819**	**%**	**13.616**	**%**	**14.197**	**%**	**14.924**	**%**	**16.661**	**%**	**17.915**	**%**
Large hydro	4.578	36	4.578	34	4.578	32	4.578	31	4.578	27	4.578	26
Coal	1.776	14	1.776	13	1.776	13	1.776	12	1.756	11	1.756	10
Fuel & oils	1.909	15	1.909	14	1.877	13	1.877	13	1.878	11	1.822	10
Natural gas	2.166	17	2.166	16	2.166	15	2.166	15	2.992	18	3.829	21
SRP thermal	1.166	9	1.295	10	1.365	10	1.463	10	1.610	10	1.696	9
SRP hydro	333	3	365	3	374	3	379	3	395	2	410	2
SRP wind	891	7	1.515	11	2.048	14	2.624	18	3.357	20	3.702	21
SRP solar	0	0	0	0	13	0	50	0	95	1	122	1
SRP waves	0	0	0	0	0	0	2	0	0	0	0	0

Table 1 – Generation capacity in Portuguese electricity system.

MW	**2005**	**2006**	**2007**	**2008***	**2009**	**2010**
Spain to Portugal	nda	nda	nda	1.216	1.204	1.112
Portugal to Spain	nda	nda	nda	1.049	1.192	1.183

*Table 2 – Average of hourly commercial available interconnection capacity.*2sem.*

a. Expected evolution

Following the European Directive 2009/28/EC, Portugal designed in 2010 a National Action Plan for Renewable Energies which define the objectives relative to the quotas of RES in the Electricity, Transportation and Cool and Heating sectors up to 2020. This Plan is subject to bi-annual updates, the latest of which has been recently performed in 2012, in light of the changes in the macroeconomic scenarios analyzed, the policy setting and the realized investments in the energy sectors. In what concerns the electricity sector, the expected installed capacity additions and retirements in the Portuguese electricity system up to 2020, based in the expectations built as of 2011, have been comprehensively described in (Amorim et al. 2011; Amorim et al.; 2013). Some of these investments are still currently being re-scheduled, others re-defined, while considerable uncertainty still persists within the possible evolutions of the sector. Table 3 below shows the revised RES installed capacity objectives by the Portuguese Government and compares them face to the initial plan. These mean that, until 2020, no other RES investments are expected besides those that are currently under construction or licensed. A disincentive is therefore noticed in less mature technologies such as waves, solar, or offshore wind. Overall, the revised Plan foresees a reduction of 19% in total RES installed capacity by 2020, despite the relative quota of RES in electricity is estimated to be higher than previously set (58% vs. 55%) (Cabral, 2012).

MW	**2020**	**Var. face to PNAER 2010**
Large and small SRP hydro	8.932	-6%
SRP thermal RES	747	-22%
SRP wind	5.300	-23%
SRP solar	550	-63%
SRP waves	6	-98%
Total	**15.535**	**-19%**

Table 3 – Total installed capacity of renewable energy sources updated.

4. The Spanish system

The Spanish system has experienced similar transformations to those in Portugal towards decarbonisation and integration of its electricity system. Spain is presently among the top 10 countries in the world with non-hydro renewable (wind and solar) installed capacity. Table 4 shows the evolution of the Spanish electricity system in what concerns the installed capacity from 2005 to 2010.

MW	2005		2006		2007		2008		2009		2010	
Total	**73.970**	**%**	**78.753**	**%**	**85.698**	**%**	**90.879**	**%**	**93.729**	**%**	**99.043**	**%**
Large hydro	16.657	23	16.657	21	16.657	19	16.657	18	16.657	18	17.561	18
Nuclear	7.876	11	7.716	10	7.716	8	7.716	8	7.716	8	7.777	8
Coal	11.424	15	11.424	15	11.357	12	11.359	12	11.359	12	11.380	11
Fuel & oils	6.647	9	6.647	8	4.810	5	4.418	5	3.008	3	2.860	3
Natural gas	12.224	17	15.500	20	20.958	24	21.675	24	23.066	25	25.235	25
SRP hydro	1.758	2	1.809	2	1.913	2	1.979	2	1.974	2	1.991	2
SRP wind	9.800	13	11.140	14	13.909	17	15.874	17	18.719	20	20.057	20
SRP solar PV	-		-		-		-		-		3.458	3
SRP sol thermal	-		-		-		-		-		682	1
SRP other RES	939	1	1.091	1	1.507	4	4.069	4	4.480	5	1.050	1
SRP non RES	6.645	9	6.769	9	6.871	8	7.132	8	6.750	7	6.992	7

Table 4 – Generation capacity in the Spanish electricity system.

While the interconnection between Portugal and Spain has been expanding and is expected to increase by 1.200 MW in 2014/2015, to 3.000 MW of commercially available capacity (REN, 2011), the interconnection between Spain and France (therefore Iberian and Central European systems) and between Spain and Morocco (Iberian/EU and North African systems) is still relatively limited. The Iberian interconnection will represent about 25% of Portuguese peak demand, which is more than the minimum amount agreed at the European Council of March 2002. The EU recommends that interconnection capacity should represent at least 10% of peak demand of the smaller interconnected system. In the period 2005-2010, only in the French borders Spain has been a net importer, while with Portugal, Morocco and Andorra it has been a net exporter (REE, 2005-2010).

5. Modelling scenarios and assumptions

Given the difficult economic context in Europe and the uncertainty of future investments in new generating capacity both in the Portuguese and Spanish electricity systems, the approach used in this work has been to leave the model free to decide on the most cost-efficient investments up to 2050 under the condition of 95% decarbonisation of the electricity sectors by 2050 and 60% reduction in 2030 (relative to 1990 emissions). The model calibration has been done for the period 2005-2010. One scenario assumes Portugal as an isolated system, while the other scenario considers the export/import balances of electricity in the Iberian electricity systems. In the first scenario a detailed characterisation of the Portuguese system was required, while the second also includes a thorough characterisation of the Spanish generation system, put under similar environmental constraints of decarbonisation by 2050 as the Portuguese, including their interconnections. For both scenarios, the evolution through time of electricity demand, fuel prices, cost of technologies and demand and resource dynamics were the same.

a. Assumptions

For the evolution of electricity demand in Portugal, we considered the joint evolution of GDP and power intensity (ECF, 2010) under the projections of the Portuguese Government until 2020 (Ministry of Finances, 2012; Cabral, 2012). For the period 2020-2030 and 2030-2050 average annual growth rates increases of 1.3% and 1.5% in power demand were considered.

The cost of coal, natural gas and fuel oil are described in Table 5. The costs of wind onshore, wind offshore, solar PV, solar thermal and wave technologies were assumed to decrease with time due to the further development of the technologies and scale effects, as shown in Table 6 (IEA, 2010; IEA, 2012; ECF, 2010; IRENA,2012; WAVEC, 2011).

Indicator	**Units**	**2011**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Crude oil	$\$_{2011}$/bbl	107.6	118.4	128.3	135.7	141.1	145	154.9	165.5	176.8
Natural Gas	$\$_{2011}$/Mbtu	9.6	11.2	12.1	12.9	13.4	13.7	13.8	13.9	14.0
Coal	$\$_{2011}$/ton	123.4	110	115	119.2	122.5	125	129.8	134.7	139.8

Table 5 - Evolution of price of commodities. (Real terms evolution €$_{2010}$, 1€=$1.287, i_{2011}=3.7%) (IEA, 2012 under Current Policies Scenario)

Technology	**Life**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2050**
Wind onshore	25	1.217	1.200	1.200	1.175	1.150	1.000	990	900
Wind offshore	25	3.300	3.000	2.840	2.520	2.200	2.125	2.050	1.900
Solar PV	25	2.550	2.000	1.540	1.370	1.200	1.100	1.000	800
Solar Central	25	-	6.993	6.731	5.874	5.051	4.373	3.694	2.200
Solar Through	25	3.574	3.467	3.360	3.092	2.904	2.737	2.569	2.200
Waves	25	5.650	5.650	4.070	3.710	3.350	3.188	3.025	2.700

Table 6 - Evolution of investment costs (€$_{2010}$/kW) for renewable energy technologies.

For the evolution of electricity demand in Spain the same methodology was considered (ECF, 2010). For the period 2020-2030 and 2030-2050 average annual growth rates increases of 1.1% and 1.4% in power demand were considered.

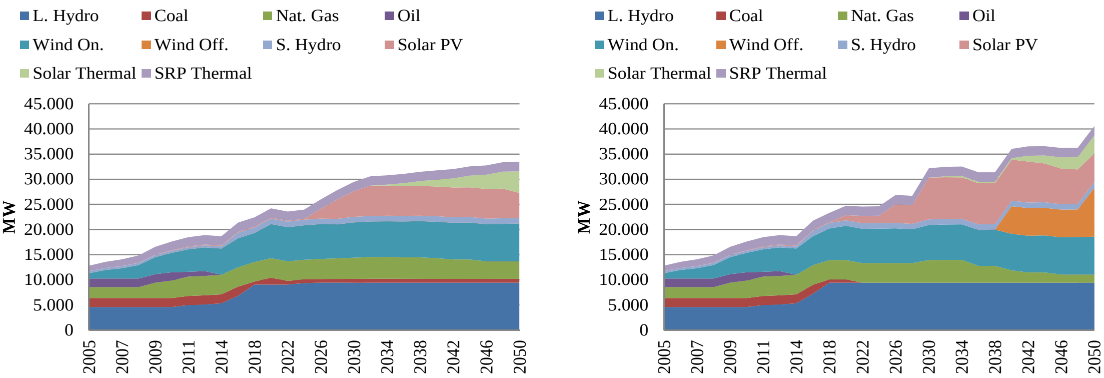
Commodities prices (Table 5) are considered 15% lower in Spain, each year, relative to the same costs in Portugal. Technology costs and their evolution in Portugal and Spain (Table 6) are considered identical. Investments in nuclear in Spain were not available.

The interconnection capacity Portugal-Spain and Spain-Portugal is assumed to evolve with a 3 years delay compared to what is planned, with 3 GW of commercially available capacity by 2018. Other international interconnections were not considered.

6. Results

The analyzed scenarios are presented below concerning the evolution on installed capacity, generation per technology and interconnection capacity and use.

a. Capacity



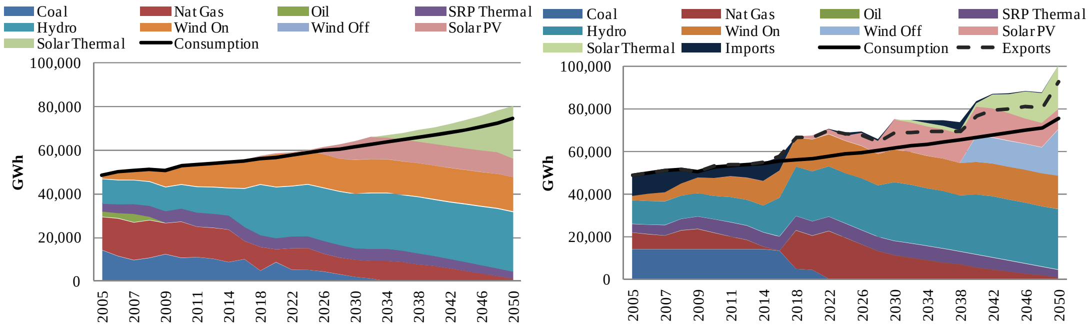
a) b)

Figure 3 – Portuguese installed capacity in a) closed and b) open system

The outcomes of the analysis show that in terms of capacity expansion both scenarios are indifferent in the period 2011-2014. In the subsequent period, until 2050, more capacity investment is made in Portugal by the model, when an open system is considered, particularly in renewable energy sources, as shown in Figure 3. This may be explained by the possibility to export electricity generated using endogenous and renewable low carbon emissions resources, to support the decarbonisation of Spain.

The availability of RES makes the electricity more competitive in Portugal in the longer run, mainly due to the harsh CO_2 restrictions in place. Investments in solar PV begin earlier and are higher in an open system Portugal rather than a closed one. Also, in an open system, the model decides to invest in wind offshore in Portugal by 2040. No significant new investments are needed in coal in an open system, while they endure until the end of the period in a closed system Portugal.

b. Production



a) b)

Figure 4 – Portuguese electricity generation in a) closed and b) open system

As shown in Figure 4, there is more electricity generation in the Portuguese open system, both due to the possibility of exporting electricity and from a higher use of the storage systems. In the period from 2018-2030, generation is still significantly supported by coal and natural gas generation, which are gradually eliminated in the remaining period as CO_2 restrictions become more stringent. From 2018 on, Portugal becomes mainly an exporter of electricity with the only significant imports of electricity occurring between 2035 and 2040. While the first transition to being electricity exporters is made through the increased production from hydro and natural gas, by 2040 the electricity exported is mainly produced from RES, such as wind offshore and solar.

This increase in electricity production, particularly from RES, enables the system to use its installed capacity more effectively by achieving a higher average annual capacity factor, as shown in Figure 5. While the investment on RES naturally brings the average annual capacity factor down due to their low availability, the possibility to export electricity in periods with excess RES allows a better management of the installed capacity which results in a higher annual capacity factor and an increased cost-effectiveness of the investment.

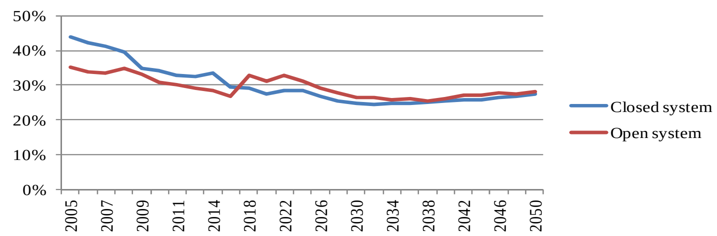


Figure 5 – Average annual capacity factor in closed versus open system (%)

c. Interconnection

With the completion of the planned expansion of hydro power plants, and using the already installed capacity of natural gas, Portugal becomes a net exporter by 2018, as shown in Figure 6. While from 2018 to 2038 there is a continuous decrease on the amount of electricity exported to Spain, leading to an almost zero balance between both countries, the investment in alternative RES technologies such as solar and wind offshore in 2040 once again increases exports.

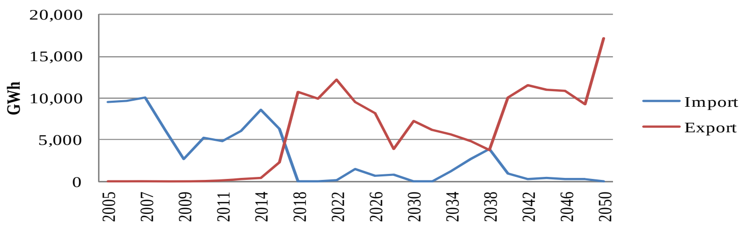


Figure 6 – Average annual imports and exports.

The results of modelling an open electricity system in Portugal interconnected with Spain, show that only in 2050 new interconnection capacity in the direction Portugal-Spain will be required. In the meantime, the available interconnection capacity built until 2018 is far from being used at full capacity, as shown in Table 9, where the use of the existent capacity estimated by the model is shown in the period 2012-2050. The figure of the base year 2010 is historical and is included as a referential for comparison.

	2010	**2012**	**2014**	**2016**	**2018**	**2022**	**2026**	**2030**	**2034**	**2038**	**2042**	**2046**	**2050**
SP-PT	45%	43%	45%	27%	0%	1%	2%	0%	5%	15%	1%	1%	0%
PT-SP	17%	2%	2%	9%	41%	46%	31%	27%	22%	14%	44%	41%	52%

Table 9 – Level of use of existent capacity available for commercial activity.

7. Conclusions

The Spanish electricity system is roughly five times larger than the Portuguese and its cost competitiveness is testified by a history of export balances of its electricity. Nonetheless, when subject to stringent and strong environmental constraints, the high potential for RES in the small

Portuguese system can lead to a shift in the import balances, with Portugal becoming a net exporter.

While most modelling works estimate the evolution of the Portuguese electricity system by considering a closed and isolated system, this can lead to the underinvestment in new generation capacity. In fact, the modelling of the joint Portuguese and Spanish electricity systems points to an opportunity for Portugal to develop its use of non-conventional RES such as wind offshore and solar and at the same time improves the cost-effectiveness of its electricity generation capacity through increased average annual capacity factors. For that reason, despite the current financial crisis, the retreat in the incentives for new renewable capacity in Portugal should be looked into cautiously.

Responses to the challenges arising from the transition to a competitive low-carbon economy should not be dealt with in isolation by national Governments. Investing in cross-border and internal grid infrastructure can contribute to achieving both cost-effective integration of RES electricity and internal electricity market goals. Transmission infrastructure benefits renewable integration because destination markets for variable renewable are enlarged. This can reduce storage requirements and backup capacity needs, thereby reducing the costs of integrating RES into the grid.

Acknowledgment

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A multi-objective interactive approach to assess economic-energy-environment trade-offs in Brazil

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Abstract

An interactive method devoted to multi-objective linear programming (MOLP) models is used to assess the trade-offs between economic, energy and environmental objectives in the Brazilian economic system. The MOLP model is based on a hybrid Input-Output (IO) framework, with monetary (R$) and physical (tons of oil equivalent) units, developed from the Brazilian IO table and the National Energy Balance. This framework is extended to assess different Greenhouse Gas (GHG) emissions, which are then aggregated into a single indicator (CO_2eq). The model includes 435 variables, 582 constraints and 3 objective functions: maximization of Gross Domestic Product (GDP), minimization of energy consumption and minimization of GHG emissions. The interactive decision support tool enables a progressive and selective search of non-dominated solutions making the most of graphical displays, namely the parametric diagram associated with the objective function "weights", to provide insightful information to the Decision Maker. A representative sample of non-dominated solutions has been computed in the interactive process, allowing to identify three main regions corresponding to solutions with different characteristics, i.e. different patterns of trade-offs between the conflicting objective functions. Illustrative results indicate that the maximization of GDP leads to an increase of both energy consumption and GHG emissions, while the minimization of either GHG emissions or energy consumption cause negative impacts on GDP.

Keywords: Greenhouse Gas (GHG), Input-Output (IO) analysis, Multi-objective linear programming (MOLP), Multi-sectoral economy-energy-environment models, interactive methods.

JEL: C61; C67; Q40.

Introduction

Energy and environmental concerns have gained a significant role in public policy agenda. Economic growth usually leads to an increase of energy consumption, which in turn has adverse effects on the environment since current energy supply is heavily reliant on fossil fuels, which are an important source of Greenhouse Gas (GHG) emissions. On the other hand, restrictive energy and environmental policies may lead to negative impacts on economic growth and social welfare. Hence, it is relevant to assess the interactions and trade-offs between economic, energy and environmental indicators in order to provide consistent tools for planners and decision makers (DM) (Oliveira and Antunes, 2004).

The current economic growth in Brazil has influenced positively the welfare and energy consumption. Although renewable energy supply has been increasing, fossil fuel production has also been raising namely due to the exploitation of new oil extraction areas. As a result, more fossil fuel consumption has led to higher impacts in terms of GHG emissions, which is a drawback for current and prospective economic growth.

Input-Output Analysis (IOA) has been traditionally used to study the inter/intra-relationships among different sectors in the economic system, describing the relationship between the inputs used and the outputs produced (Leontief, 1985; Miller and Blair, 1985). The IO models have been modified to account for environmental impacts: generalized IO models including additional rows and columns within the IO system to incorporate the environmental impacts (Leontief, 1970), economic ecological-models utilizing intra/inter-sector sub-matrices linking the economic and environmental sectors (Daly, 1968), and commodity by industry models considering the ecological commodities as products (Victor, 1972). An external expansion of the IO framework can also be made to incorporate the environmental impacts, assuming a proportional relation between the output of the sectors and the corresponding impact levels (Suh and Huppes, 2005).

IO hybrid models have been developed to assess the Brazilian economic system, investigating the interactions between employment and sector's output levels and carbon and energy intensity (Hilgemberg and Guilhoto, 2006), as well as the energy intensity and CO_2 emissions related to a specific region (Figueiredo et al., 2009).

Some studies have developed linear programming (LP) models coupled with the IO framework for different purposes (Moulik et al., 1992; Hristu-Varsakelis et al., 2010). However, MOLP models coupled with IO framework can provide a more complete assessment of different axes of evaluation of potential policies, enabling to exploit the trade-offs between competing objectives. IO MOLP models have been applied to study the impacts of regional policies on the employment, water pollution and energy consumption (Cho, 1999), evaluate the impact of energy conservation policies on the cost of reducing CO_2 emissions (Hsu and Chou, 2000), investigate the impact of mitigating CO_2 emissions considering the maximization of the GDP and the minimization of CO_2 emissions (Chen, 2001), analyze alternative development options for a national economy considering the maximization of GDP and foreign trade balance and the minimization of the energy requirements (Kravtsov and Pashkevich, 2004). Zhou et al. (2006) proposed a modified multiple objective dynamic IO optimization (MODIO) model considering a set of objective functions and a set of dynamic IO constraints. Borges and Antunes (2003) implemented an interactive approach to deal with fuzzy MOLP problems applied to an IO energy-economy planning model. San Cristobal (2012) applied an Environmental IO MOLP model combined with goal programming to assess economic, energy, social and environmental goals. Oliveira and Antunes (2004, 2011, 2012) constructed IO MOLP models to assess the trade-offs between the maximization of GDP and employment level, and the minimization of energy imports and environmental impacts. Antunes et al. (2002) developed an IO MOLP model using the TRIMAP interactive environment to analyze the interactions of the energy system with the economy for Portugal. TRIMAP is an interactive method devoted to three-objective linear programming models that enables a progressive and selective search for non-dominated solutions to grasp the trade-offs between the conflicting objective functions.

A hybrid IO MOLP model is herein presented and applied to the Brazilian economic system aimed at assessing the trade-offs associated with the maximization of GDP and the minimization of the total energy consumption and GHG emissions, considering the timeframe of 2017. The TRIMAP interactive method, which is described in section 2, has been used to make a progressive and selective search for non-dominated solutions. The extended hybrid IO model formulated in this study is analyzed in section 3. Some illustrative results are presented in section 4. Some conclusions and future developments are drawn in section 5.

2. An interactive decision support tool for MOLP

The TRIMAP method plays a key role in an interactive decision support tool enabling a progressive and selective search for non-dominated solutions, thus facilitating to focus the computational effort on the non-dominated regions where solutions more interesting for the Decision Maker (DM) are located. TRIMAP is designed for problems with three objective functions in which graphical tools, in particular the parametric diagram, provide the DM insightful information about the trade-offs at stake in those regions. TRIMAP combines three main procedures: parametric diagram (objective function “weight space”), introduction of constraints directly in the weights, and introduction of constraints in the objective function space that are then translated into the parametric diagram (Clímaco and Antunes, 1987; 1989).

The parametric diagram display is used for collecting and presenting to the DM the information obtained during the search process. The parametric diagram is filled with the indifference regions corresponding to the (basic) non-dominated solutions already computed, i.e. the regions defined by the objective function weights for which the optimization of a (scalar) weighted-sum function aggregating the multiple objective functions leads to the same (non-dominated) solution. Another graph shows the non-dominated solutions already computed, also enabling to identify non-dominated edges and faces of the feasible polyhedron in the objective function space.

This interactive system offers the DM the possibility of progressively exploiting and learning the characteristics of the non-dominated region, and then narrowing down the search toward a solution (or set of solutions) according to his/her preferences. The TRIMAP search process generally starts with a broad strategic search to gather information about distinct solutions, in particular those that individually optimize each of the conflicting functions, and then gradually focus onto regions in which more interesting solutions are found taken into account the trade-offs unveiled throughout the interactive procedure. In this way irrelevant solutions, from the DM's point of view, are avoided and a learning process of the characteristics of solutions and the trade-offs at stake between the competing objectives is privileged. Also a clarification of the own DM's preferences and judgments is facilitated. The interactive process continues until the DM has gathered "sufficient knowledge" about the set of non-dominated solutions rather than pre-specifying a given number of iterations or any other stopping condition.

3. Extended Hybrid Input-Output Model

The first step to build this Extended Hybrid IO model is rearranging the IO table to make the energy use coefficients directly available in hybrid units (physical units per monetary units). In this step, the energy flows in the Brazilian National Energy Balance (MME, 2009) are incorporated into the 2009 Brazilian IO table (Guilhoto and Sesso Filho, 2010) by considering artificial sectors (see also Oliveira and Antunes, 2004, 2011, 2012). For this purpose some adjustments and inclusion of new rows and columns in the IO table are necessary in order to incorporate the different energy sectors (or commodities). This procedure generates a new transaction matrix, thus leading to a new technical coefficient matrix and new vectors for final demand and the total output with hybrid units, in which energy flows are considered in physical quantities of energy (tons of oil equivalent, toe) and all non-energy sector flows are measured in monetary units. The adjustments performed in the IO framework provide: a square matrix with 109 activity sectors split into 51 economic sectors, 6 energy producing sectors, 5 artificial sectors used for distributing the energy consumed by each means of transportation and 47 artificial energy product sectors; 6 column vectors with the components of final demand (exports, public consumption, resident consumption, gross fixed capital formation - GFCF - and stock changes); 1 column vector for competitive imports (considered for energy products only); and 6 row vectors for the primary inputs (wages, gross mixed income, gross operating surplus, other production taxes and other production subsides).

An external expansion of the IO model is made to estimate GHG emissions from energy combustion, industrial processes, agriculture activities, waste management, wastewater treatment and discharge, and fugitive emissions. In this step, based on the IPCC (2006) methodology, emission factors for GHG emissions from carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are used in combination with the level of activity of specific sectors and final demand components. These estimates give a vector with the environmental impacts per unit of output of the sectors and the final demand, considering the corresponding Global Warming Potential (100-year horizon: 25 for CH_4, 298 for NO_2) relative to CO_2 (IPCC, 2007).

Finally, the MOLP model based on IO analysis proposed by Oliveira and Antunes (2004, 2011, 2012) for Portugal is adapted to the Brazilian economic system, which has a very different structure leading to important changes in the mathematical model. The model includes (internal) coherence constraints derived from the IO analysis and other sets of constraints associated with the structure of the economic system, employment and energy consumption, which are briefly described below. Further details about the multi-objective model can be found in Carvalho et al. (2013).

3.1 Model constraints

Coherence constraints are used to determine that the intermediate consumption and final demand of each activity sector shall not exceed the corresponding total amount available from national production and competitive imports.

The GDP (expense approach) is computed considering the final demand minus imports at FOB (free on board) prices (including tourism). The GDP (production approach) is computed by the sum of gross value added and the total of taxes less subsides on products that are not included in the production.

The gross value added is given by the sum of wages, gross mixed income, gross operating surplus, other production taxes minus other production subsides.

Taxes less subsidies on goods or services are calculated for the intermediate consumption and final demand items.

The model also establishes some assumptions for several consumption relations: the households' consumption on the territory includes the consumption on the territory by resident and non-resident households; the residents' consumption includes the consumption of households and Non-profit Institutions Serving Households (NPISH); the resident households' consumption on the territory is linearly dependent on the available income; and the tourism imports is given as a proportion of the residents' household consumption.

The GDP at current prices is estimated considering the components of GDP (expense approach) at constant prices and the corresponding deflators. Additionally, the consumption of goods and services by the public administration at current prices and the GFCF at current prices are exogenously defined.

The residents' disposable income at current prices is computed by subtracting the public administration and (non-financial and financial) corporations' disposable incomes from the National Disposable Income.

Public debt is given by the summation of the previous period debt with the symmetrical value of the public administration global balance, plus an adjustment variable.

Public administration's global balance is computed by subtracting the public administration's expenditures from the public administration's revenues.

The employment level is obtained by using labor gross productivity coefficients for each sector.

The total energy consumption is obtained from the sum of national and imported energy excluding the energy consumed for non-energy purpose. Specific technical coefficients are applied to the intermediary consumption and final demand.

3.2 Objective Functions

The model considers three competing objective functions:

- F1: Maximization of GDP as an indicator of global economic performance (thousand R$).

- F2: Minimization of total energy consumption to assess the impacts associated with economic growth and GHG emissions, taking into account that energy supply in Brazil is mostly domestic (thousand toes).

- F3: Minimization of GHG emissions considering the links with economic activity (and energy use) as well as the international agreements on the reduction of GHG emissions (Gg of CO_2 equivalent).

The detailed presentation of the multi-objective mathematical model can be found in Carvalho et al. (2013).

4. Results and discussion

The MOLP model has been supplied with realistic data gathered from several Brazilian sources (MME, 2009; Guilhoto and Sesso Filho, 2010; MCT, 2010) and estimates for the year 2017

(Carvalho et al., 2013). The MOLP model has 435 decision variables, 582 constraints and 3 objective functions. Some illustrative results obtained with the interactive decision support tool briefly described in section 2 are herein described.

Firstly, each objective function was optimized individually, resulting in 3 distinct non-dominated solutions. These solutions provide a first overview of the range of variation of the objective values within the non-dominated region. The characterization of these solutions (objective function values, decision variable values, indifference region in the parametric diagram) is presented to the DM. Therefore the DM should indicate a set of weights not yet belonging to an indifference region in the parametric diagram to compute a new non-dominated solution. The weight specification should be understood not as a precise “importance coefficient” but rather as an indication of the objective functions to be (temporarily) privileged in the subsequent search. Note that the area of the indifference region in the parametric space also gives an indication of the solution “robustness” regarding weight changes. Information about some solutions may lead the DM to conclude that it is not worthwhile to proceed with the search using weights in-between the corresponding indifference regions because the solutions then obtained would not be so different and therefore would not be relevant for decision support purposes. This enables a progressive and selective search of the non-dominated solution set using the parametric diagram as a valuable visual feedback enabling to identify sub-sets of solutions sharing similar characteristics, namely trade-offs between the competing objectives, until a satisfactory compromise solution is identified. In this example, the parametric diagram has been filled with indifference regions corresponding to 20 non-dominated (basic) solutions that have been considered providing sufficient information about different policies - see figure 1, in which ([illegible] denote the weights assigned to each objective function (F1, F2, F3) to build a scalar weighted-sum function to be optimized leading to the identification of the corresponding indifference region using the multi-objective simplex tableau.

Analyzing the objective function values, for example, of solutions 11 and 12 it is possible to conclude that the DM has information to conclude that it is not worthwhile searching for new solutions in the parametric diagram region located between the indifference regions corresponding to those solutions. The visual information displayed in the parametric diagram thus contributes to minimize the computational effort and the number of irrelevant solutions generated during the exploitation of the problem (and thus the information processing effort required from the DM).

A useful tool offered by the TRIMAP interactive method is the possibility to impose additional bounds on the objective function values in order to narrow the scope of the search to regions of interest of the non-dominated solution set. This information stated in the objective function space (which is the most familiar space for the DM) is translated via an auxiliary problem into the parametric space, in which the regions of weights leading to solutions satisfying those bounds can be computed. In this example, the DM established two bounds in the values of F1 ≥ R$ 3,903,355 x 10^3 and F2 ≤ 237,249.5 toe x 10^3 (see figure 2). These bounds represent the expression of reservation levels, i.e. the DM stating that he/she is not interested in solutions providing inferior values than those stated for those functions. This restricts the search process to regions that include the solution 12 and a still not yet searched region nearby this solution (in which new non-dominated solutions can be found if the DM wants to). This feature of TRIMAP is particularly valuable to reduce the scope of the search aligned to the DM's preferences (see Clímaco and Antunes, 1987 and 1989, for technical details).

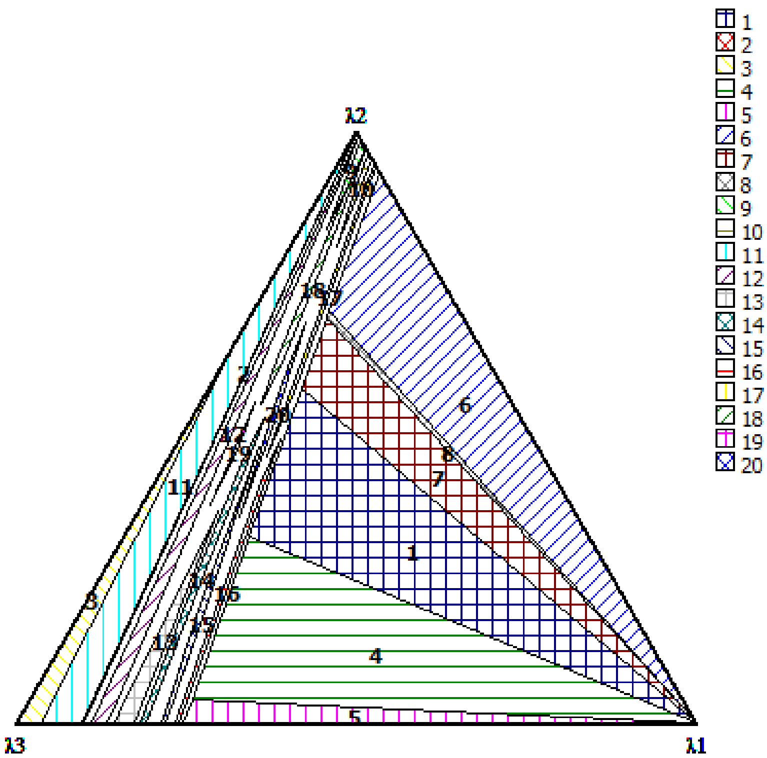

Figure 1 - Decomposition of the parametric diagram into indifference regions (corresponding to basic non-dominated solution).

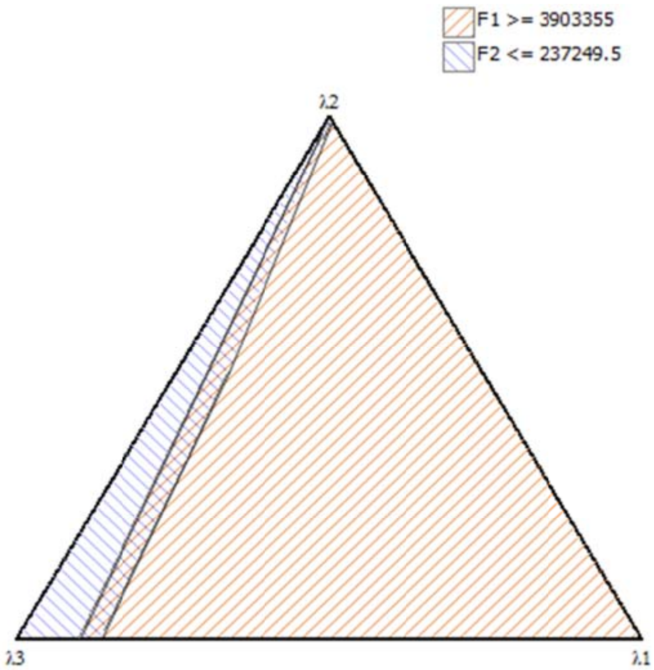

Figure 2 - Additional bounds on the objective functions and regions in the parametric diagram satisfying them.

The objective function values of the 20 non-dominated solutions computed using the TRIMAP interactive method are presented in table 1. The values in bold are the components of the ideal solution with the optimal values for F1, F2 and F3 (GDP, energy consumption and GHG emissions, respectively).

Table 1 – Objective function values for some non-dominated solutions

Solution	**F1 (10^3 R$)**	**F2 (10^3 toes)**	**F3 (Gg $CO_{2\ equiv}$)**
1	**4,465,863**	271,392	2,708,369
2	3,902,394	**237,248**	2,537,554
3	3,900,231	237,267	**2,537,377**
4	4,465,863	271,449	2,708,333
5	4,465,863	271,544	2,708,327
6	4,465,863	271,244	2,708,918
7	4,465,863	271,392	2,708,369
8	4,465,863	271,392	2,708,369
9	3,924,972	237,499	2,542,324
10	4,022,372	240,443	2,565,221
11	3,901,036	237,249	2,537,409
12	3,903,358	237,248	2,537,659
13	3,938,117	238,387	2,543,422
14	3,962,958	238,748	2,548,863
15	4,002,566	240,061	2,558,992
16	4,044,838	241,818	2,570,861
17	4,037,694	241,175	2,569,085
18	3,955,369	238,299	2,547,625
19	3,932,868	238,036	2,542,672
20	4,015,388	240,242	2,562,830

A more detailed analysis of the characteristics of the solutions can be made using the results of the model decision variables besides the objective function values. However, the illustrative results herein described will be focused on their most relevant aspects and characteristics of the main variables.

It is possible to verify a conflicting relation between GDP and energy consumption (or GHG emissions). In solution 1, which maximizes GDP (R$ 4,465,863 x 10^3), both energy consumption and GHG emissions values are very close to their worst value known in the non-dominated region (271,392 toe x 10^3 and 2,708,369 Gg of CO_2 equivalent, respectively). On the other hand, for solution 2, which minimizes energy consumption, GDP achieves a value (R$ 3,902,394 x 10^3) not far from its worst one (see table 1) and GHG emissions are very close to the optimum (2,537,554 Gg of CO_2 equivalent). In addition, for solution 3, which minimizes GHG emissions (2,537,377 Gg of CO_2 equivalent), GDP achieves the worst level (R$ 3,900,231 x 10^3) while energy consumption is only 0.01 % higher than the optimal level.

Three main regions can be distinguished in the parametric diagram corresponding to solutions with different characteristics. It is possible to note that solutions 4, 5, 6, 7 and 8 are alternative optima of solution 1 with respect to F1. It is also possible to recognize through the visual inspection of the parametric diagram that a well defined "cut" exist marked by the "western" boundaries of the indifference regions associated with those solutions (1, 4, 5, 6, 7 and 8). Until that boundary the values for GDP is the same (the optimal one) with small variations in F2 and F3 values. The GDP value decreases smoothly for solutions beyond that boundary as the weight assigned to F1 approaches zero (that is, ⍰1=0 and ⍰2+⍰3=1). Different combinations of ⍰2 and ⍰3 with ⍰1=0 enable to obtain solutions 2, 11 and 3. An important characteristic of those regions is the high values obtained for the Gross Fixed Capital Formation (GFCF) and employment, which achieves its highest value in solution 5 (56,818,158 employees). The sectors that have the highest output improvement are linked to the energy, construction and manufacturing industries.

A second region involves solutions 2, 3, 11 and 12, where the values for all objectives are very similar varying less than 0.1% for GDP and 0.01% for energy consumption and GHG emissions. This region is characterized by lower values for GDP and values close to the optimum for energy consumption and GHG emissions. An important drawback of these solutions is the negative impact on the employment level, which achieves its lowest values, especially in solution 3 (50,749,014 employees). The industrial sectors with negative impacts on their outputs in solutions 2 and 3 are the energy intensive sectors, such as the extractive industry, petroleum refining and coke, chemicals and cement.

Finally, the region containing solutions 10, 15, 16, 17 and 20 is characterized by intermediary values for all objective functions, with a variation of 1.0% for GDP, 0.7% for energy consumption and 0.5% for GHG emissions. Solution 20 is representative of the main characteristics of the solutions within this region, with well-balanced values also for employment (52,146,818 employees).

5. Conclusion

Since, in general, energy, economic and environmental aspects of distinct policies have conflicting interactions, a broad scrutiny of these evaluation axes and a thorough appraisal of the trade-offs at stake are important for the policy making process. In this context MOLP models enable to exploit the trade-offs between those competing objectives and provide an important tool in the assessment of distinct policies associated with different non-dominated solutions.

In this paper a hybrid IO framework is used to develop an MOLP model applied to the Brazilian economic system, which is investigated by using the TRIMAP interactive method. The aim is to assess the trade-offs between economic, energy and environmental objectives through a progressive and selective search of non-dominated solutions in order to provide decision support to DMs. The TRIMAP interactive environment has been used to perform a progressive and selective search based on the parametric diagram. The non-dominated solutions computed allowed to unveil some patterns and the main characteristics of three main regions in the parametric diagram corresponding to sub-sets of solutions sharing the same features. The illustrative results obtained with this model provide valuable insights about the trade-offs involved and allow identifying the performance and trends of the main variables. The IO framework coupled with the MOLP model provided an important tool to assess the interactions and trade-offs between the objective functions. The TRIMAP interactive method has provided great flexibility to the analysis, allowing a progressive and selective exploration of the compromise solutions in a user-friendly graphical environment. Future developments of this work will involve the use of other multi-objective interactive methods within an integrated framework to facilitate the DM’s tasks and provide a user-friendly interactive environment to assess the merits of distinct policies.

Acknowledgements

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Renewable energy scenarios in the portuguese electricity system

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Abstract

Portugal has been demonstrating over the years a high dependence of imported fossil fuels, especially with regard to the transportation and electricity production sectors. The urgent need to balance supply and demand as well as the growing concern about environmental issues and reduction of external energy dependency justified an increasing interest in the exploitation of renewable energy sources (RES) looking for more efficient strategies in terms of economic and social or environmental dimensions. The electricity sector represented a clear example of this RES trend with European and Portuguese policies focused on strategies promoting renewable resources and energy efficiency. Following different studies already conducted in other countries, this paper presents an approach to a possible 100% renewable electricity scenario in Portugal, supported by the application of the model EnergyPLAN. The importance of the interconnection as stabilization measure for a system highly dependent on renewable energy sources of variable output is put in evidence. The results also established that the cost structure of each scenario is mainly driven by the low marginal cost of renewable technologies along with their high investment costs.

KEYWORDS: Renewable energy sources (RES); Portugal; 100% renewable scenarios

JEL Classification: Q42; C63; P48

1. Introduction

The acknowledgment of the need to take advantage of opportunities which endorse economic growth combined with a sustainable energetic policy, has led to several investments in Renewable Energy Sources (RES), which, in turn, aim to have a positive impact on the local and regional development.

Considering energy as the source of economic growth and sustainable development, it is urgent to witness a shift of paradigm where the RES become more than just an environmental necessity, but are indeed perceived as a strategy for security, development and innovation.

Although Portugal remains as one of the European Union countries with highest energy dependency rate, there is a perceptible growing importance of endogenous energy resources, especially regarding the production of electricity.

As a result of the national and international crisis, Portugal´s economy remains inactive, or as some might consider, in contraction. However, forecasts for the sector still foreseen an increase of the electricity consumption for the next years. In order to comply with this, studies such as REN (2011) and DGEG (2012) established that the internal production would strongly rely on the expansion of the hydro and wind installed capacity combined with a special emphasis on the development of solar energy and other RES such as biomass, biogas, geothermal and wave energy.

Within this context, and so as to reduce the dependency on the fossil fuels and optimize the electricity system, several methodologies have come forward, enabling the analysis of future scenarios of generation of electricity through renewable systems. These renewable systems are expected to contribute to sustainable development and the models used for the analysis frequently rely on the computation of costs of electricity generation, CO_2 emissions and external costs and benefits (externalities). These studies have been accompanied by informatics tools which assist within the decision-making process, foreseeing scenarios and appointing optimal in each one of the electric system indicators.

This paper proposes the use of the EnergyPLAN one of the best-known models in the energy planning area (Connolly *et al.*, 2011). The model was adapted to the Portuguese case and simulating a 100% renewable electricity system.

2. 100% Renewable Models and Scenarios for electricity systems

Nowadays, it has been witnessed in many World countries, a conscientiousness of the Greenhouse Gas Emission (GHG) and its consequences towards climate, in particular over the past few years. The unpredictability and high costs of fossil fuels, the energetic dependency and the environmental hazards derived from the consumption of “traditional” energy sources, have placed the electrical generation system as one of its main contributors.

One of the most effective solutions is the integration of RES, already established in normative documentation. However, the main constraint faced by the production of electricity from RES relates to its “*intermittent nature*”, which can lead to high costs related to storage systems (Cósic, B. *et al.*, 2011).

The possibility combining different RES has been approached by different authors who have analyzed the potential of the generation of electricity systems based on 100% renewable scenarios (see for example Cósic, B. *et al*., 2011 or Mathiesen *et al*., 2011). Krajačić, G., *et al*. (2011), presented already the application of a computational model for the production of electricity in Portugal in a possible 100% RES system. The results "*demonstrated that the solution preferred 100% renewable hydropower and wind energy*," although the latter should be implemented in combination with "*reversible hydroelectric and pumping capacity*."

The complexity of the systems under analysis is evident both from the data and from the model effort required. These systems require a simulation of possible future scenarios, through the adoption of planning models based on computing tools. These simulations will enable the flexibility of the processing of data and the time-efficient elaboration of different scenarios which guarantee the possibility to introduce supplementary data, such as seasonality of demand and time variations.

3. Renewable Scenarios within electricity systems

3.1 Assumptions and data

This paper aims to present renewable scenarios for the generation of electricity in Inland Portugal relying on the EnergyPLAN model. The four scenarios established for the country, are presented below:

1. Scenario 1: reference scenario/model validation, with 2010 as reference year;
2. Scenario 2: alternative scenario for 2020, according to values presented in the National Action-Plan for Renewable Energies (PNAER) (DGEG, 2012);
3. Scenario 3: scenario for 2022, according to values presented in the Development and Investment Plan of the National Transports Network 2012-2017 (2022) (PDIRT - REN, 2011);
4. Scenario 4: 100% renewable scenario with total exchange of fossil fuels by renewable energies.

Whenever necessary, it was introduced the hourly time distribution of electricity supply and demand. In every scenario, a technical analysis of the calculation settings was undertaken, as well as a perspective of costs and associated CO_2 emissions.

The EnergyPLAN model is computer-based and aims to analyze the Energy Systems. The main goal of the model is to serve as a tool in the elaboration of national energetic strategies based on technical and economical analysis coming from the implementation of different energy systems and investments (Lund, H., 2011). Being considered as an input/output model, the model simulates a time analysis over a 1 year period. This way, the EnergyPLAN enables the optimization of the energy systems based in the technical management of its components, foreseeing the reduction of the imposed financial restraints in the established scenarios, in particular, when considering future perspectives of alternative solutions (Connolly, D., *et al.*, 2011).

The technical data included in Scenario 1 were based on public data from REN. Therefore in 2010, concerning electric consumption, Portugal presented a total of 52.3 TWh/year and a total balance imports/export balance of -2.6 TWh/year. Thermo-power plants accounted for 7407 MW and RES power plants accounted for 8404 MW. Cogeneration and the transmission capacity of the system were also accounted for with this last one achieving 1600 MW (PDIRT – REN, 2011). A minimum production stabilization rate equal to 0.3 was assumed, to ensure the stability of the electricity network with dispatching technologies.

Scenario 2 was designed for the year 2020 and figures presented after the revision of the National Action-Plan for the Renewable Energies were assumed, covering the set of goals to be accomplished by 2020 and the respective measures for this purpose, which mainly relies in principles such as reducing energy dependence of the country and aspiring to a sustainable electricity system. It should be underlined that the reduced version of this document does not present enough information for complying with all the necessary parameters for the modeling, however it is indeed the most up-to-date document and it is framed within the current economic outlook. Scenario 3 provides a forecast of the electrical system in Portugal for the year 2022 based on strategies built within the Development and Investment Plan of the National Transports Network. This scenario relies on higher electricity consumption forecasts and also on higher RES shares. The last scenario was designed with the aim of introducing an open system, with outdoor exchanges, targeting 100% RES to electricity and by this replacing all fossil fuels in the electricity system. Electricity demand projections from scenario 2 were assumed. This scenario favors the installed capacity of wind power (*onshore and offshore*) which totalizes 9970 MW. Still, in this scenario, it has been considered a sum of installed capacity for wave energy proposed by Krajačić G., *et al.* (2011). Such introduction was necessary due to the interconnection capacity being limited (3000 MW). Furthermore, decentralized electricity storage systems were not included.

Table 1 summarizes the main data used and additional details on the scenarios can be found in Fernandes (2012).

Table 1 Main data used for four scenarios under analysis

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Electric Consumption (TWh/year)	52.3	53.6	66.43	53.6
Imports/Exports Income (TWh/year)	-2.6	-1.9	-1.9	-1.9
Coal(TWh/year)	6.6	2.26	6.6	0
Fuel (TWh/year)	0.047	0.014	0	0
Natural Gas (TWh/year)	10.7	16.20	15.3	0
Biomass (TWh/year)	1.2	2	3.1	3.1
Thermoelectric plants (installed capacity - MW-e)	7407	6900	7245	0
Wind (MW)	3225	5300	7350	9970
Photovoltaic (MW)	100	500	1600	4500
Run-of-the-river Water (MW)	2380	4750	3389	3389
Waves (MW)	0	6	275	3000
Dams (MW-e)	2117	4250	6971	6971
Dams pumping efficiency (%)	100	100	100	100
Dams – average storage capacity (GWh)	3.076	6.152	10.151	10.151
Dams pumping (MW-e)	492	492	5002	5002
Dams water supply (TWh/year)	6.5	13	21.4	21.40
PRE thermal (TWh/year)	7.332	8.84	9.72	0
PRE thermal (fuel) (TWh/year)	2.866	3.33	3.24	0
PRE thermal (natural gas) (TWh/year)	2.866	3.33	3.24	0
PRE thermal (biomass) (TWh/year)	1.6	2.18	3.24	3.24

This work also aims to provide a summarized economic analysis of the scenarios. Due to significant differences between the different types of technology used for generating electricity, the used data are compiled in **Table 2.**

Table 2 Technic and economic data used for the electricity generation technologies

	Investment Costs (€/MW)	O&M (€/MWh)	Life time	Fuel costs (€/MWh)	Efficiency (%)	CO_2 (ton/MWh)	Cost CO_2 (€/ton)
Coal	1.646.820	4,65	40	23,38	37,5	0,900	15,24
Natural Gas	825.242	3,46	30	54,43	55,9	0,370	

Fuel	-	2,2	-	114,22	45,7	0,800	
Water - Dam	1.443.00	8,32	50	0	-	0	
Run-of-the-river Water	1.662.000	3,87	50	0	-	0	
Water - mini hydro	2.036.800	4,33	50	0	-	0	
Wind	1.813.060	16,92	24	0	-	0	
Photovoltaic	4.635.080	23,12	25	0	-	0	
Waves	5.000.000	30	60	0	-	0	
Biomass	2.500.000	4	20	9	27,7	0,022	15,24
Cogeneration of Natural Gas	700.000	4,5	20	54,43	75	0,289	15,24
Cogeneration of Fuel	1.050.000	9	20	114,22	78	0,695	15,24
Cogeneration of Biomass	800.000	3	35	9	75	0,022	15,24

3.2 Analysis of the results

Figure 1 represents the total amount of electricity produced from RES, where the increasing trend is evident. The value obtained for Scenario 4 in fact presents a total amount of electricity production (100% RES) higher than the expected electricity consumption which has to due to the large amount of RES power present in the system required to avoid electricity shortage in peak moments. However, this leads evidently to excess of production on lower consumption moments.

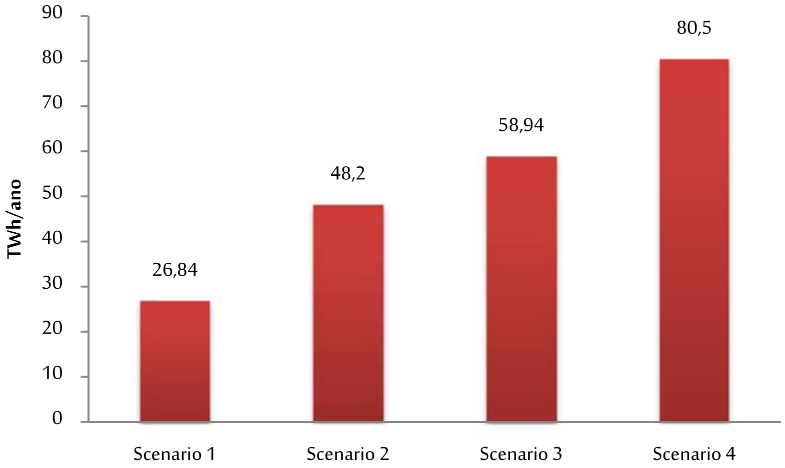

Figure 1 Production of electricity from RES

Due to the large amount of data available to be analyzed two relevant weeks were selected for further detail on the result, corresponding to a winter and a summer week.

In Scenario 1, the recorded values indicate that during winter the increased production for wind and hydro power is reported. The summer figures put in evidence the "dry" season with very low values for hydro power production.. In fact, it is observable that electricity from wind power presents higher values than electric consumption, in some days of the week. However, production coming from photovoltaic and thermal energy sources present higher figures in August. In comparison, during August, the average pumping is practically non-existent and the average values of storage sum 200 MW.

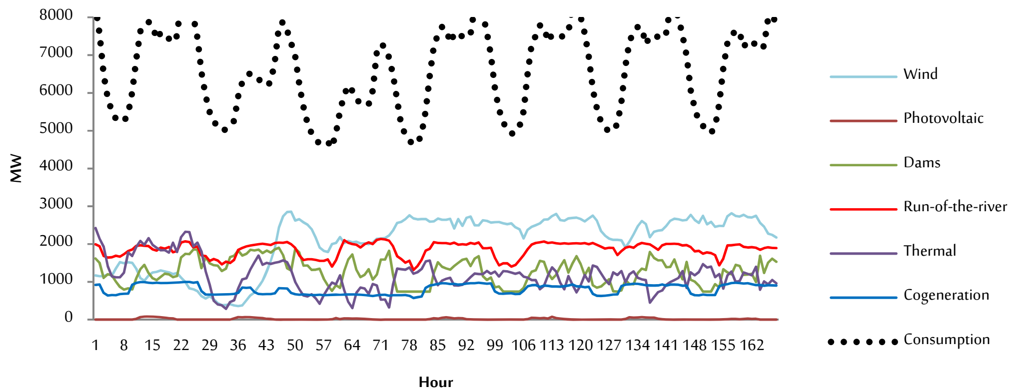

Figure 2 Hourly distribution of consumption and production of electricity in Scenario 1 in February

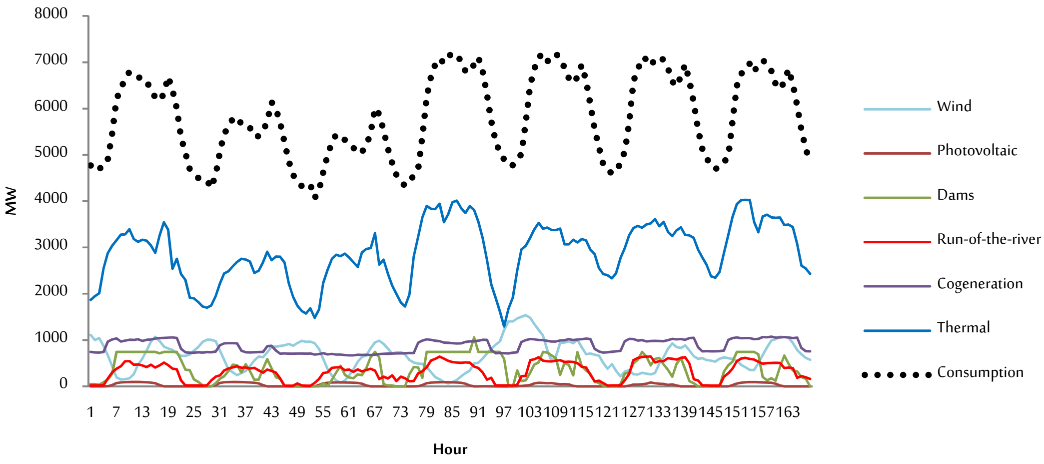

Figure 3 Hourly distribution of consumption and production of electricity in Scenario 1 in August

In Scenario 4, in the winter week, there is still a predominance of wind energy production; however, in this scenario, electricity production from dams is higher than the run-of-the-river water (including mini-hydro). As this is a 100% RES scenario, the thermal production from fossil fuels is not included.

As it was expected, during summer, photovoltaic energy presents more significant figures when comparatively to the winter week, while hydro and wind production decreased considerably. Moreover, it should be taken into account the fact that during summer the pumping capacity decreases as well as the dam storage values (457 MW on average).

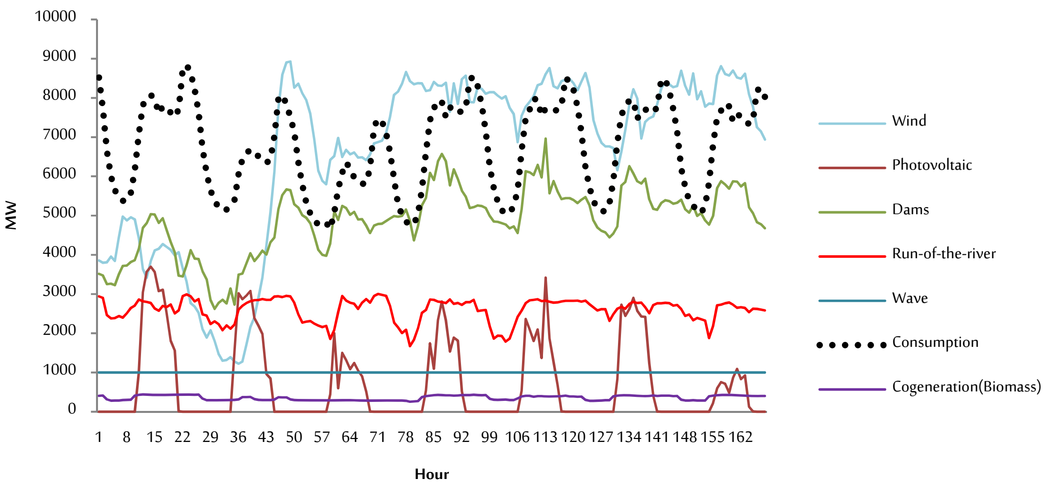

Figure 4 Hourly distribution of consumption and production of electricity in Scenario 4 in February

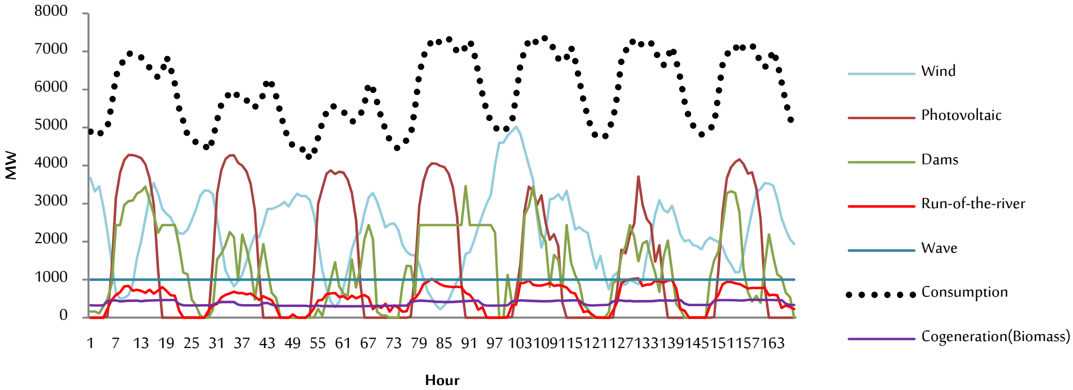

Figure 5 Hourly distribution of consumption and production of electricity in Scenario 4 in August

The EnergyPLAN model allows analyzing results related to electricity production excess throughout the year. This way, the *Critical Excess Electricity Production* (CEEP) refers to the full amount of energy which is exceeding the electricity needs and the interconnection capacity. As for the *Exportable Excess Electricity Production (EEEP),* these values relate to the amount of electricity which may be effectively exported.

This work aims to obtain a technical optimization of the electrical balances, therefore assuming open systems to the outside through the introduction of a fixed import/export scale and of a transmission capacity which varies between 1600MW and 3000MW, for all scenarios.

According to Figure 6 (see below), it is possible to recognize that additional imports assume the figure “Zero” in scenarios 1, 2 and 3. Scenario 4 (100% RES), presents an average import value of 77 MW. This scenario provides more significant importation figures during summer, as both wind and hydro production decrease during these months. Meanwhile, exports and consequently the CEEP assume higher annual average figures under Scenarios 2 and 4, which pose as a critical factor when stabilizing the network particularly in the last scenario. These CEEP peaks occur in typical winter months, when both the wind and hydro production increase which would allow exporting electricity if allowed by the interconnection capacity. However, in the typical summer months there is a considerable decrease of the mentioned RES electricity production. Although Scenario 3 assumes a similar transmission capacity, it presents lower CEEP values. These differences are justified by the assumed lower electricity consumption and lower percentage of renewable energy integration for the more conservative Scenario 2. As for the EEEP, all the scenarios have an annual average value above 100 MW. In Scenario 1, the installed transmission interconnection capacity is only 1600 MW which of course leads to lower exportation values, compared to the other three scenarios with interconnection capacity equal to 3000 MW. The importance of the importation and exportation balance is demonstrated in Figure 6 for all the four scenarios.

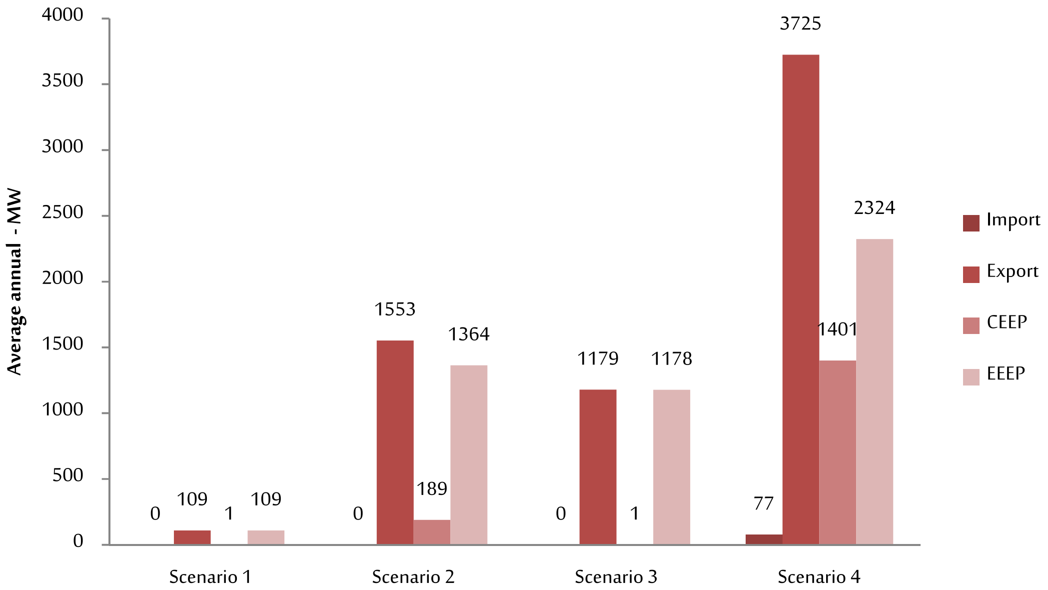

Figure 6 Average annual electricity balances

The computed costs for each one of the Scenarios were based on estimated investment cost for each one of the electricity technology production assuming an incremental approach in relation to the validation scenario (Scenario 1).

The results obtained from the calculation of the marginal costs, including the production costs coming from each technology, the operation and maintenance costs, the fuel costs and the costs with the CO_2 emissions have enabled to conclude that, when analyzed independently, they present a gradual reduction from Scenario 1 to Scenario 4. This cost reduction may be explained by a set of different factors. Firstly, it is due to the low operating and maintenance costs of renewable energy power plants when compared to fossil fuels thermal power plants. Secondly, it is due to the avoidance of fuel costs and CO_2 emission allowances brought by the increasing share of RES power plants.

Thus, Scenario 1 presents higher figures for marginal costs (35,13 €/MW) due to the presence of thermal and cogeneration power plants, as well as it presents a lower integration of renewable energy when compared with the other three scenarios. In turn, Scenarios 2 and 3 with a higher production of renewable energy present comparatively lower marginal costs (29,33 €/MW and 22,16 €/MW respectively). Scenario 4 presents considerably low figures regarding marginal costs (14,33 €/MW) due to total exchange of fossil fuels for renewable energies. The values of the marginal costs as described in Figure 7.

However, when the analysis refers to the total cost of each scenario including investment costs on the computation of the average cost of the system in €/MWh (Figure 8), the situation presents itself in reverse, with higher values in scenarios where it has been designed a greater uptake of renewable energies. This is due to the fact that the investments cost of RES power technologies are higher than the ones for fossil fuel power plants, as pointed previously in Table 2.

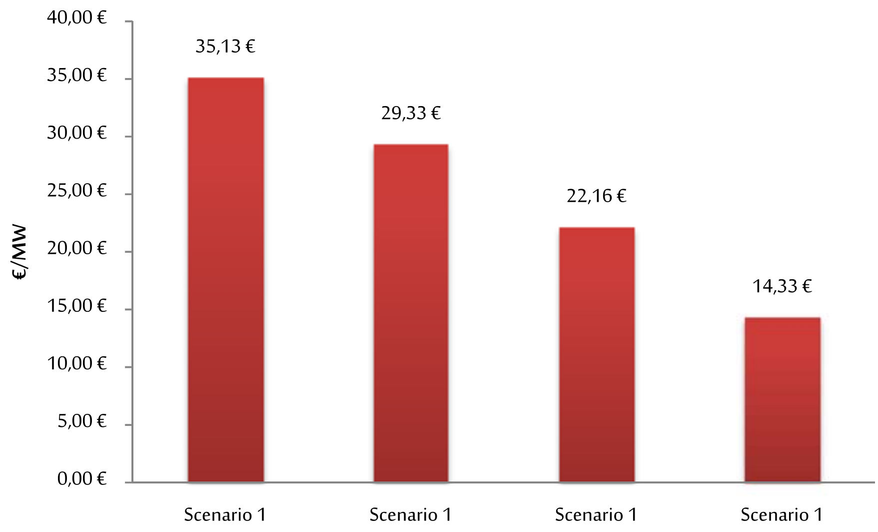

Figure 7 Marginal costs for the four scenarios under analysis

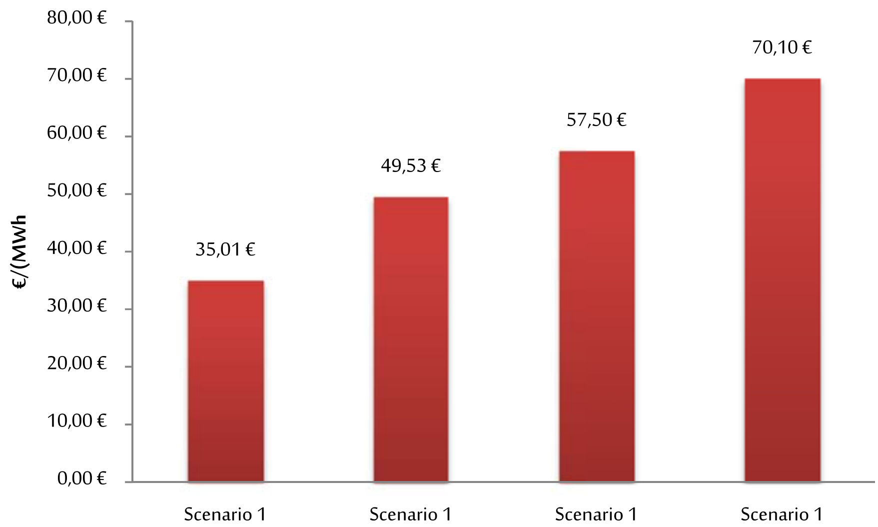

Figure 8 Average cost for the four scenarios under analysis

4. Conclusions

Nowadays, a new world order is emerging regarding energy use and consumption. In this sense, there is a pending need that all countries become self-sufficient regarding production and consumption of energy. By integrating renewable energies in their systems, there will be a considerable reduction of the energy dependency. Over the past years, there has been a description of the goals to achieve framed by national and international legislation, basically setting on renewable energies, where the electricity market stands as the main representative of the energy quotes. Portugal, however, presents itself as a country significantly dependent on energy importations, strongly relying on fossil fuels. Nevertheless, Portugal has a high potential for the development of renewable energies; thus, the Portuguese Government has defined strategic Action Plans, working as orientation and application tools, with the broad aim of achieving 31% of energy coming from renewable sources in the final gross energy consumption. The integration of these renewable energy sources in the market has been developed by taking advantage of all the existing resources and financial support, whether at a small or large scale aiming at obtaining the most suitable economic, social and environmental practices.

This work aims to contribute to the design of scenarios which include the use of renewable energy sources in Portugal, resourcing to EnergyPLAN model to undertake the simulations. The results obtained in the technical optimization for 100% RES scenario allowed to conclude achieving a 100% RES electricity system possible and could guarantee the expected consumption need, however it would generate a significant surplus of electricity translated into exportation surplus.

It was also possible to observe that electricity coming from renewable sources, such as wind and hydro power present the highest figures in all the analyzed scenarios. However, it must be mentioned that both in the PNAER foreseen scenario and in the REN foreseen scenario, a relevant contribution from photovoltaic energy, biomass and waves is included.

Concerning to the EnergyPLAN software, it enabled to obtain specific results on the importation and exportation, identifying as a critical factor the production surplus of electricity throughout the year. This factor justifies the need to introduce, in every scenario, a fixed value for importing/exporting energy, as well as a capacity to interconnect with the outside to ensure balance between supply and demand for the technical optimization. The results put in evidence the need to further explore the economic optimization of the EnergyPLAN model taking into account the hourly electricity costs and also the need to include electricity storage systems as essential elements of 100% RES systems.

The brief economic analysis conducted in this study focused in the calculation of the costs regarding the implementation of each one of the foreseen scenarios. More specifically, this analysis has mainly addressed the investment costs, the operational and management costs, and the costs with fuel and with the CO_2 emissions. It is possible to visualize that the scenarios with higher implementation of renewable energies are those which present higher investment costs, tough having the lower marginal costs. In the current Portuguese economic panorama, the investment costs associated with RES can in fact become a barrier for the implementation of 100% renewable scenarios. However, the obtained marginal costs should also be considered, demonstrating the long term gains of these technologies.

Acknowledgements

This work was financed by: the QREN – Operational Programme for Competitiveness Factors, the European Union – European Regional Development Fund and National Funds- Portuguese Foundation for Science and Technology, under Project FCOMP-01-0124-FEDER-011377 and Project Pest-OE/EME/UI0252/2011.

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JEL classifications: J10; Q41; R10

Conference topic: Energy System Analysis

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SCALING LAWS AND ELECTRICITY CONSUMPTION IN CITIES: A SECTORAL VIEW

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Abstract

With the use of electricity being increasingly concentrated in urban areas it becomes important to understand the influence of cities, and their size, over patterns of consumption. We tested the application of the scaling law to Portuguese municipalities and the sectoral consumption of electricity from 1994 until 2009. The results showed that, although the relation was true for most cases, the scaling factor changes in time and among sectors. For the residential sector the decrease of this factor might be related with the electrification of the heating and cooking system that has started in the. For the services sector the scaling parameter was fairly constant during the 16 years of the study, showing a super linear relation. The largest variation was found for the industrial sector whose scaling factor decreased 15-20% in the time frame analyzed, though this sector was the one where electricity consumption appeared to be the one with the weakest relation with city size.

1. Introduction

Since the energy crisis in the 70´s energy demand has been a hot issue for researchers in economy, planning and engineering. In 2006, 76% of electricity consumption was concentrated in urban areas (IEA 2008) when cities comprised less than half of the total population (United Nations 2007). With the foreseen growth of urbanization it becomes imperative to study the dynamics of cities and their impact on energy use.

There are many models of energy or electricity consumption in cities, most of them relating it with income and price, typically, through the calculation of elasticities and their significance level. Applying econometric methods has been a frequent choice in the literature using, for example, a multiple first-order linear model (Larivière & Lafrance 1999), general-to-specific modeling, or co-integration analysis using time series or panel data (Narayan et al. 2007; Narayan & Smyth 2008; Zachariadis & Pashourtidou 2007; Yuan et al. 2007). However, with this work the aim was to find possible patterns linking city growth and energy use. Therefore, this work focusses on the application of scaling laws to the specific case of electricity consumption in urban areas of continental Portugal. Although this application has been made to other countries such as China (Bettencourt et al. 2007; Zhu et al. 2009), Germany (Bettencourt et al. 2007) and Spain (Horta-Bernús et al. 2010) this study come as the first one, as far as we know, that explores the time dynamics of its coefficients. Furthermore, we perform a sectoral analysis to identify possible differences in the observed patterns.

2. Urban scaling laws

Inspired by the connection between physiological characteristics of some biological organisms and their body mass, Bettencourt et al. (2007) tested the existence of a scale relation between city size and a set of indicators. This relation is described by the equation [1]:

$$I = \alpha S^{\beta} \qquad [1]$$

Where I is the indicator that we are trying to relate with city size (S) using a scaling relation of factor β and a normalization constant (α). For the particular case when β is one, becomes the per capita value of the indicator. In this equation the scaling factor β also represents the elasticity of the indicator in relation to population. This elasticity gives the proportional variation of the indicator caused by a proportional variation of the population.

For the case of energy related variables Bettencourt et al. tested total and residential electricity consumption obtaining for the former a β of 1.07 (for Germany) and, for the latter, an approximately linear relationship (β=1.00 for Germany and β=1.05 for China).

3. Data and methodology

The source of data for annual electricity consumption at the municipal level between 1994 and 2009 was the Portuguese energy agency - DGEG (Direcção-Geral de Geologia e Energia).

In order to use the same unit of data collection municipalities were used as the minimum scale for the demographic data which was taken from INE's (Instituto Nacional de Estatística) database. To identify which municipalities correspond to urban areas we defined two conditions based on the parishes' classification (*urban*, *semi-urban* and *rural*), which was set using the official thresholds of total population and population density for the year 2001. This was the only year for which we had demographic data of parishes´ population and municipalities' electricity consumption. The conditions used are described in Table 1.

Table 1 - Criteria of urban municipalities (percentage of population)

	Urban	Semi-urban	# Municipalities
Condition 1	15%	50%	24
Condition 2	40%	-	99

Equation [1] applied to the consumption of electricity in municipalities takes the form:

$$El_{mun,t} = \alpha S_{mun,t}{}^{\beta} \qquad [2]$$

Where the indicator *is now* the consumption of electricity El in municipality mun in year t ($El_{mun,t}$) and city size S also relates to that same municipality and year.

To use Ordinary Least Squares (OLS) regression we applied the logarithm to equation [2].

$$ln(El_{mun,t}) = \ln(\alpha) + \beta ln(S_{mun,t}) \qquad [3]$$

General tests of heteroscedasticity (graphical and Breusch-Pagan / Cook-Weisberg test) were run and, otherwise stated, all the conditions of OLS application were met (Breusch & Pagan 1979; Coenders & Saez 2000). For the regressions and tests, Stata 11, a software package for statistical analysis, was used.

4. Cross-section analysis

In this section, we analyze first the results for total electricity consumption, followed by the results for the different sectors: residential, services and industry.

4.1. Total urban electricity consumption

Given that in this work we only used one explanatory variable, one of the best tools to test for heteroscedasticity is the direct visualization of the relation of the residuals and the variable itself. We used this test for all years that very similar results. In this graphs it was possible to see the presence of a clear outlier, the municipality of Sines. Other test for heteroscedasticity used was the Breusch-Pagan / Cook-Weisberg test which failed when used for the whole set of municipalities.

Sines is an industrial center and the location of the biggest oil refinery in Portugal, remaining, however, a small city. It is a clear exception, especially in terms of total and industrial energy consumption and, for that reason, will be excluded from these analyses. Performing the Breusch-Pagan / Cook-Weisberg test again, excluding Sines, we verified the existence of homoscedasticity with a range of χ^2 values between 0.51 and 2.27 which are below the threshold of 3.84 for the 95% interval level.

Applying the scaling law to each year separately showed interesting and relevant (R^2 values were around 0.80) results (Figure 1). The most surprising is the decreasing trend of β showing that electricity consumption started to follow more closely the distribution of population over the years, e.g., evolved towards a linear scaling law. Another fact to take into consideration is the increase of α. This may be explained by two facts: the growth of electricity consumption per capita along the years (around 50% increase between 1994 and 2009) and a compensation for the decrease of the β coefficient observed.

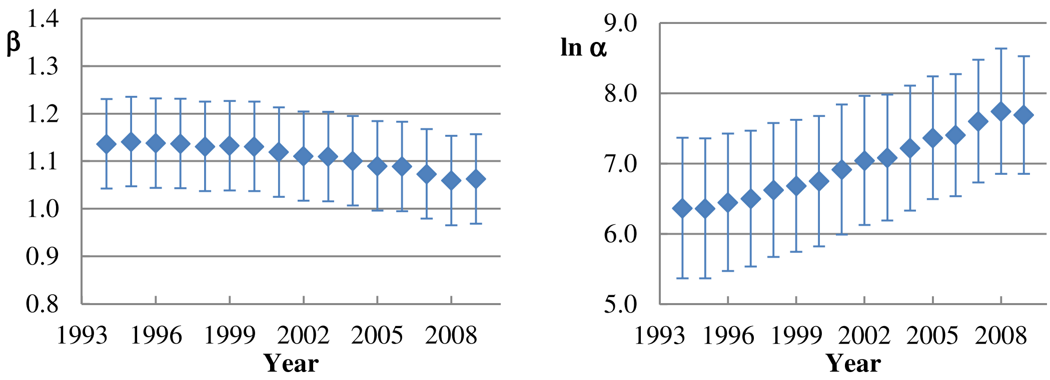

Figure 1- Parameters of total electricity scaling laws in urban municipalities between 1994 and 2009 with 95% confidence intervals error bars

If we look to the literature (Bettencourt et al. 2007) we can see the β's obtained in this work are consistent with the one found for Germany for 2002 (1.07). However this comparison does not seem to be of great relevance due to the large range of values in Figure 1.

The structure of consumption remained relatively. Both households and services had little changes in their share; industry had the most relevant change, decreasing from around 48% in 1994 to around 37% in 2009 (Table 2).

Table 2 – Structure of urban electricity consumption divided by sectors

Year	Residential	Services	Industry	Others
1994	25.4%	20.6%	47.5%	6.4%
1995	24.8%	21.1%	47.5%	6.6%
1996	25.5%	21.8%	46.1%	6.7%
1997	24.9%	22.4%	46.2%	6.6%
1998	24.4%	23.1%	45.6%	6.8%
1999	25.2%	24.0%	44.8%	6.0%
2000	24.8%	24.2%	44.0%	6.9%
2001	24.5%	26.8%	41.8%	6.8%
2002	26.1%	24.0%	42.2%	7.6%
2003	26.1%	24.5%	41.5%	7.9%
2004	26.4%	24.4%	41.1%	8.2%
2005	27.3%	24.8%	39.7%	8.2%
2006	26.8%	25.6%	39.6%	8.1%
2007	27.0%	25.6%	39.3%	8.1%
2008	26.5%	26.2%	39.1%	8.3%
2009	28.4%	26.9%	36.4%	8.3%

Nevertheless, it is important to remember that, enclosed in total electricity, are several types of consumption from the different sectors of activity and the overall pattern may not reflect the behavior of electricity consumption of each one separately. Furthermore, the dynamics can be influenced not only by the dynamics of each sector in particular but also by the reduction of the Industry share.

4.2. Residential sector

Bettencourt et al. (2007) found two different values for the scaling parameter β (1.05 and 1.00) for electricity consumption of households in China and Germany, respectively, although the relation was considered linear in both cases. Following this work, Horta-Bernús et al. (2010) did a similar study for the region of Andalucía in 2005 obtaining a value of 1.04 for the scaling factor of residential electricity consumption. Thinking of a set of cities in the same social context (i.e., similar average income, educational levels and respective distributions), household consumption represents individual needs that, rationally, should be alike, whichever the city is, which is in line with the results obtained in the literature.

For Portugal, the fit of residential electricity consumption distribution to a scaling law is very good (R^2 around 0.94) as it can be observed in Figure 3 and yet, once again, β coefficient results show a temporal dynamics that goes against the notion of this being a simple linear scaling relation (Figure 2).

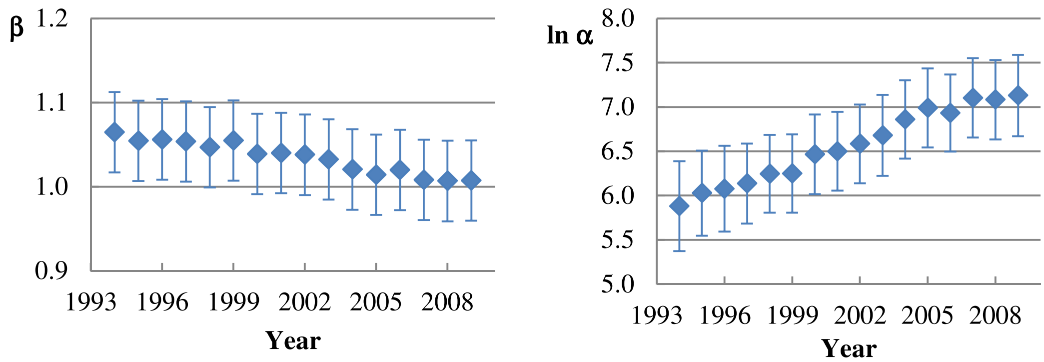

Figure 2 - Parameters of residential electricity scaling laws in urban municipalities between 1994 and 2009 with 95% confidence intervals error bars

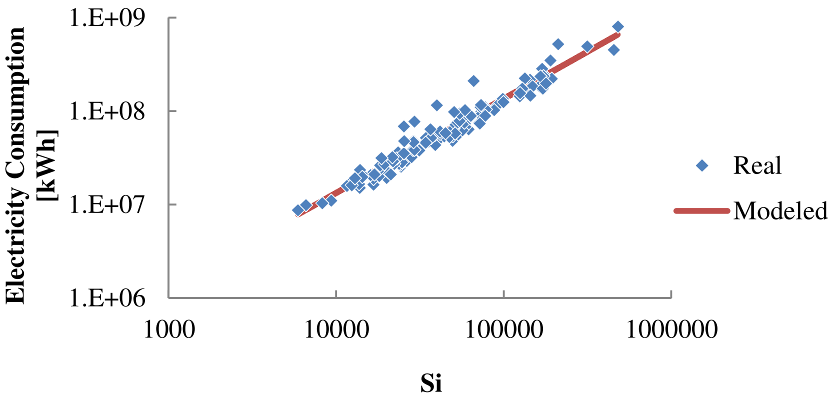

Figure 3 – Comparison between the regressed and real values of residential electricity consumption in 2009

One possible explanation for the non-linear behavior in earlier years might be the growing electrification of energy consumption, especially in thermal heating and cooking systems (INE & DGEG 2010; DGE 1989; DGGE 1996). In rural areas and smaller cities, the use of gas and/or wood as the source of heating and cooking was the standard choice until recent years. During the 90s, electrical thermal devices (both for temperature control and cooking) started to become more common. In fact, the proportion of electricity in the total energy spent for these uses more than tripled between 1996 and 2010 (DGGE 1996; INE & DGEG 2010). This led to an increase of electricity in the energetic bill of households affecting mostly the consumption of wood and bottled gas (Table 3). As technological transitions are usually faster in larger cities where innovations are more easily accessible and innovators are concentrated, it is expected that the spread of these electrical devices was not even within Portugal. As the dissemination reached smaller cities, the electrification of heating became more uniform and, with it, the values of electricity consumption as we saw on Figure 2. This rationale could also explain the difference in the values obtained by Bettencourt et al (2007). Germany is a country where the residential heating technology is very mature and so, similar in all regions. China is a developing country with big inequalities between larger and smaller cities that, possibly, extends to the use of electricity in the households.

Table 3 - Percentage of energy carriers' contribution to domestic energy consumption (Source: DGE, 1989; DGGE, 1996; INE & DGEG, 2010)

Energy Carrier	1989	1996	2010
Electricity	17%	28%	46%
Natural Gas	2%	2%	10%
Bottled Gas	20%	27%	14%
Wood	60%	43%	25%
Others	1%	1%	5%

4.3. Services sector

The available data set is divided into 7 categories (domestic, non-domestic, agriculture, industry, street lighting, governmental buildings' lighting and other). All other sectors were directly inputted to the corresponding category; for Services we considered non-domestic and governmental building's lighting. Analyzing the data for this sector we found some inconsistencies in the values reported by DGEG for 2001, and, therefore removed this year from this analysis.

For this sector the only reference that we could find to use as a comparison is the one done for the Andalucía region in Spain for 2005 (Horta-Bernús et al. 2010). The relation found was a super-linear one with a scaling factor of 1.21.

Our results showed a lower coefficient, but also larger than 1 which implies that larger cities have larger services' electricity consumption. Furthermore, in contrast with what happened in sections 4.1 and 4.2, where there was a clear decreasing trend, the value of β remained relatively constant (Figure 4). It is also relevant to mention that the R^2 values obtained were between 0.75 and 0.83.

Once more, the parameter α showed an upwards trend which, in this case, as β values are quite constant (especially when comparing directly the second and last years), is only explained by the increase of per capita consumption which was the largest of all sectors (more than 100%).

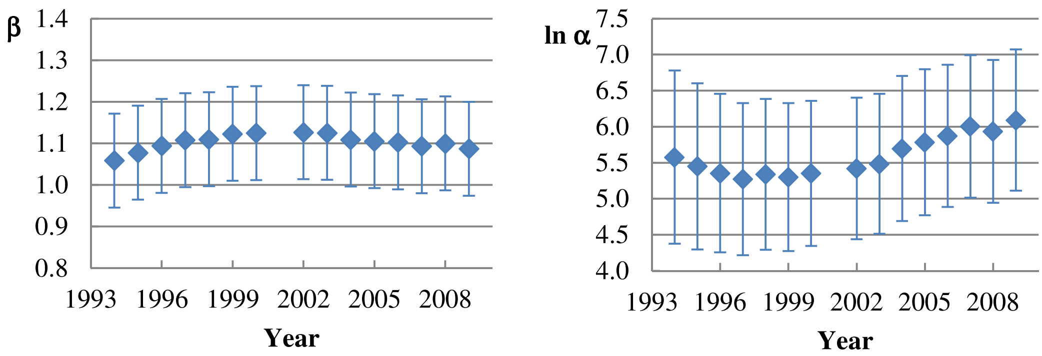

Figure 4 - Parameters of services electricity scaling laws in urban municipalities between 1994 and 2009 with 95% confidence intervals error bars

Looking at these results it seems plausible to hypothesize that this scaling relation is related with specific characteristics of cities. Due to the nature of services companies, location and distance to the client is, usually, more important than for other sectors. For example, the location of a restaurant, supermarket and/or bank branch is crucial for the success of the business, as for a metallurgic or toy factory is much more important to maintain the costs low. Thinking on the basics of urban economics that reports the importance of transportation needs in terms of city structure (Fujita 2010; Fujita et al. 1999), urban environment seems to be well suited for services in general, and, the larger the city is, the better. Therefore, it seems logic to conclude that services are more concentrated in cities and, the larger cities are, the larger this effect is.

4.4. Industrial sector

For the industrial sector, the heteroscedasticity visual test showed a presence of a clear outsider (Sines) as happened in sub-section 4.1. Again, we disregarded this municipality in the analysis performed and, afterwards, the values of χ^2 obtained in the Breusch-Pagan / Cook-Weisberg test were below the 95% threshold (a range of 0.02-0.78).

The results obtained were different from the ones from previous subsections. Values of R^2 for this sector were the lowest of all, being, approximately 0.5 and the 95% confidence intervals obtained were considerably larger than for the other sectors as can be seen in Figure 5 (an average deviation of 16%, 10% and 5% for the industrial, services and residential sector, respectively). There is also a larger dispersion of the points in relation with the regressed curve (Figure 6). These facts on its own seem to indicate that, in case of industry, city size and electricity consumption do not have such a strong correlation as the one observed for households and services.

Nonetheless, looking at Figure 5 we can observe a decrease of the scaling coefficient of 15% between the first and last year of the analysis, yet always above 1. Even with a lower accuracy of the results it is possible to conclude that industries were highly concentrated in larger urban areas and, although this concentration has diminished, it still exists.

The little information available together with the observation of a weaker correlation between city size and electricity consumption make it difficult to explain the observations mentioned above.

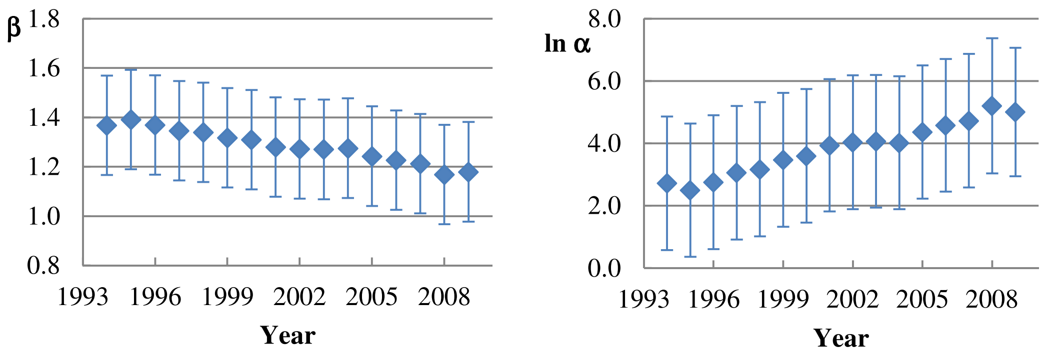

Figure 5 - Parameters of industrial electricity scaling laws in urban municipalities between 1994 and 2009 with 95% confidence intervals error bars

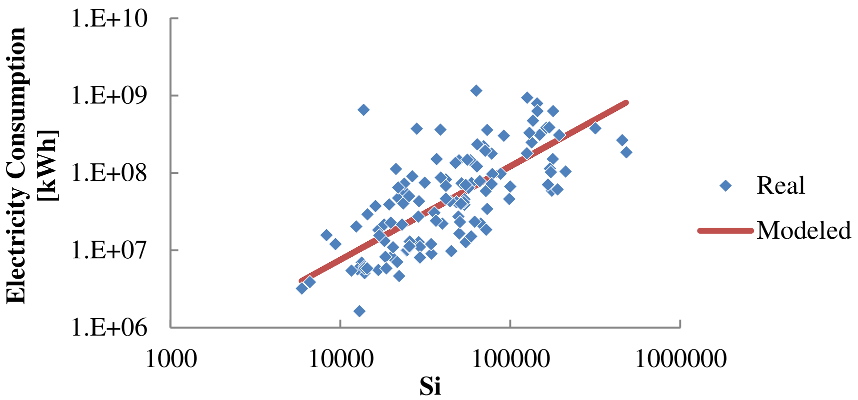

Figure 6- Comparison between the regressed and real values of industrial electricity consumption in 2009

A comparison with the value found in the literature (Horta-Bernús et al. 2010) seems to be counterproductive as, in this paper, the value of the Adjusted R^2 was even lower (0.28) than the ones obtained in our study.

5. Conclusions

Among all, the residential sector was the one for which the urban scaling law obtained better correlation coefficients. Though, the shape of the scaling law changed through time evolving towards a linear relation. A possible explanation for a higher scaling coefficient in the first years of the analysis was the diversity of energy carriers used for cooking and heating. Thermal energy suffered an electrification that started in the 1990's causing a decrease in the use of wood and bottled gas. Making a parallel to what usually happens with innovations, we believe that the electrification started in the largest urban areas, spreading, afterwards, to the rest of the country. A parametric study of the scaling coefficient is being undertaken to test this hypothesis using the share of electricity in the residential energetic system. It will also be used a proxy of the inequality of wealth of the different municipalities' households to understand if this factor plays a role in the evolution of the β coefficient.

Services, on the other hand, showed a relatively constant scaling factor. Technology shifts that influenced the scaling law for households do not apply for this sector as fireplaces and small size gas heaters (the traditional forms of heating) are only used by residential consumers. We could assess that there is a clear concentration of services electricity consumption in the larger cities which we attributed to the attraction of the markets that large urban areas provide.

The industry sector comes out, in the structure analysis on electricity demand, as the one with larger weight (Table 2). In fact, the time dynamics shown is similar to that of total consumption with an accentuated decrease of the scaling factor. However, it is also the sector with the lowest accuracy and worst correlation indicating that city size is not as relevant as it is for services and households. With the weight of industry in total consumption it would be important to find an explanation for the decreasing of β and the low accuracy obtained which was mainly due to the lack of data at the municipality scale. As future work we will focus on determining a model that could answer these questions and help us understand the mechanisms behind the energy consumption of this sector.

Although there are still a few questions left to be studied in more detail, the results obtained were surprising, especially regarding the time evolution of the scaling parameter for total, residential and industrial electricity consumption. Furthermore, we observed the relevance of technology shifts in the distribution of residential electricity consumption explaining the deviation from a linear relation in the first years of the study.

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DAY 9 - 14:30		
Room 639 - Economic Growth and Sustainability 1		
Useful work accounting: Final exergy-to-useful work analysis in Mexico from 1971 to 2009	Zeus Guevara[1]; André Serrenho[1]; Tânia Sousa[1]; Tiago Domingos[1]	[1]Instituto Superior Técnico
Impact of Electricity Consumption on Output in Malaysian Manufacturing Sector	Dzul Hadzwan Husaini[1]; Lean Hooi Hooi[2]	[1]Faculty of Economics and Business, Universiti Malaysia Sarawak; [2]Economics Program, School of Social Sciences, Universiti Sains Malaysia
Fuel wood use and Economic Growth in Ghana: Implications for Climate Change Mitigation	Jonathan D. Quartey[1]	[1]Department of Economics, Kwame Nkrumah University of Science and Technology
Analysis of green net national income and genuine saving: Portugal, 1991 - 2005	Rui Mota[1]; Tiago Domingos[1]	[1]IST UNL

Useful work accounting:

Final exergy-to-useful work analysis in Mexico from 1971 to 2009

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Abstract

Useful work analysis provides insight into the relationships between structural changes and energy transitions in an economy because it focus on what energy is used for rather than where it comes from. Useful work was accounted for Mexico in the period of 1971-2009. The selected methodology, developed by the IST energy and environment group, includes energy carriers that are usually missed in conventional energy analysis. It was found that useful work had a steady evolution, led by mechanical drive and other electric energy uses. Structural changes such as industrialization, specially manufacturing, and complete electrification of the country are associated to useful work transitions. Technological progress, mainly by transfer, and electricity availability caused an increase of the aggregate final-to-useful efficiency of the economy. In addition, useful work economic intensity suggests that effective decoupling is possible under specific conditions. The resultsof the present work may provide insights to energy transitions in developing countries that underwent enforced industrialization.

Keywords: energy; useful work; energy efficiency; energy transitions.

JEL: *Q43, O13*.

1. INTRODUCTION

Energy transitions describe the changes of energy quantity, energy quality and the way energy is used by an economy (Henriques, 2011, Warr and Ayres, 2010). These transitions, especially since the 18th century, are strongly related to wealth accumulation, population growth and improvements in the standard of living beyond Malthusian limits (Alam, 2009, Stern, 2011).

Most approaches to study energy transitions in literature are focused on primary and / or final energy variables. Therefore, these approaches tend to overlook the productive role of energy within an economy (what it is done with it) by focusing on energy sources (where it comes from) (Ayres and Warr, 2009). Opposite to these conventional energy transition analyses, Serrenho et al., 2012 proposed a methodology based on Warr et al., 2010 that accounts for useful work, based on the final-to-useful work conversion stage of energy use.

Useful work is defined as the minimum amount of work required to produce a given end use. It quantifies the amount of exergy that is delivered to a final function. E.g. mechanical work used by water pump from electricity and the exergy of the heat provided to an industrial process by a steam boiler. According to Ayres and Warr, 2009, useful work can be considered an aggregated energy variable since it represents the quality and productivity of the energy used in the economic system.

Serrenho et al., 2012 selected Portugal between 1856 and 2009 as a case study to apply the methodology. The results show that useful work “is linked to structural changes in the demand of energy services”. It was also found that the final-to-useful work efficiencies improved most likely, due to energy quality and structural / technological shifts in the economy. The analysis of energy transitions might help understand the productive structure of the economy in the context of energy transitions (ibid) and give further insight into the role of energy on economic growth.

The present work applies the methodology of Serrenho et al., 2012 to account for useful work in Mexico between 1971 and 2009. The purpose is to understand energy transitions and identify related structural changes in the country. In section 2, the selected methodology is described. Section 3 presents details of the application of the methodology to Mexico. In section 4, aggregate results of useful work evolution, efficiencies and intensities are discussed. Finally, in section 5, summary and main conclusions of the work are presented.

2. METHODOLOGY

The methodology for useful work accounting consists of five steps:

Step 1 Conversion of existing final energy data to final exergy values

Conversions between energy data to exergy values are linear. The proportionality constant is the exergy factor, usually defined as the ratio of exergy content $(B)$and total energy(E) input of any energy flow. The exergy ratio is defined for each type of energy carrier for final use and the values were taken from Serrenho et al., 2012.

Step 2 Allocation of each final exergy consumption to one useful work category

Final exergy values are allocated into five useful work categories: heat, mechanical drive, light, other electric uses and muscle work.

Heat: This category includes all heat uses in the economy. It is subdivided in three types of use, based on temperature ranges of the hot reservoir (Ayres et al., 2003): 1) High temperature heat (>600ºC), 2) Medium temperature heat (120-600ºC)and 3) Low temperature heat (<120ºC).

Mechanical drive: This category consists of mechanical work, i.e. any conversion to drive and movement by a mechanical deviceindependent from the energy source input. Examples of this category are energy uses through internal combustion engines, animal-drawn vehicles, motors of household appliances and electric motors.

Light: It includes the total lighting for industrial and residential use from any energy source. In modern / urban economies, most lighting services are produced from electricity. However in developing / rural economies, lighting was obtained from oil products, fat or town-gas.

Other electric uses: This category includes others uses for electricity not mentioned above. According to Ayres et al., 2005, it is divided into two subcategories: 1) Communication, electronic and electric devices and 2) electrochemical processes.

Muscle work: The last category consists of useful work fromingestedfood and feedgross exergy by humans and animals, respectively.

Step 3 Computation of final exergy consumption by useful work category

Useful work values can only be obtained after the estimation of second law final-to-useful efficiencies (ϵ). Final-to-useful efficiency, also known as exergy efficiency (Cullen and Allwood, 2010 and Ford et al., 1975), represents the fraction of an exergy input that is converted into useful work. It measures the distance between results of real and theoretical ideal processes. Ford et al., 1975 presented ϵas:

$$\epsilon = \frac{\substack{minimum\ amount\ of\ work \\ required\ to\ produce\ the\ desired\ energy\ transfer}}{\substack{Maximum\ amount\ of\ work \\ that\ could\ be\ produced\ from\ the\ relevant\ energy\ input}} = \frac{U}{B} \qquad \textbf{\textit{(1)}}$$

Exergy efficiency differs from energy efficiency or first-law efficiency (η)because the former gives a figure of merit (quality and closeness to ideal) for a certain process of energy use, which allows to compare processes between each other. Specifics of how to define final-to-useful efficiencies for each category are presented in the following paragraphs.

Heat:ϵ_{heat} is obtained through

$$\epsilon_{heat} = \frac{Q_2}{B}\left(1 - \frac{T_0}{T_2}\right) \approx \eta\left(1 - \frac{T_0}{T_2}\right) \qquad (2)$$

where:ηrepresents the technological level of heat end use devices, T_0 is the reference temperature at the location, and T_2 is the temperature at which heat transfer occurs (considered as constant for each type of heat use).

Mechanical drive:Given the variety in energy sources and devices in this category, ϵ_{mech} is estimated for the specific subcategories of mechanical drives, based on equation (1) instead of an aggregate efficiency for the whole category.

Light: ϵ_{light}differs from the others since it measures the amount of generated lumens per watt input with respect to a reference value. This approach to $\epsilon_{light}$is supported by most lighting and efficiency literature (see e.g. Ayres et al., 2005, Fouquet and Pearson, 2006, Nordhaus, 1994).

Other electric uses:$\epsilon_{o.electric}$followsequation (1) for each sub-category. It is estimated based on historical studies of second-law efficiencies, and the share of each electric use sub-category.

Muscle work:ϵ_{muscle} for this category corresponds to the efficiency of human and animals to convert food and feed gross exergy into muscle work. ϵ_{muscle}accounts for incomplete absorption / digestion, body growth and other body energy uses, physiological state of the system, etc. (FAO, 2003).

Step 4 Definition of an aggregated second-law final-to-useful efficiency for each useful workcategory

Having allocated final exergy into useful work categories and estimated Second-law final-to-useful efficiencies, the aggregated $\epsilon$is calculated according to the share of final exergy by useful work category.

Step 5 Calculation of an aggregated useful work value for each category

Aggregated useful work figures are computed based on the values of aggregated efficiencies and final exergy by useful work category obtained from previous steps.

3. MEXICO USEFUL WORK ACCOUNTING

The methodology described in the previous section was applied to account for useful work in Mexico over the period 1971-2009. Data was mainly collected from the International Energy Agency´s Energy Statistics and Balances (IEA, 2011) for the following energy carriers: Coal and coal products, Oil and oil products, Natural gas, Combustible renewables, and Electricity. Final food intake per capita as metabolizable energy data and as-is-weight livestock feed supply was obtained from the Food and Agriculture Organization databases (FAO, 2011). These data were converted into final consumed gross exergy based on FAO, 2003 and Wirsenius, 2000.

Consistency of data was evaluated by comparing IEA´s values with data from the National Institute of Statistics and Geography (INEGI, for its Spanish acronym), World Bank data bank and Organization for Economic Cooperation and Development statistics (INEGI, 2010b, World Bank, 2011, OECD, 2011).

Additionally, for an extended analysis and support of assumptions, other economic indicators and variables (e.g. GDP per capita and demographics) were collected from INEGI, 2010b, World Bank, 2011, OECD, 2011 and IEA, 2011.

Step 1 Conversion of existing final energy data to final exergy values

Final exergy values were calculated with final energy data and exergy factors from Serrenho et al., 2012. The evolution path of final exergy (Figure 1) shows the dependency of the economy on oil, which accounts for more than half of total final exergy consumption. Furthermore two periods of growth energy consumption can be identified (according to the stiffness of the curves). The first between 1971 and1981 is characterized by a larger growth rate that may have been caused by a period of adaptation of new industries promoted by the governmental strategy of import substitution[1] (UNAM, 2012). The sharp increase of energy demand decreased in the second period (1982-2009) since the new industries reached stability and import substitution officially ended in the 1970's (Ibid).

[1] The import substitution strategy consisted of government protection of heavy industries. The aim of the program was to develop these industries within borders hence improving the country's productive structure and reducing its imports. It was recommended to developing nations after the Second World War by the main world development organizations, including the World Bank (Lin, 2009)

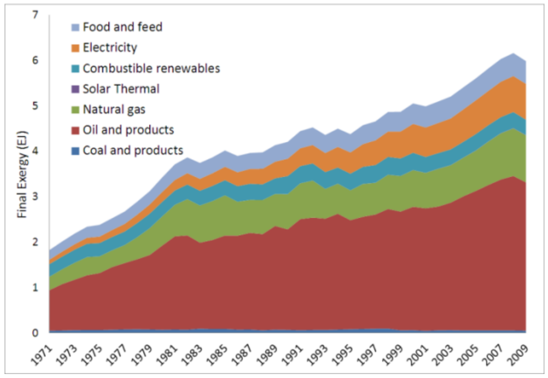

Figure 1. Final exergy by energy carrier in Mexico 1971-2009

Step 2 Allocation of each final exergy-consumption to one useful work category

The allocation of final exergy uses from IEA´s energy balances was mainly based on the assumptions for allocation by Serrenho et al., 2012. However few modifications were applied to account for Mexico´s specific conditions and available data. In the following sections, a description for the allocation´s rationale for each energy carrier is presented.

I. Coal and coal products: Metallurgical industries held most of coal consumption for high temperature processes before 1980´s as railroad transportation evolved into diesel technology (EstaciónTorreón, 2012) and coal demand for electricity generation was insignificant, i.e. 0.2% in 1981 (INEGI, 2012, Tonda, 1993). However following the government´s decision to diversify the electricity sector(Wallace, 2009) coal demand for electricity generation grew to reach 64% of total coal demand in 2009, though generating just 12% of total electricity output (third place after natural gas and oil-fuelled generation). Residential uses are negligible over the whole period.

II. Oil and oil products: Oil is fundamental for the economy because exports have accounted for a significant share of all Mexican exports since 1974: 68 %, 37%, 10% and 16% in 1985, 1990, 2000 and 2011 respectively, (INEGI, 2012, Alvarez de la Borda, 2006)). Oil was widely used for electricity generation (non-final use). Oil power went from 40% share of total generation in 1965 to a peak of 83% in 1985 (INEGI, 2012). Subsequently oil electricity generation steadily declined getting to 16% in 2010 (SENER, 2010) with the expansion of natural gas generation.

The transportation sector accounts for the largest demand for oil and its products. Automotive vehicles as well as major automobile manufacturers entered in Mexico early in the 20th century (Caballero Ruiz 2010). Oil-fuelled motorization expanded and nowadays dominates freight and passenger transportation (Capasso, 2007).

Demand for oil products (kerosene and oil lubricants) for residential uses, such as lighting and heating, were still significant in the second half of 20th century due to the slow introduction of electricity. By 1970, over 40% of the population remained without electricity. Further electrification was implemented reaching 87% electricity coverage by 1990 and 98% in 2011 (Merrill and Miroì, 1997). Therefore lighting and heating residential use for oil products have practically vanished. On the other hand, industrial heating with oil products is shrinking too.

III. Natural gas: Industrial heating, mainly medium and high temperature, held most natural gas consumption before 2000 (COLMEX, 2008), when electricity generation took the lead in demand (Figure 2).

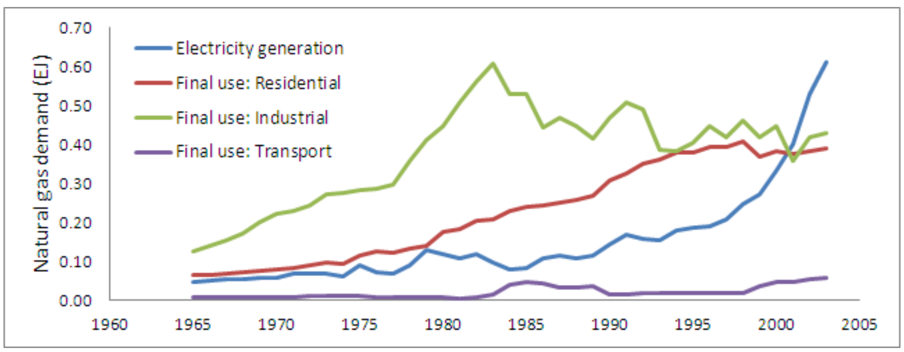

Figure 2. Natural gas demand by sector (INEGI, 2012)

Around 1983, industrial natural gas demand shifted from its increasing trend, most likely due to high natural gas prices in the 1980's (Valdez, 2003). The industry responded to high prices by mainly substituting natural gas for oil-based fuels between 1983 and 1993. After this period, natural gas demand stabilized, while industrial demand for oil-based products and electricity continued to grow (INEGI, 2012). Finally, demand for residential uses (low temperature heat) has been steadily rising, not affected by prices since gas products are subsidized for the residential sector (PROFECO, 2012).

IV. Combustible renewables: According to INEGI, 2012, two combustible renewables are mainly used in the period 1965-2011: sugar cane bagasse and wood for industrial and residential uses, respectively. Other sources, such as biofuels, waste and biogas are also used but in smaller quantities. However, data with respect to residential use is likely to be underestimated due to lack of information of biomass consumption in rural areas (40 to 22% of total population during this period, INEGI, 2010b, McCaa, 1997).

Residential uses comprise low temperature heat for space, water and cooking. Industrial uses mainly correspond to medium temperature heat for sugar production, since bagasse is fed into boilers at ~ 280ºC temperature (DÁngelo et al., 2006). In recent years, other combustibles renewables had been included, e.g. biofuels for transportation (i.e. mechanical drive) and waste for electricity generation (non-final use).

V. Electricity: The allocation of useful work of final electric uses follows a sectorial analysis. This energy carrier gained relevance over the studied period since, as mentioned above, the country reach full electrification.

The residential sector uses electricity for lighting, electric appliances and electronic equipment. Usually TV´s, radios and fridges lead consumption (INEGI, 2010), except in urban areas where electronic devices are widely used and in regions with extreme climates where air conditioning is needed. In the case of the industrial sector, electricity is used for lighting, machinery, refrigeration, electronic appliances and air conditioning. Detailed data of residential and industrial consumption is limited: only few data points are available (CONAFOVI, 2006, CONUEE, 2010, Maqueda and Sánchez, 2008, SENER and IEA, 2011). Therefore useful work shares were obtained by adjusting these available data points according to U.S. and U.K. estimates and data (EIA, 2010, Ayres et al., 2005, Fouquet and Pearson, 2006).

Finally, the transport sector uses electricity mainly for subway transportation, which started in the 1960´s, and has had since a significant participation in the three most important cities (SETRAVI, 2005) However electric transportation remains negligible in terms of total transportation energy use and total electric uses (<1%, IEA, 2011).

VI. Other non-conventional: Other non-conventional sources, such as wind flow to propel sailing ships and hydraulic mills, are negligible for the studied period of 1971-2009. However the contribution of solar thermal systems for water heating is included in IEA´s databases.

Step 3 Computation of final exergy consumption by useful work category

The definition of ϵ for each category and sub-category are described below.

Heat: Second law efficiencies for this category are given by equation (2). The values for these variables were obtained as follows:

The evolution of first law efficiencies $(\eta)$for most heat processes were estimated based on a representative industry for each temperature range and efficiencies of generic heat conversion devices (Cullen and Allwood, 2010). For the high temperature range, estimates were obtained from studies of the iron and steel industry (De Beer et al., 1995, Worrell et al., 1997). In the case of the medium temperature range, the ammonia industry (Smil, 2001) and medium temperature processes of the iron industry (De Beer et al., 1995) were used. For the low temperature range, efficiencies were based on space heating devices, an overall insulation efficiency of 50% and Serrenho et al., 2012’s estimates.

Concerning the environment reference temperature (T_0), Mexico possess a wide variety of climates, yet it has three main industrial regions (Centro, Norte and Bajio) centered by three most important cities: Mexico City, Monterrey and Guadalajara. Therefore six different reference temperatures were taken into account, i.e. average temperatures during cold months and yearly average temperature during the rest months for each one of the industrial regions (SMN, 2010). The share of total heat uses among regions is considered homogeneous. Finally the temperature at which heat transfer occurs $(T_2)$is defined within the limits of each heat sub-category.

Mechanical drive: The evolution ϵ_{mech} for gasoline, as well as, ϵ_{mech} for other mechanical equipment, were estimated based on engine specific information (Cullen and Allwood, 2010, IEA-ETSAP, 2010, Ford et al., 1975) and the evolution paths of the U.S. (Ayres et al., 2005, Warr et al., 2010, Serrenho et al., 2012) since most equipment was imported from or manufactured according to standards of the northern neighbor.

Lighting: Final-to-usefulefficiencies for lighting, as defined in previous section, are obtained from adjusting U.S. estimated data (Ayres et al., 2005). Fouquet and Pearson, 2006's and Nordhaus, 1994's data were used for other energy carriers (i.e. kerosene) and for evaluating consistency of adjusted data.

Other electric uses: Similarly to for lighting, other electric uses ϵ's were obtained based on U.S. estimates by Ayres et al., 2005. In addition, estimates from Rosen and Bulucea, 2009 were used for evaluating consistency of the results

Muscle work: According to Wilson et al., 2004, it is assumed that humans and animals convert exergy content from food and feed into muscle work with a $\epsilon_{\mathrm{muscle}}$ of 25%.

Steps 4 and 5 Definition of an aggregated second-law final-to-useful efficiency and Calculation of an aggregated useful work value for each useful work category

Useful work estimates per carrier and per economic sector, allocated by category, were added up to define an aggregated useful work per category and to calculateaggregated second law efficiencies for each useful work category.

4. RESULTS AND DISCUSSION

Mexico experienced a fourfold growth in final exergy consumption over the studied period from 1.8 EJ to over 6 EJ (Figure 1). The exergy mix did not significantly change, i.e. the shares of the two main energy carriers (oil and natural gas) remained with little variation over the entire period (Figure 3). However electricity gained relevance from a 5% share in 1971 to 13% in 2009 since in this period the country reached full electrification.

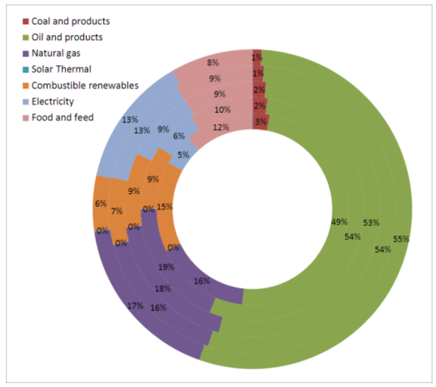

Figure 3 Exergy mix in selected years:1971(inner circle)-1980-1990-2000-2009 (outer circle)

Useful work figures show the evolution of exergy use, influenced by structural changes in the demand of energy by the economy. As seen in Figure 4, useful work had a close-to constant growth rate (it describes a straight line) over the analyzed period.

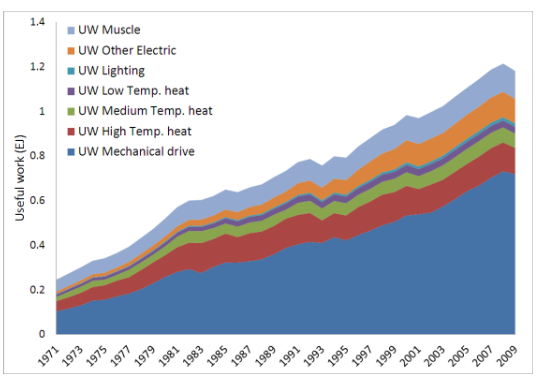

Figure 4 Useful work in Mexico 1971-2009

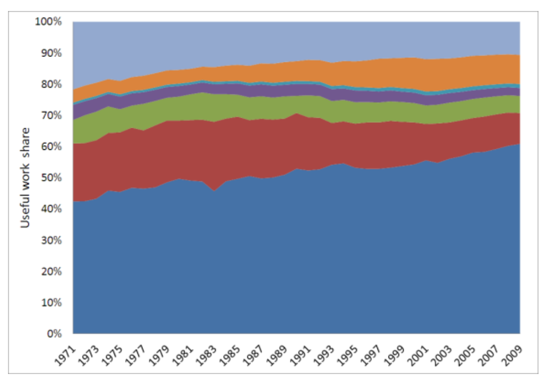

Figure 5 Useful work shares Mexico 1971-2009

Despite the steady growth of useful work, the shares of each category significantly changed (Figure 5). The role of mechanical work on the economy progressively increased in opposition to a decrease of the high temperature heat share. This may have been due to a disproportional expansion of the manufacturing industry (mechanical-drive intensive) compared to metallurgical and chemical industriesand to growing energy needs for transportation (pure mechanical drive). The share of other electric uses also grew because of electricity availability and the deployment of electronic devices, especially in urban areas. Finally the share of muscle work was reduced by a half though it seems to have stabilized around 12%since 2000. This differs from the case of developed countries, e.g. 2% in Portugal, (Serrenho et al., 2012), which may be explained by the less degree of automation of Mexican industries, i.e. Mexico is still more labor intensive than developed economies.

Final exergy demand increased four times between 1971 and 2009, while useful work increased six times. The reasons for this are improvements in processes and devices for energy use and the transition to energy carriers with more quality (i.e. electricity). The former reason is related to updates of the productive structure and a better match between energy carriers and end uses;while the latter had limited impact since the exergy mix did not considerably change, as explained above.

Theaggregated second-law efficiency (ϵ_{ag}) in Figure 6 represents the improvements that the structure of the Mexican economy went through during the studied period. Progress based on technological transfer from more developed countries, mainly U.S., brought more energy efficient devices and processes and led to an increasing trend of ϵ_{ag}. In addition, full electrification allowed the use of electric devices, which have higher final-to-useful efficiencies than others.

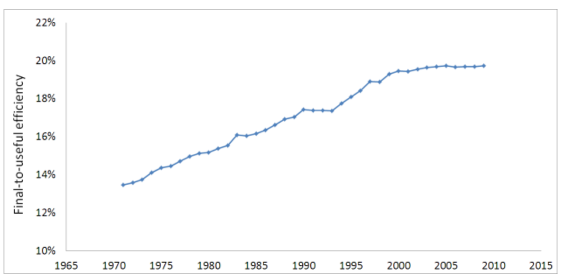

Figure 6 Aggregated second-law efficiency

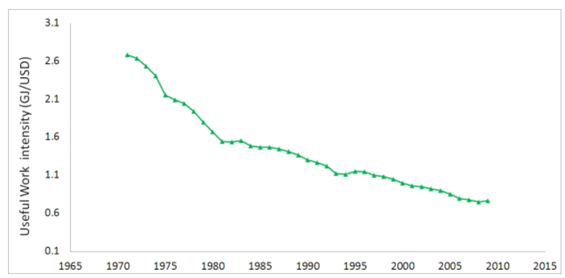

Figure 7 Economic useful work intensity

The useful work intensity, as seen in Figure 7, of the economy is characterized by a stable decline, which implies that the Mexican economy has been reducing its minimum energy requirements to produce one unit of GDP. The latter results suggest that decoupling (see Stern, 2011) can be achieved under specific conditions. Moreover, they give insight into Mexico's capacity to leverage its advantage of backwardness with respect to developed economies (see Aghion et al., 2009) by technological transfer, openness and resource exploitation. However, according to Serrenho et al., 2012, there might be a given amount of energy services that need to be supplied to produce a unit of GDP, which is specific to the economic structure of the country. Therefore energy – economic growth decoupling will eventually stop.

5. CONCLUSIONS

Useful work in Mexico over the period 1971-2009 was characterized by a slow evolution, related to structural changes in the economy. The country increased its dependency on mechanical drive and other electric uses due to the intensification of transportation needs, manufacturing and ownership of electronic devices. Technological progress rather than energy mix transitions led to a steady improvement of final-to-useful conversion efficiencies. Furthermore, the economy benefited from this progress, reaching a higher level of efficiency of use of energy resources (as seen from the decline of useful work economic intensity). The present work may provide insight to energy transitions in developing countries that underwent enforced industrialization. It may also help to understand the effect of economic backwardness on the demand of energy services.

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Impact of Electricity Consumption on Output in Malaysian Manufacturing Sector

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Abstract

This paper investigates the relationship between electricity consumption, price and output in Malaysia's manufacturing sector by using multivariate framework. This study has two objectives. The first objective is to discover the existence of long-run relationship among the variables and the second objective is to examine the short-run causality among the variables. This is a time series analysis with the sample period covers from 1978-2010. Johansen and Juselius cointegration test and Granger causality test are employed in order to achieve the objectives of the paper. We found that electricity consumption, output and price are cointegrated in long run. VECM Granger causality test indicates that it has one unidirectional causality running from output to electricity consumption. On the other hand, only one unidirectional relationship exists in the short run which is running from electricity consumption to output. Hence, this result indicates the output is the significant determinant of electricity consumption. However, there is not enough evidence to prove that the electricity consumption significantly determine the growth in output.

Keywords: Electricity consumption; Output; Granger Causality; Cointegration

1. Introduction

Research on the role of energy in generating economic growth becomes new interest nowadays. It is respond to high dependency on energy usage in residential sector, commercial sector, agriculture sector and industrial sector. Many studies have been done at macro and micro level to explore the impact of energy on economic growth.

To date, there are a lot of studies have done on the relationship between energy consumption and economic growth as an aggregate by using bivariate model, multivariate production function model and multivariate demand function model. However, little have been done to explore the essential of energy in one particular sector especially the energy based sector like manufacturing sector. It is important to discover the essential of energy in strategic sector like manufacturing sector consequently some significant implication can be made for both policy makers and manufacturing firms. Thus, there is a need to determine whether the amount of energy consumption gives significant impact towards manufacturing sector performance. In addition, it is also crucial to explore the determinant of electricity consumption in manufacturing sector, hence, in this study the factor of price has been put into account in order to know the impact of changing in price towards the trend of electricity consumption and output[1]. In sum, the pattern of energy consumption may improve forecasting of the manufacturing sector's contribution to the growth at micro and macro level.

A few study on relationship between production in manufacturing sector and the amount of energy consumption (which in the study used electricity consumption since electricity is heavily used in manufacturing sector) call further research need to be done regarding on this matter. To this point, this paper will explore the relationship between the amount of electricity consumption and output in manufacturing sector. This study has two objectives, 1) to examine the long run relationship between electricity consumption, output and price in manufacturing sector and 2) to explore the short run as well as it causal relationship between electricity consumption, output and price in manufacturing sector.

2. Literature Review

Most studies use bivariate model to explore the relationship between energy and output. They found a mix empirical result of bidirectional and unidirectional relationship between energy and output (Ozturk et al, 2010 and Ying et al, 2011). On the other side, some of them found that there is no relationship exists between energy and output (Ozturk and Acaravci, 2011 and Tang, 2008). This inconsistency findings regarding on the relationship between energy and output

[1] The factor of price is importance in influencing the pattern of electricity consumption and income (Lean and Symth, 2010b)

mostly from studies which use bivariate model is probably derived from the problem of omitted variable in the model.

Therefore, most researchers suggest that it is better to use multivariate model to discover the relationship of energy consumption and output. It is because energy consumption is not giving the big impact even a direct impact on GDP. In fact, there are others variables which are more significant in contributing output. As a result, it leads the problem of omitted variable in the model. In order to avoid this problem, latest studies use multivariate model by adding others variables such as energy price, labor, capital, export, population, urbanization and so on to come out with robust empirical result. Mahadevan and Asafu-Adjaye (2007) and Odhiambo (2010) are some of the recent studies used multivariate model. Apergis and Payne (2009), and Menyah and Wolde-Rufael (2010) are some of the study used production function multivariate model to explore the essential of energy in production. While, Odhiambo (2010), Lean and Smyth (2010b) and Chandran et al. (2010) uses energy demand function multivariate model to explore the impact of energy consumption on output by taking into account the factor of price in the model.

Due to the argument of Soytas and Sari (2007), inconsistency findings from the previous studies regarding on the study of relationship between energy consumption and economic growth is also refers to the different in term of the pattern of energy usage and also the availability of energy resources and commodity in each of the country. There will have different impact on economic growth for every different used of energy sources and commodity. The study related on this matter was made by Lotfalipour et al. (2010) and Lee and Chang (2005) where in their study they examine the impact of each type of energy commodity (such as gas, coal, and oil) on economic growth. However, Yoo and Ku (2009) and Apergis and Payne (2011) explore the impact of each type of energy resources such as renewable energy and nuclear energy on economic growth

In micro level, it is essential to explore the impact of energy consumption on output by sectorial especially energy based sector like manufacturing sector. It is because different sector has different energy intensity and it may have different impact on the performance in each sector. To best of our knowledge, the first study on this matter is Soytas and Sari (2007) and it follows by Kouakou (2011) and Bekhet and Harun (2012) who did a research in manufacturing sector. In addition, Turkekul and Unakitan (2011) did a research regarding on this matter in Turkich agriculture sector. Indeed, there is limited studies has been done in micro level.

In Malaysian cases, Tang (2009), Chandran et al. (2010) and Lean and Smyth (2010a) are some of the studies in Malaysia explored the role of energy in economic development. To the extent of our knowledge, Bekhet and Harun (2012) is the first study in Malaysia explores the essential of energy at micro level which is in their study they explore the impact of energy on manufacturing output.. Towards an extended, this study intends to investigate energy demand function which in the study uses electricity consumption in Malaysian manufacturing sector by considering the factor of price. Theoretically, the change of price will give a direct impact on the trend of consumption and also the cost of production consequently contracted output (Odhiambo, 2010).

3. Data and Methodology

This study explores the relationship between electricity consumption, output and price which in this study use consumer price index (CPI) since there is no time series data of electricity price in Malaysia. The use of CPI as the other alternative to represent electricity price also has been supported by Lean and Smyth (2010b) and Odhiambo (2010).

Energy demand function model has been employed to explore the relationship between electricity consumption, output and price. The regression model as follow:

$$EC_t = f(VA_t, P_t) \qquad \text{(Eq. 1)}$$

Or

$$EC_t = \beta_0 + \beta_1 VA + \beta_2 P + \varepsilon_t \qquad \text{(Eq. 2)}$$

Where,
VA – Value added in manufacturing sector (Constant at 2000 RM)
EC –Electricity consumption in industry (ktoe)
P- Consumer Price Index (constant at 2000 RM)

All variables are employed with their natural logarithms form. It is as follow:

$$LEC_t = \beta_0 + \beta_1 LVA + \beta_2 LP + \varepsilon_t \qquad \text{(Eq. 3)}$$

This study employs annual time series data for Malaysian manufacturing sector from 1978 to 2010. The data for value added in manufacturing sector and consumer price index (CPI) are taken out from Department of Statistics Malaysia and electricity consumption in manufacturing sector is taken from Malaysian Energy Information Hub database. The Eviews 7 has been used in order to analyze the dataset. Figure 1 shows the time series plots for each variable.

Philips and Perron (1998) test is employed for stationary test before conducting cointegration test and granger causality test. The Johansen and Juselius cointegration test (1990) is constructed to test long run relationship and the Granger causality is employed to test short run relationship same as the direction of the relationship.

First step is to check for stationary of the each time series data. The application of Granger causality test (1988) and Johansen and Juselius cointegration (1990) test require that the time series data to be stationary. If the test result found that it is non-stationary, both long run and short run test cannot be regressed respect to the problem of spurious regression. The Philips and Perron test is used to examining the unit root and stationary test for each variable.

In order to identify the long run relationship, Johansen and Juselius cointegration test is employed to identify the existence of a long-run relationship between the variables in the model and estimate the vector error correction model (VECM) which include error correction term to capture long-run causality. Johansen and Juselius cointegration test is based on trace statistics and maximum eigenvalue statistic.

Finally, the last test need to be done is Granger causality test (1988). It is the test to identify which variable leads the other as well as the short run impact. The estimated Granger causality test is based on the following regression:

$$\Delta LEC_t = \beta_1 + \theta_{1i} \sum_{i=1}^{k} \Delta LEC_{t-i} + \mu_{1i} \sum_{i=1}^{k} \Delta LVA_{t-i} + \phi_{1i} \sum_{i=1}^{k} \Delta LP_{t-i} + \Omega_1 ECT_{t-1} + e_{1t} \quad \text{(Eq. 5)}$$

$$\Delta LVA_t = \beta_2 + \theta_{2i} \sum_{i=1}^{k} \Delta LVA_{t-i} + \mu_{2i} \sum_{i=1}^{k} \Delta LEC_{t-i} + \phi_{2i} \sum_{i=1}^{k} \Delta LP_{t-i} + \Omega_2 ECT_{t-1} + e_{2t} \quad \text{(Eq. 6)}$$

$$\Delta LP_t = \beta_3 + \theta_{3i} \sum_{i=1}^{k} \Delta LP_{t-i} + \mu_{3i} \sum_{i=1}^{k} \Delta LEC_{t-i} + \phi_{3i} \sum_{i=1}^{k} \Delta LVA_{t-i} + \Omega_3 ECT_{t-1} + e_{3t} \quad \text{(Eq. 7)}$$

The symbol of Δ represented the first difference while LEC, LVA, and LP are the natural logarithms of manufacturing electricity consumption, value added of manufacturing sector, and price. θ_n, μ_n, ϕ_n(n=1,2,3) are the coefficients determine short run causality. If the null hypothesis is able to be rejected, it is significantly has a Granger causality (equation 5-7). The expected result from the Granger test is either there is no granger causal or granger causal (Uni-directional or Bi-directional). Statistically, the hypothesis test to investigate causality test in the model as what has been shown in the table 1.

Table 1: Hypothesis test for Granger causality

Null Hypothesis	Decision
$H_{01}: \mu_{11} = \mu_{12} = \mu_{13} = . . . = \mu_{1k} = 0$	LVA does not Granger cause LEC
$H_{02}: \phi_{11} = \phi_{12} = \phi_{13} = . . . = \phi_{1k} = 0$	LP does not Granger cause LEC
$H_{03}: \mu_{21} = \mu_{22} = \mu_{23} = . . . = \mu_{2k} = 0$	LP does not Granger cause LVA
$H_{04}: \phi_{21} = \phi_{22} = \phi_{23} = . . . = \phi_{2k} = 0$	LEC does not Granger cause LEX
$H_{05}: \mu_{31} = \mu_{32} = \mu_{33} = . . . = \mu_{3k} = 0$	LEC does not Granger cause LP
$H_{06}: \phi_{31} = \phi_{32} = \phi_{33} = . . . = \phi_{3k} = 0$	LVA does not Granger cause LP

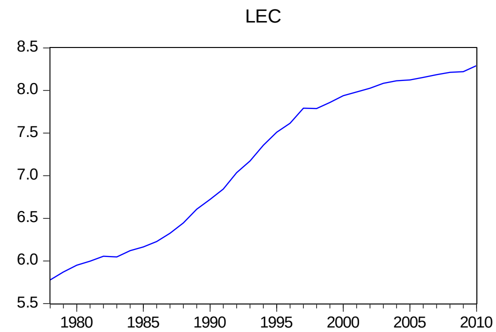
The ECT is referring to error correction term. Ω_n(n=1,2,3) are the coefficients to determine long run relationship. If the null hypothesis is able to be rejected, it is significantly has a long run Granger causality (equation 5-7). The hypothesis test for ECT shows in table 2.

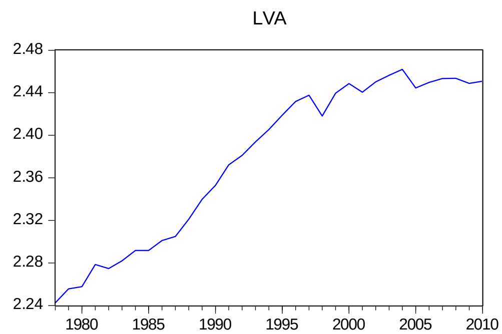
Table 2: Hypothesis test for ECT

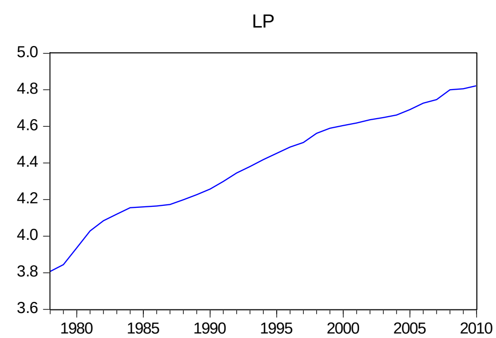
Null Hypothesis	**Decision**
$\mathrm{H}_{01}: \Omega_{11} = \Omega_{12} = \Omega_{13} = . . . = \Omega_{1k} = 0$	LVA and LP do not jointly cause LEC
$\mathrm{H}_{02}: \Omega_{21} = \Omega_{22} = \Omega_{23} = . . . = \Omega_{2k} = 0$	LEC and LP do not jointly cause LVA
$\mathrm{H}_{03}: \Omega_{31} = \Omega_{32} = \Omega_{33} = . . . = \Omega_{3k} = 0$	LVA and LEC do not jointly cause LP

4. Empirical Result

First of all, it begins with the test for unit root in each variable. In general, Philip-Perron unit root tests, which are not reported, indicate that all variables are stationary of order 1.







Since all the variables are stationary at order 1, we can employ the Johansen and Juselius cointegration test. Choosing an appropriate lag length is required as the test is sensitive to the number of lag length selected. The lag length of 2 was selected on the basis of the Akaike's information criterion.

Table 3: Johansen and Juselius Cointegration

Rank, r	Trace Statistic	Max-Eign Statistic
None	41.2486**	25.2054**
≤1	16.0432	12.2926
≤2	4.8516	4.8516

Notes: Rank (r) denotes the number of cointegration equations for each tested hypothesis. Lag length was selected on the basis of the Akaike's Information Criterion. The asterisks (*) and (**) denote significant at the 1% and 5% levels respectively

Results of the cointegration test are documented in table 3. Both the maximum eigenvalue statistic and trace statistic suggest there is 1 cointegration exists in the model at 5 percent significant level. Thus, it implies the existence of long run relationship though the direction is still not clear.

Table 6: VECM Granger Causality Result

Independent Variable	**Dependent Variable**		
	LEC	**LVA**	**LP**
LEC		5.2213***	2.8601
LVA	3.1558		2.0588
LP	0.6798	0.2421	
ECT	-1.7785*	0.73732	2.93237

Notes: The asterisks (***), (**) and (*) denote rejection of the corresponding non-causality hypothesis at the 1 %, 5 % and 10% respectively. Lag length was selected on the basis of the Akaike's Information Criterion.

In order to get more details on the result of long run and short run relationship, VECM Granger causality test has been conducted. The VECM Granger causality test suggests that in the long-run Granger causality runs from LVA to LEC (ECT significant at 1 percent significant level). The error correction term shows that there is 1 significant equations found out of 3 suggested equations. This result also has been found by Ozturk et al. (2010). In the short run, it has been found that there is only one unidirectional relationship exist in the suggested model from LEC to LVA at 10 percent significant level. Ozturk and Acaravci (2011) and Ciarreta and Zarraga (2011) also found the same result of unidirectional relationship running from electricity to output.

5. Conclusion and Policy Implication

This study attempted to test multivariate energy demand function with the variable of electricity consumption, output and price in Malaysian manufacturing sector. The suggested model estimates long run relationship and short run relationship as well as its causal relationship. Result from Johansen and Juselius cointegration test indicates that all variables are significantly cointegrated. Evidence from ECT test via VECM shows that only one unidirectional relationship exists and it is running from output to electricity consumption in long run. However, there is only one significant unidirectional relationship running from electricity consumption to output in the short run.

Thus, empirical result indicates that the developments in manufacturing sector will eventually stimulating greater demand for electricity in the long run. For that reason, the output growth may give much impact on electricity consumption. However, electricity consumption may not give much impact on output growth in manufacturing sector. Therefore, any changes in energy policy may not affect much the performance of manufacturing sector in the long run. Based on our empirical result, any changes in energy policy may just give some impact on output growth in the short run. In order to encourage rapid growth in manufacturing sector, the industrial policy and its implementation is very crucial and need to be emphasized more. In energy policy side, the government needs to make sure that the supply of electricity meets the demand of electricity in manufacturing sector which is increases in the same line with its output growth. Currently, government introduces renewable energy policy in order to enhance the capacity of electricity generation (by depending much on biomass and hydropower) to meet the demand of electricity which steadily increase time to time (Bekhet and Harun, 2012; Keong, 2005). High dependency on renewable energy is responded to high cost of energy (such as oil and gas) and environmental concern (in order to reduce negative impact on environment).

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Fuel wood use and economic growth in Ghana: implications for climate change mitigation

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Abstract

Modern energy sources are widely regarded as a basic necessity for economic growth and development. However, in spite of traditional biomass accounting for over 60% of the total energy consumption in Ghana over the past two decades, impressive gross domestic product growth rates have been realized. To achieve projected middle income status in a changing climate, it has been suggested that Ghana needs to reorganize its generation, processing and use of energy. Diversification however, means additional opportunity cost to households and firms whose activities thrive on the use of fuel wood. These opportunity costs serve as a constraint to climate change mitigation in Ghana. This paper used a Travel Cost model to assess the economic value Ghanaians place on fuel wood and the net economic benefit from fuel wood use. To promote sustainable economic growth, the net economic benefit from proposed alternative sources of energy must be greater than or equal to the net economic benefit from fuel wood use forgone. The results also indicated that Ghana is currently in a fuel wood energy trap. Cultivation of energy forest plantations, introduction and use of improved charcoal stoves and improved charcoal production kilns stand a great chance of ensuring efficient use of energy for sustained growth. These measures could also be one way to attract climate change mitigation related funding for economic growth and development through the energy sector.

Keywords: Climate change, Economic growth, Energy, Fuel wood, Ghana, Travel Cost.

JEL codes: Q40; Q42; Q43; Q48; Q54; O44

1. INTRODUCTION

The use of modern energy sources has undeniably become a necessary condition for economic growth and development in all economies. Ghana's economy has for the past decade grown at an average rate of 5.8% per annum. Additional crude oil induced growth is expected to provide higher growth rate of over 9% per annum. As a contributor to economic growth, Ghana's energy sector shows signs of high susceptibility to climate change (World Bank, 2009). This indicates that achieving the targeted middle income status would require a reorganization of generation, processing and use of energy resources. In line with these projections, total energy requirements have been growing from 7 million tonnes of oil equivalent in 2004 and is expected to reach 22 million tonnes of oil equivalent by 2020 (Ghana Energy Commission, 2006). Current trends in energy use indicate that the energy requirement is to a large extent met through traditional biomass sources, accounting for about 63% of total energy consumption (NDPC, 2010). Such a trend appears highly unsustainable for continued economic growth, particularly in the wake of recent and projected climate change shocks and persistently high levels of deforestation.

Before the early 18th century man's main sources of energy were muscles, firewood and charcoal. These were supported by a limited use of water and windmills. The Industrial revolution saw a dramatic increase in the use of coal, oil and gas which can be said to have massively aided production. However, the massive increase in productivity also brought with it a greenhouse gas induced changing world (Girardet and Mendonca, 2009). Arnold et al (2003) assert that it was probably not until the early 20th century that wood lost its place as the main fuel in the rural areas of most industrialized countries. In these economies, the move away from fuel wood was not only rapid but continuous. However, in developing countries due to the inability to afford alternative modern sources of energy, wood has continued to be a dominant fuel. They further assert that in the rural areas of developing countries fuel wood is the most highly treasured form of domestic energy simply because most of its supply and use occur without monetary expenditure, making subsistence easier to live by. It is observed that the use of fuel wood does not require any complex or expensive device(s). It is also easy to use in the open and can mostly be obtained at no cost greater than the labour of collecting and preparing it.

Following the Eckholm (1975) assertion that a third of the world's people were in a daily scramble for fuel wood for cooking, the issue of fuel wood gained further importance in the 1970s. This assertion, the "fuel wood gap" raised widespread concerns about the socio-economic implications of fuel wood use by people. Dewees (1989) however, saw much of the earlier analysis about the 'gap' as a failure to distinguish between the physical and economic issues which governed fuel wood use and availability. The rapidity of population growth in urban areas coupled with low urban incomes in most urban areas in Africa implies strong growth in the use of fuel wood will continue to occur. Such a trend in the light of deforestation and climate change shocks provide challenges to further economic growth worth studying if developing economies like Ghana will have to strive towards better welfare realization.

2. GHANA'S ENERGY SECTOR

Biomass has for several decades been the main source of Ghana's energy consumption. This has been in the form of fuel wood and charcoal, accounting for about 63% of the total energy consumption. Electricity and Petroleum products constitute about 9% and 27% respectively of the energy consumed. The average energy consumption is estimated at about 6.6 million tonnes of oil equivalent. Fuel wood and charcoal alone account for more than 93% of energy used for cooking and LPG (Liquefied Petroleum Gas), Kerosene and electricity use though cleaner, account for 4.1%, 1.1% and 0.4% respectively. Other fuels like crop residue and cow dung account for about 1.4% (Ministry of Energy, 2008). Economic growth for Ghana means more extraction, processing, distribution and consumption. This means more energy consumption or use. Ghana's target of sustained middle income status requires a sustained GDP growth rate of about 8% per annum. This requires a more than double of the current energy consumption (Akuffo, 2007). The pertinent issue is whether the continuous dependence on fuel wood can lead to the desired growth in Ghana.

Supplies of fuel wood to satisfy about 63% of net energy consumption could pose a potentially serious problem over the long term in Ghana. Spot shortages have occurred in the north east where people spend an increasing amount of time on gathering wood for fuel, which have resulted in the frequent burning of agricultural residues, thereby adversely affecting agricultural productivity.

Energy sector weakness has been a major constraint on the growth of the Ghanaian economy. As the Ghanaian economy strives to sustain a low middle income status, a central issue from the medium to long term would be how to meet the associated energy requirement under the existing financial constraints and climate change shocks. While the concentration on growth is essential, the responsibility to keep Ghana's contribution of GHG emissions at the lowest possible level must not be overlooked. This paper used the Travel Cost Method (TCM) as well as official data to provide an economic assessment of switching to the use of modern energy sources from the predominant biomass use. The climate change mitigation implications were analyzed within the framework of climate change shocks and the desire to sustain a low middle income status.

3. CLIMATE CHANGE IN GHANA

Historical evidence attests to the fact that in Sub-Saharan Africa, climate change has had a generally significant and negative influence on economic growth. Economic activities in the form of extraction, processing, distribution and consumption generate greenhouse gases thereby causing anthropogenic climate change. Climate change then tends to have adverse effects on the economy thereby lowering economic growth where the level of vulnerability is high.

Various extreme climatic events point to the fact that climate change is being experienced in Ghana. Within the past 4 decades, temperatures have risen by about 1 degree Celsius, while within the same period; rainfall and runoff were recorded to have decreased by about 20% and 30% respectively (Ghana EPA, 2000). Analysis based on 56 IPCC GCM model results for 4 scenarios of climate change suggest adverse climate impacts on GDP for Ghana, becoming stronger towards 2050. The projected climate change induced decline in real GDP ranges from – 5.4% per annum (Global dry) to – 2.1% per annum (Ghana wet) by 2050. This trend is in line with the crop simulation model runs that predict more severe negative yield impacts towards the middle of the 21^{st} century. Real household consumption is set to decline in all the models with a sharper decline for rural households than urban households. The production of all crops is also set to decline, becoming more pronounced over time. Agricultural production relative to the baseline scenario will decline between 1-6.5% per annum by 2050, with output declining annually between 1.3% (Ghana Wet) and 13% (Ghana Dry) by the 2050 (World Bank, 2009).

It is worth noting that biomass growth thrives on favourable conditions for agricultural output. Using the fact that most fuel wood comes from the Ghana dry region, this may mean a 13% reduction in the output of fuel wood or a proportionate increase in its price by 2050. Much as adaptation to climate change is helpful, considering the magnitude of the projected loss, mitigation measures have the tendency to promote sustainable economic growth in Ghana.

3.1 Climate Change Mitigation in Ghana

Shalizi and Lecocq (2010) assert that mitigation in most cases might be the cheapest long term solution to the problem of climate change. It also promises to be the best form of insurance against extreme effects from climate change. This makes the shared responsibility of climate change mitigation by both the rich and the poor crucial. No matter how much adaptation occurs, it is becoming clearer that some irreversible changes in economies and ecosystems are unavoidable due to climate change. Also, uncertainty about the magnitude of the effect of climate change should cause developing countries to realize that such effects if severely catastrophic might erode the little development that has been achieved so far. These make mitigation for developing economies a cost effective approach in the long run.

Ghana's Greenhouse gas emissions represents about 0.05% of the total global emissions and rank 108 in the world. This represented a total per capita emission of nearly 1MtCO_2e per person as at 2006. At the continental level, Ghana ranks equally with Senegal and Mali as the 21st most GHG emitting country in Africa. Though Ghana's emission level appears relatively lower compared to other major developing economies, the trends clearly indicate a strong peaking potential in the near to medium term horizon, as the economy of Ghana continues to grow. The development of new frontiers dominated by agriculture, forestry and the oil and gas industry are expected to pose further challenges for climate change mitigation efforts (EPA Ghana, 2010).

The residential sector was the second largest contributor to the total energy emissions between 1990 and 2006, contributing 32% of the total energy sector emissions. This is due to the increasing population and subsequent increase in consumption of biomass to meet domestic energy needs. Thus mitigation strategies for the energy sector will have to be closely linked with the forestry sector. Broadhead et al. (2009) suggest that achieving climate change mitigation through forestry requires that forests are managed in ways that fundamentally reduce carbon emissions. The simplest way to mitigate climate change would be to reduce all the uses of the forest that make it lose its reservoir and sink capacities unsustainably. These include maintaining or increasing forest land area, reduced deforestation, increased forestation and reforestation, reduced degradation, wildfire management, and increased use of wood products from sustainably managed forests. For society to benefit fully however, forests must be managed for both mitigation and adaptation purposes.

3.2 Fuel wood use and climate change in Ghana

Users of Natural resource goods like fuel wood often find it very difficult to adjust to potential reductions in the availability of these goods, because of their lack of close substitutes within reach of the incomes of the users. Thus even though in Ghana fuel wood use should have been sensitive to availability, there is currently little tendency for switching to other sources of energy for cooking even in the wake of climate change shocks. Also, land is directly affected through high temperature increases and drought, floods leading to erosion and loss of fertility as well as crop and resource damage keep occurring. Vegetation, particularly forests are thus affected, accounting for shortages in the availability of fuel wood or at least increasing the difficulty of access to fuel wood. Biomass and for that matter fuel wood happens to be a climate sensitive renewable source of energy. This makes it more vulnerable to climate variability than other renewable sources of energy like solar and wind. The inelasticity of fuel wood use to the cost of acquisition will mean a loss of welfare as the cost of acquiring fuel wood continues to increase for the average Ghanaian household.

The use of biomass as a household source of energy involves natural growth and harvesting. This is a means of competition for land with agriculture and forestry as well as nature conservation.

Household energy consumption in Ghana is primarily for lighting and cooking. About 67% (24, 890 GWh/yr) of total energy consumption in the household is used for cooking (Ministry of Energy, 2008). The UNDP (2011) estimates that 90% of households in Ghana rely on traditional biomass (fuel wood and Charcoal). It further estimates that every person in Ghana currently uses around 1 cubic meter or 640 kg of fuel wood per annum.

The statistics indicate a strong attachment to fuel wood by households in Ghana, which must have contributed strongly to the activities responsible for the rate of economic growth recorded so far. The repercussions of such a fuel wood consumption pattern on forest resources are immense. High deforestation has resulted in a loss of biomass in Ghana and depleted the capacity for carbon sequestration as a means of combating climate change through the natural forests.

Sustainable economic growth however requires growth policy to mitigate climate change.

REDD+ programmes target carbon sequestration and will be largely incompatible with the current situation in Ghana where the rate of biomass harvests exceed the rate of natural regeneration. Decreased precipitation and increased temperatures are likely to cause a reduction in biomass production due to water stress on woody plants and also general land degradation.

Decreased agricultural productivity due to changing agro-ecological zones, lack of water for irrigation and outbreaks of pests and diseases would also decrease the amount of biomass available for energy.

The above discussion points to the fact that climate change is not going to allow the continuous use of fuel wood at the current rate. For instance, the FAO (2011) indicates that as at 2008 Ghana was producing and consuming 35,363,000 m3 of fuel wood. This rate of production and consumption in addition to commercial logging would deplete in a very short time the forest cover, leading to severe effects from climate shocks and hence a fall in economic growth rates as well as welfare. Thus the current rate of fuel wood use would exacerbate the vulnerability of Ghana to climate change shocks. Table 1 below explains clearly how the impact of climate change can be translated through fuel wood use to finally affect economic growth and Development.

Table 1: The effects of climate change on biomass-based energy use

Change in climate variable	**Impact on biomass-based resource**	**Impact on energy generation**
Temperature increase	Lower availability of biomass if plants reach threshold of biological heat tolerance or if sea level rise	Either increased or decreased biomass availability or crop variety.

	reduces the area where plants grow, otherwise there is an increase in biomass availability, increased fire risk.	Increased fire risk may jeopardise crop harvest.
Increase in average precipitation	Higher biomass availability if the precipitation increase occurs during the growing season.	Increased energy generation potential
Decrease in average precipitation	Lower biomass availability unless precipitation decrease occurs outside the growing season. Increased fire risk.	Decreased energy generation, increased fire risk may jeopardise harvest.
Droughts	Lower biomass availability, increased fire risk.	Decreased energy generation, increased fire risk may jeopardise harvest.
Floods	Decreased availability of biomass resources if floods affect area where biomass is sourced.	Decreased energy generation if energy source is flooded, destroyed or biomass availability is reduced.
Increased frequency and/or strength of storm/cyclones	Decreased availability of biomass resources if storms affect area where biomass is sources.	Decreased energy generation if power plant id flooded, destroyed or biomass availability is reduced.

Source: Based on amendment from Urban and Mitchell (2011)

The effects explained in Table 1 generally indicate that Climate Change will serve as a drag on economic growth through a general decrease in the energy availability if Ghana does not depart from the Business-as-usual trend in the energy sector. Also, the health, security and educational setbacks of the use of fuel wood in the traditional way are indicators of low level welfare for households. The Growth and Poverty Reduction Strategy (GPRS) II of Ghana tried to address some policy issues in this direction.

4. FUEL WOOD USE AND GHANA'S ECONOMIC GROWTH POLICY

Fuel wood plays a very important role in the socio-economic development of Ghana, supplying about 70% of energy consumed (Aabeyir et al., 2011). The issues that are of importance to growth are that, reductions in access to fuel wood due to climate change will negatively affect the welfare of the poor. Also, the incomes of fuel wood sellers will be adversely affected and lastly the harvesting of biomass can have adverse effects on forest conservation (Arnold et al, 2003).

Ghana has substantial energy resources, of which fuel wood and hydropower are the most prominent. About 18.3million hectares of land are under tree cover, an equivalent of about three-quarters of the land area, although actual forests have fast depleted and are much less than 2 million hectares. Two main types of forest areas exist in Ghana. The first is the high forest zone in the southwest, covering about 34% of the land area. This area has the larger tree stock and faster incremental growth due to an annual rainfall of 1,300-2,200 millimeters. The second forest area is the savannah wood land zone in the northern part. This area is less forested but happens to be more important for providing fuel wood in Ghana. Here the annual rainfall is between 1,000 – 1,500 millimeters. This region is recorded to be losing about 22,000 hectares of trees annually mainly for fuel wood and charcoal (Daily Graphic, 2011).

Attaining a middle income level of US$1,000 per capita by 2015 meant demand for wood fuels were expected to grow from about 14 million tonnes in 2000 to 38-46 million tonnes by 2015, and 54 – 66 million tonnes by 2020. This would put the nation's dwindling forests under undue stress which could result in serious consequences on climate change, agriculture and water resources. Based on Ministry of energy official computations, the estimated optimum energy and fuel needed to drive the Ghanaian economy to achieve the US$ 1000 per capita by 2015 and consequently, maintain a middle-income status up to 2020 are indicated in million tonnes in Table 2. The underlying assumption is that of a consistent and moderately high rate of economic growth.

Table 2: Estimated optimum energy needed to drive the Ghanaian economy to achieve US$ 1000 per capita by 2015 and maintain middle income status by 2020 (in million tonnes).

Energy source	**2015**	**2020**
Fuel wood	29-35	40-50
LPG	0.161	0.295
Kerosene	0.089	0.110
Jet Kerosene	0.152	0.226
Gasoil	0.821	1.100
Premix Gasoil	0.073	0.082
Diesel	1.28-1.43	1.51-2.0
Electricity	0.014-0.016	0.020-0.022

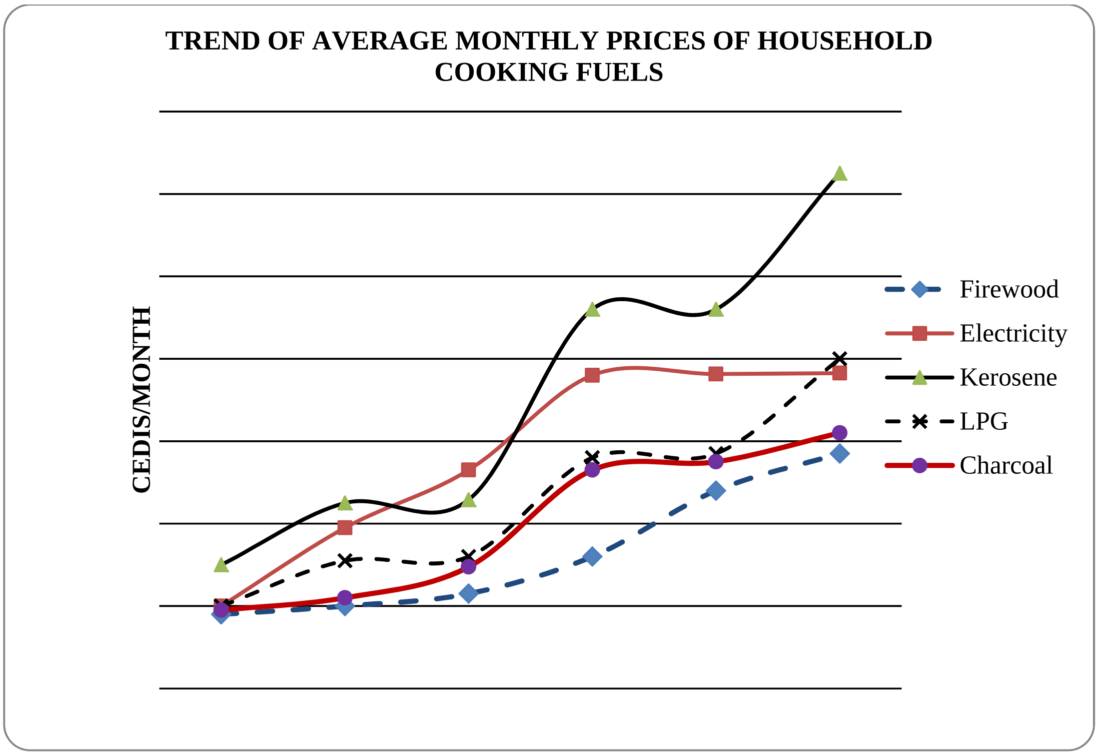
Source: Ghana Energy Commission (2006)

It is evident from Table 2 that Ghana's growth policy does not foresee a move away from a substantial dependence on fuel wood as its main source of energy.

The Ghana Energy Commission (2006) has indicated that all sectors of the Ghanaian economy utilize fuel wood and charcoal with the household sector using the largest share of over 70% per annum, followed by the industrial sector (26%).

Another welfare issue is the price of fuel wood compared with other sources of energy. Figure 1 indicates that fuel wood has the least average monthly price among all the available household cooking fuels. Generally, apart from convenience for subsistence existence, the low price of fuel wood is what makes it attractive to the low income earners in developing countries. With the prominence of biomass in Ghana's growth policy, the next section provides an empirical estimation of the value assigned to fuel wood by its users in Ghana.

Figure 1: Trend of average monthly prices of household cooking fuels in Ghana.



Source: Ghana Energy Commission (2006)

5. THE TRAVEL COST MODEL

Even though not heavily forested, the northern savanna zone of Ghana has been very well known for its nationwide supply of biomass for energy in Ghana. The Tamale Metropolis is the largest settlement in Northern Ghana and acknowledged to be one of the fastest growing cities in West Africa, with a population of about 293 881 (Ghana Statistical Service, 2000). The Metropolis lies between the latitudes $9^0\ 18^1$N and $9^0\ 26^1$N and longitudes $1^0\ 15^1$E and $1^0\ 23^1$W. The choice of Tamale was deemed appropriate since the use of fuel wood there was well established even though not very different from some other areas in Ghana. Two main modes of acquiring fuel wood exist in Ghana - through collection and purchases. In most urban centers commercial and large household users purchase fuel wood from sellers at very moderate prices depending on the season and also tree species. However, most household users in Ghana collect fuel wood freely from nearby wooded vegetation.

Face-to-face interviews were used to elicit responses from respondents who were household heads. The number of trips to fetch fuel wood from various sites was the sum of trips of all members of the household who went to fetch firewood. Communities were selected by simple random sampling, while households were selected through a second stage systematic sampling. The total number of communities was 179 out of which 100 communities were selected. Given a total population of households using fuel wood in the Tamale Municipality as 20,407 (GSS, 2000) a sample size of 392 was computed.

A zero price was assigned for fuel wood collected. Sellers of fuel wood would normally price the product based on where they went to collect the wood and the cost of transportation to the point of sale. The wood itself is normally freely obtained in most cases. The Travel Cost (TC) in this case represents the cost of collection, which is its implicit price. Travel distance costs were based on fares of locally used means of transport (called “tro-tro”), commonly used by low income earners in Ghana, while time cost (opportunity cost of time) was one-third of the minimum wage as used by Cesario (1976).

5.1 Results of Travel Cost estimation

Using the zonal travel cost estimation, households were grouped according to their distances from the places of fuel wood collection: Zone 1 being the nearest with an average distance of less than 2 km, Zone 2 with a mean distance of 3 km, Zone 3 with a mean distance of 6 km, Zone 4 with a mean distance of 9 km and zone 5 being the furthest with mean distance of 12 km.

Table 3: Computation of annual TC for fuel wood collection in the Tamale Municipality in Ghana cedis (GH¢). [US$1.00 = GH¢1.60]

Zone	% of Households	Population of households	TC per visit in GH¢	No. of Visits per year	TC per year for population in GH¢
Zone 1	19.9	4,061	0.56	25,324	14,181.44
Zone 2	53.3	10,877	0.58	65,884	38,212.72
Zone 3	20.7	4224	3.98	10,764	42,840.72
Zone 4	2.0	408	6.77	572	3,872.44
Zone 5	4.1	837	10.75	832	8,944.00
Total	100	20,407		10, 3376	108,051.32

Source: Author's field work, 2010

Table 3 shows the computation of the TC per trip of fuel wood for each household member in Tamale. Based on the fact that it is mainly women and children who pick fuel wood (even though some men bring home loads on their bicycles from their farms also), and given an average family size of 5.5 for the Northern Region, about 3 members of the average household normally go out to fetch fuel wood. This makes the TC per year 108,051.32 x 3 = GH¢ 324,153.96. About 60.7% of households predominantly rely on fuel wood for their energy needs in Ghana (Armah, 2004). This makes the total number of households in Ghana using fuel wood 3, 361, 566. Thus if for the households sampled the TC per year is GH¢324,153.96, then for the proportion of Ghanaian households who use fuel wood, the total travel cost would be GH¢53,396,625.21, which is an equivalent of US$33,372,890.76 per annum. Since the TC estimation shows the value placed on the commodity, the US$ 33,372,890.76 represents the annual value placed on fuel wood by its users in Ghana per annum. This is also described as the benefit derived from consuming fuel wood by households in Ghana per annum.

6. SWITCHING FROM FUEL WOOD

In considering a switch from fuel wood to more modern and efficient energy forms for the Ghanaian economy, two key sectors will be crucial. These are the informal and commercial/service sectors and households. The discussion is therefore based on these two sectors because they constitute over 95% of the users of fuel wood for energy in Ghana. All the official data in this section were obtained from Ghana Energy Commission publications, the only body mandated by government to produce such data for official purposes.

6.1 The Informal and Commercial/Service Sectors

The Growth and Poverty Reduction Strategy (GPRS) high economic growth scenario wood energy requirement is driven by the energy demand of the informal manufacturing and commercial/service subsectors of the economy. Encouraging these informal industries and commercial/service entities to switch to alternative fuels like LPG will lessen the pressure on the country's forests and also make them more efficient. The total LPG requirements in tonnes for the industrial and commercial/service sectors to substitute for fuel wood is 5 million for 2012, 6 million for 2015 and 7 million for 2020. This LPG demand, the Ghana Energy Commission asserts, will be practically impossible to achieve in the short-to-medium term and will put excessive pressure on the country's refinery capacity. It is however hoped that this could be a test case for private sector to take up the challenge to invest in refinery of LPG as well as the production of gas cylinders that would be needed. However, since wood remains the least expensive heating and cooking fuel, it is likely that significant proportion of the informal industries and commercial/service entities will be reluctant to make a switch unless the LPG supply is highly subsidized.

6.2 Household Use

For the household sector, cost considerations and availability seem to be the most prominent issues in a shift from firewood to charcoal and then to other cooking fuels such as LPG, Kerosene and electricity. Costs involved in the various cooking modes as computed by the Ghana Energy Commission are indicated Table 4.

Table 4: Costs involved in use of various cooking devices in Ghana.

Device	**Initial Investment cost US Dollars**	**Total cost per year US Dollars**
Three stone – mud firewood stove	0	44 – 62
Traditional charcoal stove	1.5 – 3	67 – 80
Improved '*Ahibenso*' charcoal stove	10	37 – 43
LPG (one-two burner) cooker	30 – 50	83 – 98
Electric (one-two burner) cooker	20 – 50	81 – 93
Kerosene (one-two burner) cooker	17 – 25	138 – 161

Source: Ghana Energy Commission (2006)

Even though, there is no initial capital investment in making a three-stone or mud firewood stove particularly, in rural areas, it is more expensive to use when compared with improved charcoal stove in the case where firewood is purchased. Otherwise, the three-stone or mud firewood stove is the least expensive cooking device and has the lowest life-cycle cost as well. For health reasons however, it will be wise to encourage a switch from firewood stove to charcoal stove usage but that involves an initial capital investment of about US$10.00.

On the environmental front, charcoal usage consumes more wood than firewood and for that matter not an attractive option for CDM and other large climate change related financial facilities. Charcoal usage leads to higher greenhouse gas (methane) emission because it takes between four – six units of wood to make a unit of charcoal, whilst firewood is used directly from the field.

A switch from fuel wood usage to kerosene for cooking is the most expensive option in terms of annual expenses. Secondly, kerosene is a fossil fuel and so the shift is not environmentally attractive.

A switch from fuel wood to electricity for cooking presents the cleanest option in terms of indoor pollution. However, it is not global-warming friendly, if the electricity is thermal-based generation. Carbon dioxide emission from fuel wood is neutral in terms of global warming whilst emissions from fossils are non-biogenic. There is also the issue of availability since national electricity access is still less than 50 percent.

The most advocated option is the switch from fuel wood to LPG use, since the latter is 'environmentally' friendly. LPG is a cleaner fuel in terms of indoor pollution, with far less emissions of particulate matter, acidic and other pollutants.

The LPG required to substitute for the fuel wood will be 750 thousand to 1.9 million tonnes by 2012 – 2015; and 950 thousand to 2.8 million tonnes by 2020. This additional LPG demand is likely to put a lot of pressure on the crude oil refining capacity of the country, unless the LPG shortfall is imported. This can create an opportunity to increase the refinery capacity of the country and boost gas cylinder manufacturing in the country. Introducing LPG to rural users however will require an efficient distribution network and back-up support to control potential gas accident associated with it and occasional shortages due to distances from retailing centers. Mobile LPG retailers exist but have higher premium than stationary retailers. For rural areas, it will be a significant extra payment to make, unless rural supplies are targeted and subsidized.

The switching from fuel wood use to liquefied petroleum gas (LPG) for residential cooking and heating has probably been the boldest step taken so far to mitigate climate change in the energy sector of Ghana. Such a policy had the capacity to reduce deforestation. This also led to the creative and increase use of LPG as fuel in the road sector. Many commercial drivers rapidly converted their gasoline-based commercial passenger vehicles to LPG-based, since this was realized to be more cost-effective. The adoption of LPG for commercial vehicle use has of late created some shortages for household users and has tended to defeat the purpose of promoting LPG use in Ghana. Net benefit comparisons are made for the switch from fuel wood to LPG in the next section.

7. NET BENEFIT COMPARISONS

The switch from fuel wood to LPG has been seen as the most feasible alternative (Energy Commission, 2006). It is however worth assessing whether the net benefit of LPG use surpasses that of fuel wood in Ghana. The LPG programme was initiated in 1990 to promote the under use of LPG as a substitute for charcoal and firewood in order to slow down the rate of deforestation caused partly by the production and use of wood fuels (Damptey and Mensah, 2008). The programme however has been derailed to a large extent as a result of cost, organizational and structural deficiencies. The net benefit implications are however very relevant to inform policy on the possible way out, which can ensure continued growth in the face of climate change challenges.

In the first place the use of fuel wood does not come with any installation cost, since the tripods used are molded out of common clay found in abundant quantities in Ghana. The total cost of use per year as computed by the Energy Commission (2006) in cases where fuel wood is bought is on average $62 per annum.

LPG (with a one-two burner cooker) however has an initial installation cost averaging $50 and then a cost of use of $98, making a total of $148. Thus the cost difference in switching from fuel wood to LPG is about 239% of the cost of using fuel wood.

From the derived value of the TC estimation, the proportionate benefit from LPG use would be about US$79,664,319.88 for household users. This means for LPG to provide the same benefit as fuel wood it must be subsidized to the tune of US$46,291,429.12 annually for household users.

Current subsidy for LPG of US$110 million from the government of Ghana is for all users of LPG. Based on use patterns it has been estimated that US$80 million of this subsidy goes to urban and peri-urban users whose use of it is of less value than for those who will need to switch from fuel wood (IMANI Ghana, 2011). Thus only about US$30 million of the subsidy goes to supplement LPG for a supply that meets only about 45% of the domestic need. To meet domestic need, the remaining LPG must be imported, considering the current operational challenges of refinery activities in Ghana. This comes with a huge cost to growth, with the potential of creating a worse situation of export dependency. Currently the greatest problem with LPG use even by the affluent in Ghana is the lack of availability. Also, the uncertainty that has come to be associated with LPG shortages in Ghana has not been a good sign for the switch from fuel wood to LPG. Clearly the net benefit of switching to LPG from fuel wood is negative given the current income and energy situation in Ghana. This implies a switch imposed on the status quo will lead to a decrease in growth and therefore welfare. Ghana appears trapped in a fuel wood energy trap in the short to medium terms. The only alternative left is to continue to use biomass; this compounds the issue of GHG emissions through persistent deforestation and degradation of forest resources, posing a serious threat to climate change mitigation.

8. CONCLUSION

There is currently no competitive alternative to fuel wood as the most important household fuel in Ghana. This means the use of fuel wood by households in Ghana is bound to continue. Growth policy projects an increase in fuel wood use as incomes and population increase. This trend makes the energy sector in Ghana very vulnerable to climate change shocks, an increasing contributor to GHG emissions and eventually a welfare reducing factor for the economy. Promoting cultivation of energy forest plantations, introduction and use of improved charcoal stoves and improved charcoal production kilns could lead to greater efficiency in the energy sector and create massive jobs for rural communities involved in the plantations for sustained non-oil GDP growth levels. These steps could also attract climate change mitigation related funding for development.

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Analysis of green net national income and genuine saving:

Portugal, 1991 – 2005

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Abstract

The context of this paper is the measurement of welfare and weak sustainability (defined as non-declining utility) in dynamic economies, i.e., comprehensive or green accounting. We estimate the green net national income (GNNI) and genuine saving (GS) for Portugal, for the years 1991 to 2005, accounting for the disamenity of air pollution emissions, the depreciation of commercial forests and the value of time, discussing the assumptions behind these terms for the inclusion in the green accounting model. The influence of short run cycles is analyzed by estimating GNNI and GS excluding business cycles from the data. We find that GNNI and GS are positive, thereby indicating no sustainability problem in Portugal, although both depict a trend towards unsustainability. Excluding technological progress there is a contradiction in the sustainability message of GNNI and GS: GS is negative after 2002, whereas GNNI is always positive, indicating that welfare increased.

Keywords: Sustainability; Green accounting; Portugal; Technological progress; Business cycles

JEL Classification: Q20, C51, C55

1. Introduction

The study of sustainability with the tools of the theory of dynamic economies has provided support for the use of sustainability indicators based on national accounting. Here we estimate two environmentally-adjusted aggregates for Portugal – green net national income (GNNI, also known as green GDP) and genuine (or adjusted net) savings (GS).

Regarding the empirical applications of environmental accounting, the literature is dispersed and many studies are not published in scientific journals. Vincent and Hartwick (1998) reviewed more than 30 studies, of which more than 20 since the late 1980s, which estimated either GNNI or GS. More recently, Lange (2003) reports on several industrialized and developing countries with environmental accounting programs of which 6 estimate macro aggregates. Overall, these studies extend the usual accounting system to include non-market goods and services from natural resources like forest and agricultural resources, fisheries, subsoil assets (oil and mineral resources) depletion, and several environmental (dis)amenities. On average, the adjustment for the depletion of natural resources ranges from 0.2 to 4 % of GDP. Most of these studies concerned developing economies and most of the studies of developed countries are concerned with forest resources and environmental amenities, such as biodiversity and landscape value. Regarding the damages from air emissions, Hamilton and Atkinson (1996) devised a simple model for flow pollutants (local effects) and found that GS ranged from 4 % to 14 % of GDP in Europe and that, total air pollution damage is 1 to 8 % of GDP. The set of pollutants they consider is not the same we consider here, as we explain in section 3.1. For stock pollutants we mention the World Bank's GS estimates that include the global climate damages of CO2, and the health damages from particles.

Regarding the saving measure of sustainability, the first estimates were reported by Pearce and Atkinson (1993) using data for 18 countries. Their results suggest that many countries are unlikely to pass a weak sustainability test. For the world as whole, net forest depletion is around 0.05%, energy depletion is around 3% of gross national product or income (GNI or GNI), mineral depletion averages 0.2% of GNI, the damage from CO2 emissions is around 0.4% of GNI and from particles is 0.5%.

Most empirical studies of GNNI and GS ignore technical progress and shifts in terms of trade. On this topic, we refer Weitzman (1997) on exogenous technical progress, Vincent et al. (1997) on exogenous shifts in oil export prices and Pezzey et al. (2006) on both. Overall, the empirical results suggest that, by neglecting exogenous technological growth, one obtains a downward biased estimate of GNNI. This bias can be as high as 40-50%, i.e., yearly NNI should be scaled by 1.4-1.5.

This paper is organized as follows. Section 2 summarizes the theory and results behind GNNI and GS in a general setting and in the case of a small open economy. Section 3 describes the data for Portugal while commenting on its drawbacks and use. The estimates of GNNI and GS are also presented in section 3, along with its analysis excluding business cycles. Section 4 concludes.

2. The theory of comprehensive accounting

2.1 General model

Here we present a summary of the comprehensive accounting results. Consider a representative agent, competitive, open economy with constant population. The consumption bundle $\mathbf{C}(t)$ contains everything that influences utility $U(\mathbf{C}(t))$,[1] including all non-market commodities (environmental or produced at home) and amenities. The economy's stocks include physical, financial, natural and human capital (education and knowledge accumulated in R&D), forming a vector $\mathbf{K}(t)$, with net (of depreciation) investment, $\dot{\mathbf{K}} = \mathbf{I}$. The production possibilities set constrains the decisions to invest and consume such that $(\mathbf{C}(t), \mathbf{I}(t)) \in S(\mathbf{K}(t), t)$, where S represents the attainable production possibilities. The time argument denotes an uncontrolled stock that causes changes in production possibilities frontier such as exogenous technological progress or other externalities.

The representative agent, seeking to maximize welfare, $\int_0^\infty U(\mathbf{C}(t))e^{-\rho t}dt$, with a constant and positive utility discount rate, ρ, chooses the paths of consumption and net investment subject to the attainable production possibility set, obeying the initial conditions for the stocks of capital. The following results are valid on the optimal path $(\mathbf{C}^*(t), \mathbf{I}^*(t), \mathbf{K}^*(t))$ of the above problem so for ease of exposition we abstain from using asterisks. The maximized welfare is defined as $W^*(t) := \int_t^\infty U(\mathbf{C}^*(s))e^{-\rho(s-t)}ds$, and using the appropriate Divisia CPI to transform utility metrics into real money prices, real GNNI $Y(t)$ is defined as

$$Y = \mathbf{P}\cdot\mathbf{C} + \mathbf{Q}\cdot\mathbf{I} + Q^t, \tag{1}$$

where $\mathbf{P}(t)$ and $\mathbf{Q}(t)$ are the vectors of real prices for consumption and net investment. $\mathbf{P}(t)\cdot\mathbf{C}(t)$ then represents real consumption expenditures and $\mathbf{Q}(t)\cdot\mathbf{I}(t)$ real net investment (or genuine saving). The vectors of real Divisia prices for consumption and net investment are defined, respectively, as, $\mathbf{P} := (\partial U / \partial \mathbf{C}) / \Lambda$, $\mathbf{Q} := \mathbf{\Psi} / \Lambda$ and $Q^t := \Psi^t / \Lambda$, where $\mathbf{\Psi}(t)$ and $\Psi^t(t)$ are respectively the shadow prices of capital and time, $\Lambda(t) > 0$ is an extended price index (Pezzey et al., 2006) verifying the Divisia property in continuous time $\dot{\mathbf{P}}\cdot\mathbf{C} = 0$. Using the above definitions, Asheim and Weitzman (2001) show that growth in $Y(t)$ indicates welfare improvement. Formally

[1] The convention throughout the text is that vectors are represented in bold.

$$\dot{Y} = R(\mathbf{Q}\cdot\mathbf{I}+Q^t) = RI\Lambda\dot{W}, \tag{2}$$

where $R := \rho - \dot{\Lambda}/\Lambda$ is the real interest rate. The value of time is $Q^t(t) = \int_t^{\infty} Y_s(s)e^{-R(s-t)}ds$ (Pezzey, 2004). Thus, if $R(t) > 0$, instantaneous changes in real GNNI deflated by a consumer price index have the same sign as changes in welfare. Thus, provided that the real interest rate is positive, growth in real GNNI deflated by a consumer price index, i.e., in fixed net investment prices can be used to measure welfare improvement along the optimal path (Asheim, 2007). Defining a sustainable development path as one ensuring non-decreasing utility, Pezzey's (2004) 'one-sided unsustainability test' is:

$$\mathbf{Q}\cdot\mathbf{I}+Q^t \leq 0 \text{ or } \dot{Y} \leq 0 \Rightarrow \text{decreasing utility in the future.} \tag{3}$$

However, positive net investment or genuine saving do not entail that the economy is sustainable (Pezzey, 2004). So far, no general test for sustainability is known.

2.2 Small open economy

In this section we present a particular case of the general model, for a small open economy that follows from Pezzey et al. (2006). We wish to include the stocks of commercial forest, the welfare costs of air emissions and the value of technological progress. The vector of capital assets is now $\mathbf{K} := (K, K^f, \mathbf{S})$. $\mathbf{S}(t)$ represents the vector of stocks of commercial forests, $K(t)$ the stock of domestic man-made capital, which grows at the rate of gross investment minus consumption of fixed capital (CFC), as in $\dot{K} = I - CFC$, and $K^f(t)$ represents the stock of net foreign capital held privately or by the government, which earns a return at the exogenous, constant world interest rate *r*. Let $K^f(t)$ grow as a result of interest on capital plus net exports of the consumption/investment good, $X(t) - M(t)$, and net resource exports, $\mathbf{Q}^R\cdot(\mathbf{R}^X - \mathbf{R}^M)$, at world resource prices, $\mathbf{Q}^R(t)$, according to

$$\dot{K}^f = rK^f + X - M + \mathbf{Q}^R\cdot(\mathbf{R}^X - \mathbf{R}^M). \tag{4}$$

The stock of commercial forests is harvested for domestic use in the production process, $\mathbf{R}^d(t)$, and to export, $\mathbf{R}^X(t)$, and regenerates at the natural rate, $\mathbf{G}(\mathbf{S}(t))$. Therefore, $\mathbf{S}(t)$ changes according to

$$\dot{\mathbf{S}} = \mathbf{G}(\mathbf{S}) - \mathbf{R}^d - \mathbf{R}^X. \tag{5}$$

Production, with exogenous technological progress, uses the stock of man-made capital along with the commercial resources harvested for domestic use and imported to produce a consumption/investment good according to $F(K,\mathbf{R}^d+\mathbf{R}^M,t)$. So, the production and net imports of the good, $F(K,\mathbf{R}^d+\mathbf{R}^M,t)+M-X$ are used for consumption $C(t)$, gross investment $\dot{K}(t)+CFC(t)$, firms' total pollution abatement expenditure is $a(t)=\sum_j a^j$ for each pollutant *j*, and harvesting, with the firms' harvesting costs, $f(\mathbf{R}^d+\mathbf{R}^X,\mathbf{S})$. Formally,

$$\dot{K} = F(K,\mathbf{R}^d+\mathbf{R}^M,t)+M-X-C-a-f(\mathbf{R}^d+\mathbf{R}^X,\mathbf{S})-CFC. \tag{6}$$

The household's utility function is $U(\mathbf{C}):=U(C,\mathbf{E})$, where $C(t)$ is material consumption and $\mathbf{E}(t)$ is the vector of net emission flows dependent on production and abatement expenditure $\mathbf{E}(F(\cdot),\mathbf{a})$. The marginal cost of abating pollutant *j* is $e^j(t):=-(\partial E^j(\cdot)/\partial a^j(t))^{-1}$. This formulation assumes that the cost of air emissions is accounted for in agents' decisions justifying why they spend resources on abating pollution. This assumption can be justified by the change in consumer habits due to increasing awareness of air emissions damages, or the introduction of stricter laws and policies regulating air emissions. The matter for comprehensive accounting is that emission costs are not included in any conventional economic aggregate.

In order to maximize welfare subject to (4), (5) and (6), the central planner controls are $C(t)$, $\mathbf{R}^d(t)$, $\mathbf{R}^X(t)$, $\mathbf{R}^M(t)$, $\mathbf{a}(t)$ and $M(t)-X(t)$. Net national product according to national accounts' procedures is interpreted as $NNP:=C+\dot{K}+\dot{K}^f$. Note that according to the general model, NNI and all other variables in GNNI and GS should be used in constant prices deflated by a comprehensive CPI that includes all things that affect welfare. The best proxy at hand is the usual CPI. According to the results of the previous section,

$$\text{GNNI: } Y = P^C\left\{NNI+(\mathbf{Q}^R-\mathbf{f}_\mathbf{R})\cdot\dot{\mathbf{S}}-\mathbf{e}\cdot\mathbf{E}+Q^t\right\}, \tag{7}$$

$$\text{GS: } Q\dot{K}+Q^t = P^C\left\{NNI-C+(\mathbf{Q}^R-\mathbf{f}_\mathbf{R})\cdot\dot{\mathbf{S}}+Q^t\right\}, \tag{8}$$

$$\text{with } Q^t(t)=\int_t^\infty F_s e^{-R(s-t)}ds, \tag{9}$$

where P^C is the price of the consumption good and is set equal to unity when the marginal cost of emissions is constant, according to

$$\frac{\dot{P}^C}{P^C} = \frac{\mathbf{e}\cdot\dot{\mathbf{E}}}{\left(C - \mathbf{e}\cdot\mathbf{E}\right)} \quad . \tag{10}$$

Expression (10) was obtained by applying the Divisia price index condition. It is likely that the estimates of GNNI and GS are altered if the marginal cost of emissions is not taken as constant.

The adjustments to reach GNNI from the usual NNI are shown in (7) and (8), i.e., deduct the welfare cost of emission $\mathbf{e}\cdot\mathbf{E}$, deduct the value of rents from resource stock depletion $(\mathbf{Q}^R - \mathbf{f}_\mathbf{R})\cdot\dot{\mathbf{S}}$ and add the value of time. These are the expressions we estimate for Portugal in 2000 prices.

3. Comprehensive accounting results

3.1 Pollution emissions and valuation

We wish to account for the damages due to emissions of the following flow pollutants: sulphur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM2.5), ammonia (NH3) and volatile organic compounds (VOC). These pollutants and associated impacts are considered to account for a large part of the total damages from air emissions (Holland et al., 2005). These impacts are the health damages of PM2.5 (both acute and chronic effects) and ozone, O3 (only acute). Both long-term (chronic) and short-term (acute) exposures are accounted in Holland et al. (2005). The quantification uses both mortality (i.e. deaths) and morbidity (i.e. illness).

The emission data is available in the National Inventory Report (2007) for the period 1990 - 2005. The marginal benefits/damages of emissions were obtained from the reports of the Clean Air For Europe (CAFE) programme (Holland et al., 2005). In table 1 we present the prices used to calculate $\mathbf{e}\cdot\mathbf{E}$ (converted to € of 2000). [Table 1] The best estimate in table 1 corresponds to chronic mortality based on mean VOLY estimates of €120,000 with no threshold for ozone. The low estimate uses the median estimate of VOLY of €50,000 for mortality impacts of PM2.5 and ozone with the 35 ppb threshold. The high estimate uses the mean VSL estimate of €2,000,000 for mortality impacts of PM2.5 and mean VOLY for ozone without threshold.

3.2 Depreciation in commercial Portuguese forests

Here we present the data used to estimate $(\mathbf{Q}^R - \mathbf{f}_\mathbf{R})\cdot\dot{\mathbf{S}}$ in (7) and (8). We have considered the three most important commercial sources of forest products (wood and cork) in Portugal, that is, cork, conifers and eucalyptus forests. Since Mendes (2005) argues that 'the industrial demand for cork induces harvesting of all sustainable production and not more', we have considered that the net growth of "cork forests", equals zero when estimating the depreciation of commercial forests, according to (7) and (8).

We estimate $\dot{S}(t)$ directly with data from the National Forest Inventory 2005/06 (IFN) of the DGRF (Direcção-Geral dos Recursos Florestais) for the years 1990, 1992, 1995 and 2005 in hectares. The data on volumes of standing stock (m^3/ha) was also obtained from the IFN 2005/06. Prices data was obtained through the SICOP system[2], for the period 2000 - 2005, and directly from DGRF for the period 1990 - 1995 based on roadside prices. Our own linear estimations completed the time series for the period 1990 – 2005. An estimate of the marginal cost of harvesting of 7 €/m^3 was obtained through inquiries with several providers of forest services.

The Portuguese commercial forests considered here have been depleting from 1990 to 1993 and from 1996 to 2005, especially pine forests. Compared to GNI, the depletion of forest resources ranges between the maximum depreciation of 0.4% and the highest appreciation of 0.2%, with an average depreciation of 0.1%. This corresponds to an average yearly loss of 120 million €. In Portugal, the value added of the forest sector is around 3 %, which implies that, when at its highest values, the depreciation of commercial forests is of the order of 10 % of the value added of the forest sector. In order to perform sustainability analysis, the forest value added is 10 % less the conventional to account for (the loss of welfare due to) the loss of future timber due to harvest in the current period.

3.3 The value of technological progress

Including the value of technological progress requires estimation of (9). Data on total factor productivity (TFP) annual growth rates for Portugal was obtained from the annual macro-economic database of the European Commission. We consider this to be our estimate of F_t/F. Since the value of technological progress is forward-looking we need projections of TFP growth and GDP growth. This was estimated by extending a long term average growth of GDP (1974-2007) of 2.5% and TFP growth of 1% until 2020 and using (9) truncated to the year 2020 (i.e., T = 17 years). We performed sensitivity analysis for various truncations of (9). After 2020, a rate of 1% was used for the yearly growth of GDP and TFP in order to calculate the integral truncated for T=20, 40, 60, 80 and 100 years. The tradeoff is between uncertainty of the scenarios of future growth and the accuracy of the value of the integral. The results seem at first sight to reinforce the idea from Weitzman (1997) that the evaluation of sustainability appears to depend more critically on future projections of TFP than on the typical corrections now being

[2] http://cryptomeria.dgrf.min-agricultura.pt/

undertaken in environmental accounting. However, we know that TFP is overestimated, and there is no indication that the value of exogenous TFP is not close to zero.

3.4 Green net national product and genuine saving

To estimate GNNI and GS using (7) and (8), data on GNI, consumption of fixed capital (CFC), CPI and gross saving was obtained from the AMECO database. The GNI, CFC and gross saving were originally in current prices and then deflated to constant € of 2000 by using the CPI according to the theory of section 2. GNNI is always positive with an increasing trend, suggesting that welfare increased during the accounting period. The GS was obtained by adding the value of time and depreciation of commercial forests to net saving ($NS = NNI - C$) following (10). Table 2 presents the relative values of net saving, and four estimates of GS. [Table 2]

3.5 Excluding business cycles

Although the analysis of the interactions between terms provides insights into the indication of welfare changes and sustainability, the theory in section 2 assumes a competitive economy on its optimal path and so full capacity utilization of stocks at all times. This is approximated by filtering out the short-run fluctuations or business cycles of the variables. These cycles are also not desirable when measuring the long-run sustainability since, as perceived from the previous section, they affect the sustainability message of the indicators although having little to do with long-run economic growth or sustainability.

The Portuguese economy presents business cycles of roughly 10 years, which are also present in economic data other than GDP. Particularly, both TFP and GDP roughly depict a ten year business cycle with decreases in 1975, 1984/85, 1993 and 2003. Using a Hodrick-Prescott filter we obtained the trend of the initial time series, approximating the value of the variable in full utilization of resources. Following Ravn and Uhlig (2002) a smoothing parameter of 6.25 is adequate for filtering the components with cycles between 9 and 16 years. The results show that the indications of unsustainability from GNNI, discussed in sub-section 3.4, are related to business cycles, i.e., potential GNNI did not decrease in the accounting period. Therefore there is no indication of unsustainability although potential GNNI shows a markedly decelerating trend.

4. Concluding comments

We have estimated two measures of weak sustainability from 1991 to 2005, to include the value of technological progress and exclude business cycles. Moreover, we discussed the assumptions, possible inconsistencies in green accounting exercises, and compared the sustainability message of the two indicators estimated.

Assuming the data is reliable, GS seems to consistently indicate movement towards unsustainable development, whereas GNNI indicates both no sign of unsustainability and that welfare increased. We report a mismatch in the message of sustainability between GNNI and GS without including the value of time. Genuine saving indicates unsustainable development of the Portuguese economy after 2002 when the value of technological progress is not accounted for. Overall, the adjustments proposed are around 15% of GNI, being the environmental adjustments – depletion of forest resources and cost of air emissions – of the magnitude of 7% of GNI. The later may seem small; however, we did not include relevant stocks of natural capital as fish, mineral, water, soil, or environmental amenities such as biodiversity, landscape and other types of constraints like the proximity of thresholds in ecosystem dynamics. Also, including the value of technological progress may be problematic since it has an important role in indicating sustainability, but the existing TFP data is not adequate for green accounting. Thus, there is a need for green growth accounting estimates. We believe a sound relationship between theory and data is essential to develop measures of welfare and sustainability. For that matter, we have to guarantee that the various assumptions associated with the data and the comprehensive accounting growth model, do not conflict.

Acknowledgments

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Table 1 – Estimates of marginal damage costs by air pollutant in Portugal [€2000/ton].

[€2000/t]	Best	Low	High
SO_2	6872	3472	9972
NH_3	7399	3699	10999
NO_x	2040	1140	3040
VOC	1150	450	1550
PM2,5	44000	22000	64000

Table 2 – The sustainability message. Negative values, suggesting unsustainable development, are inside boxes.

Growth rates [%]	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
GNI	3,8	3,8	-1,1	2,5	4,1	2,7	5,6	5,5	4,6	3,3	0,9	2,0	-0,2	1,4	0,5
NNI	4,4	4,5	-1,4	2,3	2,4	2,7	5,7	5,8	4,5	2,5	0,6	1,9	-0,3	1,2	0,5
GNNI	3,5	3,6	-0,1	5,7	2,9	-0,4	4,3	4,3	3,7	2,2	0,6	4,0	2,3	3,5	1,0
GNNI, T=100	2,9	3,0	0,1	4,7	2,5	-0,1	3,6	3,6	3,2	2,0	0,6	3,5	2,1	3,0	1,0
GNNI, no Qt	4,2	3,9	-0,4	2,6	2,6	3,2	5,5	5,8	4,7	3,0	0,6	2,4	0,3	0,8	0,7
Potential GNNI	2,5	2,7	2,9	3,1	3,0	2,8	2,8	2,8	2,7	2,6	2,6	2,6	2,6	2,4	2,1
Potential GNNI, T=100	2,4	2,4	2,5	2,6	2,5	2,4	2,5	2,5	2,4	2,3	2,3	2,3	2,3	2,1	1,9
Potential GNNI, no Qt	4,6	3,7	3,1	3,0	3,2	3,6	3,9	3,9	3,6	3,0	2,3	1,7	1,2	0,9	0,7
							(1991=100)								
Net Saving	100	96	61	51	60	53	57	73	60	21	14	11	2	-19	-59
GS	100	99	85	98	106	84	83	85	74	53	50	60	69	77	61
GS, T=100	100	100	94	101	105	96	96	97	93	84	83	89	93	98	91
GS, no Qt	100	96	64	53	66	53	58	75	58	20	13	9	0	-22	-64
Potential GS	100	93	88	85	84	80	76	70	64	58	55	55	57	59	61
Potential GS, T=100	100	97	96	95	95	94	92	90	88	86	85	85	87	88	90
Potential GS, no Qt	100	88	75	65	60	57	54	51	43	31	18	4	-12	-29	-46

DAY 9 - 16:30		
Room 626 - Energy System Analysis 1		
Application of solar lighting energy system: Anadolu Airport in Turkey	Nilgun F. Bayraktar[1]; Emre Kiyak[1]	[1]Anadolu University
Exergy-to-useful work analysis in Brazil from 1971 to 2009	Francisco Vieira de Sá[1]; André Cabrera Serrenho[2]; Tânia Sousa[2]	[1]Instituto Superior Técnico; [2]Department of Mechanical Engineering and IN+, Instituto Superior Técnico
Measuring the Impact of Renewable Energy Sources on the Optimal Generation Mix: An Application to the Iberian Electricity Market	Carla Manuela Tavares Mendes[1]; Isabel Soares[1]	[1]School of Economics, University of Porto
Electricity cost optimization in a renewable energy system	Sérgio Pereira, Paula Ferreira, A.I. Vaz	Center for Industrial and Technology Management, Universidade do Minho

Application of solar ligting energ system:

Anadolu Airport in Turkey

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ABSTRACT

That current energy needs are met has come to prominence today. In this context, two main subjects are analysed in this paper. In first part, greener solutions for illumination system of Anadolu Airport within Anadolu University are presented. The other part, the financial analyses has been carried out to meet energy needs of presented solution with solar energy. In both analysed issues, energy saving and fiscal saving obtained have been emphasized. Consequently, the solutions have been suggested for estimating negative situations, advantages of using alternative energy resources have been put forth. Additionally, a case study has been carried out for both terminal building and similar buildings.

Key words: Solar energy, lighting, airport

JEL classification codes: JEL: O52

1. INTRODUCTION

Nowadays, one of the types of renewable energy to be used widely is solar energy used in heating, electricity generation. Despite their high installation cost, they meet the cost in point with their high rate of savings in short time. Also one of the fields utilized solar energy is lighting system. Because its consumption of electricity energy is high rate, all green approach such as using alternative energy resource, applying the novel energy saving luminaires are of great importance to the nature. Studies conducted in this field have increased day by day parallel with the expansion of consciousness. That real case photovoltaic applications have been dealt with (Andrei et al, 2007), that the development process of the photovoltaic has been examined (Chaar et al, 2011), that solar heating in buildings and calculations of solar collector area have been analysed (Jing and Qian, 2011), that the effects of solar control films on lighting and cooling systems have been researched (Li et al, 2008), that electricity production with building integrated photovoltaic system has been examined (Ban-Weiss et al, 2013), that the importance of the solar energy for urban environment has been stated (Santamouris, 2001), that solar cells and building integrated photovoltaic systems have been investigated (Yoon et al, 2011), that relation with heating and photovoltaic systems are dealt (Fung and Yang, 2008), that technical and economic analyses of solar energy are set forth (Adhikari et al, 2011), that solar energy generation systems have been examined (Loh et al, 2010), that indoor lighting installation and energy efficient lighting systems are put forward (Ryckaert et al, 2010), that energy saving in lighting in office building has been stated (Dubois and Blomsterberg, 2011), that solar house design have been researched (Candanedo and Athienitis, 2009), that lighting system and photobiology have been analysed (Bellia et al, 2011), that relation with lighting and architectural design have been examined (Ng et al, 2001), that obtaining energy savings with different control systems have stated (Roisin et al, 2008), that hybrid lighting systems have been analysed (Schlegel et al, 2004), that building integrated solar systems and their way of working have been explored (Wahab et al, 2011), that the search has been carried out on lighting and carbon dioxide emissions (Mahapatra et al, 2009), that building integrated systems and solar cells have been stated (Jelle and Breivik, 2012), that applying integrated photovoltaic system to buildings has been tackled (Reijenga and Kaan, 2012), that general solar thermal systems and difficulties in their performance have been pointed (Oliveira, 2012), that developing building integrated photovoltaic systems have been studied (Norton et al, 2011), that relation with solar radiation and photovoltaic system sizing are analysed (Markvart, 2006) can be given example of the studies in point.

When considering all above mentioned studies, as distinct from them, in this paper illumination system, energy saving application, illumination system and one of the alternative energy types solar energy have been dealt with together. An application about the subjects in point has been designed for Anadolu Airport.

2. LIGHTING SYSTEM OF THE ANADOLU AIRPORT TERMINAL BUILDING

Aviation sector is one of the high greenhouse gas emissions (Figure 1) (Turkish Statistical Institute). This paper has been prepared for contribute to reducing this rate; and illumination system of Anadolu Airport Terminal Building has been analysed for this aim. The reason of analysing the illumination system is that the illumination system is responsible high rate energy consumption in a building.

	CO_2 Equivalent emissions			The share of the transport sector (%)
Transportation Type	1990	2008	2009	2009
Highway	23 350,70	40 565,29	40 199,62	84,74
Civil Aviation	**914,98**	**5 240,75**	**5 158,93**	**10,87**
Railway	521,52	458,15	444,8	0,94
Seaway	499,39	1 540,57	1 636,36	3,45
Variation of	2008-2009		1990-2009	
	CO_2 (Gg)	%	CO_2 (Gg)	%
Highway	-365,67	-0,9	15 848,92	65,09
Civil Aviation	**-81,82**	**-1,56**	**4 243,96**	**463,83**
Railway	-13,34	-2,91	-76,72	-14,71
Seaway	95,79	6,22	1 136,97	222,67

Figure 1 CO_2 Emissions of some transport sectors

Anadolu Airport is located in Eskisehir in Turkey. Its terminal building divided into two parts arrival and departure has 4000m2 indoor area. When considering the terminal building in terms of illumination system, it is seen that any energy saving applications have not been applied. In addition this, it is an extremely negative situation that one type of luminaires have been used. Taken the building as a whole, it is seen that 713 pcs Philips TL-D 18W/54 type fluorescents have been used. Their annual consumption of electricity is approximately 129.37 MWh.

In this paper, the calculations have been carried out for general waiting room part of the terminal building. This part is about 307 m2 and in this area 33x4 pcs Philips TL-D 18W/54 type fluorescents have been used. Annual electricity consumption of this area is about 6 MWh.

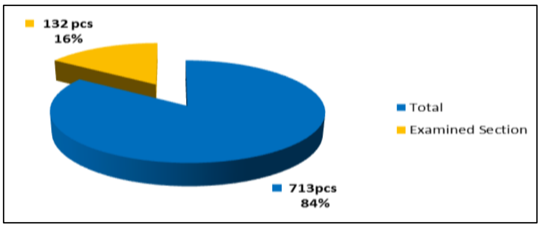


Figure 2 Number of luminaires

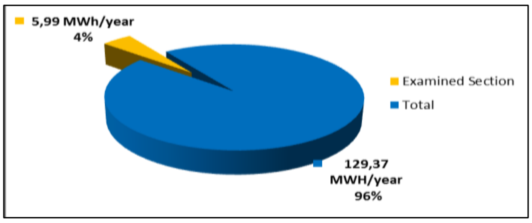
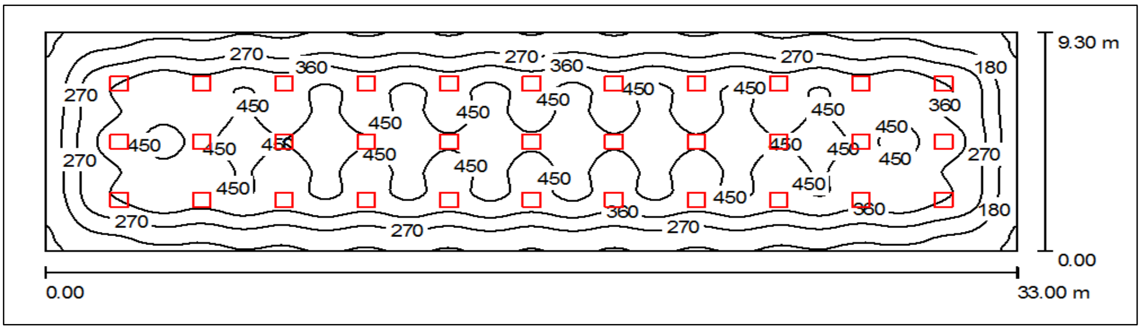


Figure 3 Electricity consumption (MWh/year)

When analysing an illumination system, both consumption of electricity, energy saving and some parameters have been taken into account. These parameters have been limited with some standards. Because of this, illumination calculations are of great importance. In this study, the calculations in point have been carried out by using DIALux program and their outputs have been commentated.



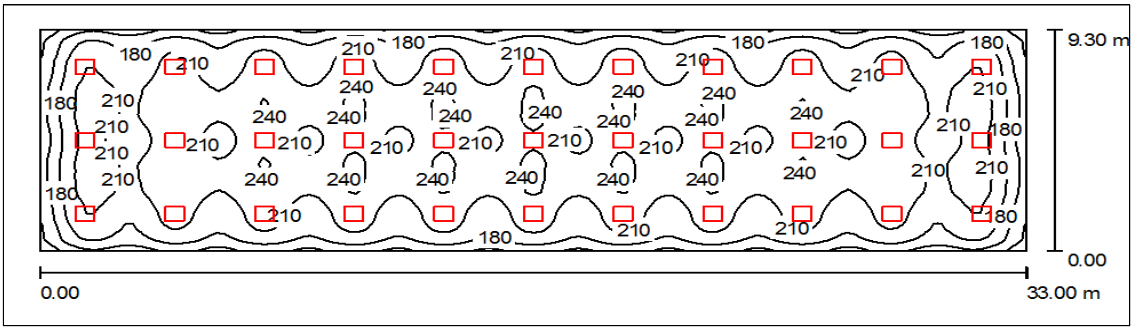
Number of Luminaire	Type of Luminaire	ϕ[lm]	P[w]	H	LPD
33*4	Philips TL-D 18W/54	4200	72	3m	7.74W/m^2

Surface	P [%]	E_m [lux]	E_{min} [lux]	E_{max} [lux]	E_{min} / E_{max}
Workplace	/	349	80	513	0.230
Floor	70	335	115	478	0.342
Ceiling	70	183	90	247	0.490
Walls (4)	50	168	91	256	/

Figure 4 Outputs of the current system

From the outputs obtained with DIALux program, it is seen that the current illumination systems is not suitable for the international standard ASHREA-IESNA 90.1 (ASHRAE-IESNA, 2004). According to this standard, energy level (Em) must be lower than 200 lux and, light power density (LPD) must be lower than 6 W/m2 but for the current system value of Em is equal 349 lux and value of LPD is 7.74 W/m2 (Figure 4).

Many different proposed solutions have been searched and developed for the current system. The solution to be suggested for reducing current energy needs and that the system is brought into line with the standard consist of 33 pcs Philips TL-D 90 De Luxe 36W/950 type fluorescents. Monthly electricity consumption of this area is about 250 kWh. Its illumination system has been modelled with DIALux program.



Number of Luminaire	Type of Luminaire	ϕ[lm]	P[w]	h	LPD
33	Philips TL-D 90 De Luxe 36W/950	2800	36	3m	**3.87 W/m^2**

Surface	P [%]	E_m [lux]	E_{min} [lux]	E_{max} [lux]	E_{min} / E_{max}
Workplace	/	**207**	99	246	0.477
Floor	70	196	113	246	0.574
Ceiling	70	93	55	111	0.597
Walls (4)	50	107	53	154	/

Figure 5 Outputs of the solution

The model's outputs shows that the proposed solution is suitable for the standard because its value of Em is lower than 200 lux and the value of LPD is lower than 6 W/m2 (Figure 5). It means that higher quality and energy efficiency illumination system has been obtained.

3. SOLAR ENERGY AND SUNSHINE DURATION OF TURKEY

Solar energy one of the types of renewable energy is used in many field such as lighting, heating, cooling, pumping. In addition this, the production of electricity from solar energy was discussed for the first time in 1839 by Alexandre-Edmond Becquerel. Solar cells described as the devices transform solar energy to electricity energy directly were produced for the first time in 1883 by Charles Fritts. Although solar cells are based on very old history, they have recently begun to be widely used (Fahrenbruch and Bube, 1983)

The logic of the solar cells is based on photoelectric effect. The photons structure of the solar cells hitting the semiconductor plate cause energy alteration in this plate. This energy absorbed the plate brings about the current. To obtain the desired current cells are connected each other in different ways and these structures are named with module, panel, array etc. Also the methods of electricity production from solar energy have developed day by day. Photovoltaic, concentrated solar energy and concentrated photovoltaic can be given as an example of these methods. The photovoltaic technology transforms the light emitted from the sun to electricity energy directly. Concentrated solar energy technology focuses the light to a small area by using reflectors and transforms it to heat energy. The difference between concentrated photovoltaic and concentrated solar energy technology is to transformation of the energy to electricity (Foster et al, 2010).

Considering the solar energy system as a whole, it consists of battery used for storage energy, charging regulator used for charging, inverter used for transforming DC current to AC current. Additionally, the system in point can be analysed in two main parts. In grid-connected systems more electricity is produced is given to grid and the electricity needed is provided the grid. Of-grid systems are used in the area it is difficult to transport powers lines.

Although the solar systems have high installation cost, they respect for nature and are clean energy system. Also to increase their efficiency, some parameters such as the slope of the installation areas, sunshine duration, the mean temperature stand out When the subject in point is evaluated in terms of Turkey, according to data from Turkish Ministry of Energy and Natural Resources, it follows that its southern regions of Turkey are more efficient in terms of the parameters (Figure 6 and 7).

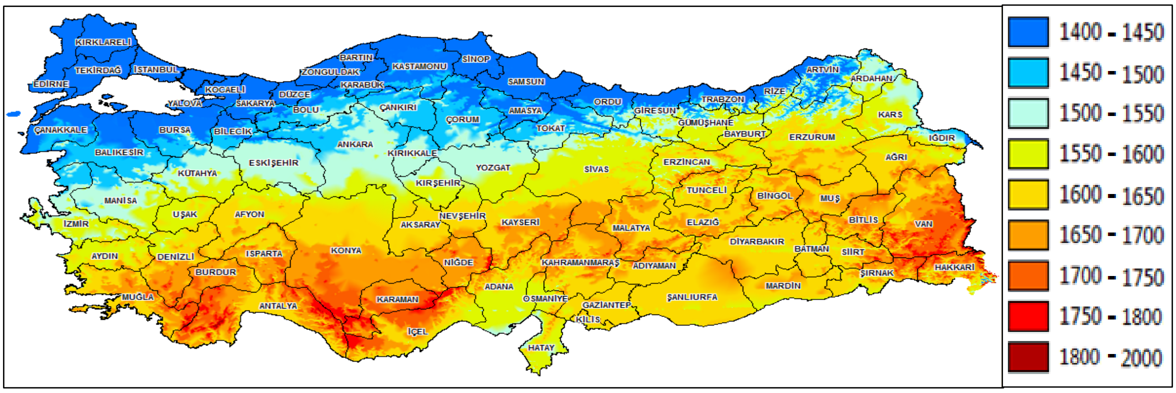


Figure 6 Total Solar Radiation of Turkey (kWh/m^2-a year)

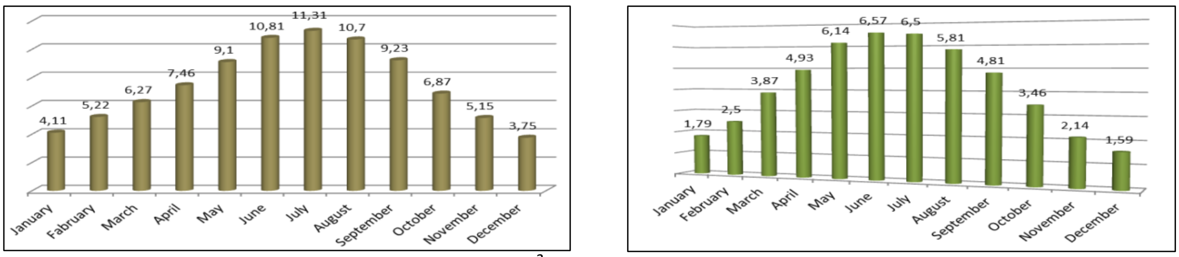


Figure 7 Global radiation values (kWh/m^2-a year) and sunshine duration (hour) of Turkey

Anadolu Airport is located in Eskisehir in Turkey. Its average sunbath durations are about 4 hours in during the winter, 6 hours during the summer and 10 hours during the spring (Figure 8).

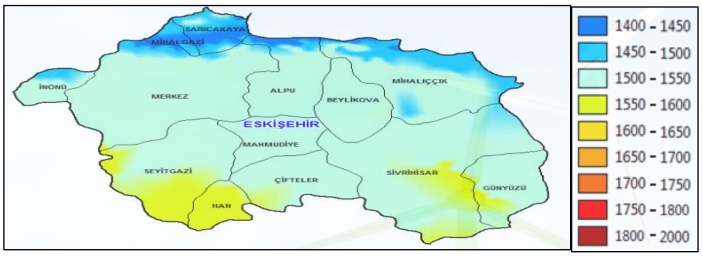


Figure 8 Global radiation values (kWh/m^2-a year) of Eskisehir

4. MEETING ENERGY NEEDS OF THE SOLUTION WITH SOLAR ENERGY

Daily energy need of the solution is approximately 8.3 kWh. Also Anadolu Airport does not have any solar system to meet its energy need. In this context, it is predicted that the solar system is installed in the roof of terminal building for meeting the need in point. The data about the current roof area, the amount of energy to be produced and the calculations obtained from ESS ENERGY which is a company working on solar energy systems are as follows:

Table 1 Calculations for solar panel

Definition	Values		Definition	Cost
Current roof area	1114 m^2		Panel	157000 €
Area to be used	873 m^2		Platform	4350 €
1 panel	9 m^2 / kW-h		Charging control unit	11000 €
For area to be used	(873 m2) / (9 m2 / kWh) = 97 kW-h		Inverter	28200 €
Average sunshine duration	[(4*4)+(5*6)+(3*10)]/12 = 6.3 h/day		Automatic control unit	6500 €
Production	97 * 6.3 = 611 kW-h / day		Cable, mounting	13000 €
			Total Coast	**220000 €**

The system to be installed has a daily production capacity of 611 kWh as can be seen from the Table 1 and its installation cost is about 220000 €.

In day 8.4 kWh electricity energy saving will be provided by applying the solution to the current illumination system. Installation cost of the solution is about 230 € and the annual saving obtained from solution is approximately 35.7 €. Considering all of aforesaid information, it follows that the system will meet its cost of installation in 6 months and after that time, 8.4 kWh electricity energy will be provide in a day

Table 2 Comparing consumption and saving belong to the current system end the solution

	Electricity Consumption (kWh/day)	**Coast of Consumption (€/day)**	**Electricity Saving (kWh/day)**	**Fiscal Saving (€/day)**
Current System	16.7	2.36 €	8.4 kWh	1.19 €
Suggested Design	8.3	1.17 €		

The roof of terminal building has daily production capacity of 611 kW and its cost of installation is about 250,000 €. Also monthly electricity consumption of the solution is about 250 kWh and the cost of the system to be installed for meeting this need is about 3400 €. Monthly cost of the current system's electricity consumption is 70.7 €. It follows from the aforesaid data that the system will meet its cost of installation in 4 years. Additionally, total daily electricity consumption of the terminal building illumination system is 360 kWh. According to these data, it is understood that the solar system can produce up to 2 times daily need so, although its cost of installation is high, it can be met by buying the more energy to the grid in a shorter time.

5. CONCLUSION

This paper clearly reveals the importance of using now technology in eco-friendly devices and alternative energy resources. Although its cost of installation is high, the investments made are of great importance for protecting the nature in the long run. Additionally this paper shows that high rate of saving can be obtained by applying the energy saving applications to the illumination systems in building sector has a high rate of energy consumption.

When compared with the studies in literature, in this paper, the system that energy saving applications have been applied and the building contains the system are completely different therefore; it is thought that this paper will lead the studies will be carried out in this field. It is predicted that the illumination standard and installation coast of solar energy system have been included will make a major contributions to the following studies.

ACKNOWLEDGEMENT

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Exergy-to-useful work analysis in Brazil from 1971 to 2009

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Abstract

This paper presents an improved methodology for useful work accounting and applies it to Brazil from 1971 to 2009. It considers heat uses and divides mechanical work uses in two categories: fixed mechanical work – which includes work done by stationary motors – and transports The energy carriers taken into account are: coal and coal products, oil and oil products, natural gas and combustible renewables. Results show that the energy transition from wood to oil occurred in Brazil in 1979 to 1985. Regarding the analysis of useful work it was concluded that Brazil favors low temperature heat processes due to its big production of combustible renewables which cannot reach high temperatures. Furthermore, the second-law efficiency from final exergy to useful work has risen very slightly because this evolution has been controlled only by technological evolution. The match between energy carrier and end-use has not been improved. An example is the Brazil's policy regarding the investment in flex vehicles that have lower second law efficiency in converting fuel into mechanical work. Future work regarding this study will include electricity and food and feed as energy carriers and light, specific electrical uses and muscle work as additional end uses.

Key words: exergy, energy, useful work, efficiency, Brazil.

JEL codes: Q40

1. Introduction

Jim O'Neill published a study, in 2001, which emphasized that developing countries would eclipse the economy of the richest countries by the year of 2050. These countries are Brazil, Russia, India and China – which usually are known by BRIC and represent more than a quarter of Earth's land area and more than 40% of the world's population (Goldman Sach, 2013).

Since Brazil is one of the countries that is predicted to be one of the most economically developed, it is crucial to carry out studies that characterize its economy and, consequently, its energy, so that its growth occurs in a sustainable way, without doing the same mistakes that currently industrialized countries have committed (Mielnik & Goldemberg, 2000).

There are many energy studies for different countries. However, most of them focus their analysis on the primary or final energy levels instead of the useful level (Serrenho et al.,2012).

Useful work is the minimum amount of work that is required to produce a given use (Ayres & Warr, 2005). This concept can provide a more accurate picture of the tendencies regarding the energy use and the consumption habits. It is an important tool that can be used to achieve a characterization of energy use in a particular country, namely Brazil, in order to make it more sustainable. Using this concept, it is possible to find out if a source is ideal (or not) to obtain a given energy use (Ayres & Warr, 2005).

In this work we did an extensive exergy accounting from 1971 to 2009 for Brazil, focusing on the final to useful transformations processes using an improved version of the methodology applied in Serrenho et al., 2012., in order to understand, energetically, one of the countries with highest prospects to grow economically and to compare it with Portugal.

To do that, it is necessary to calculate energy and exergy efficiencies, obtaining an aggregated efficiency and identifying the sectors that may be more efficient in energy (and exergy) terms.

2. Exergy, efficiency and useful work

Exergy measures potential effectiveness of energy. In other words, it is a measure of the quality of an amount of energy (Serrenho et al., 2012). It is formally defined as the maximum amount of work that a subsystem can do on its surroundings as it approaches thermodynamic equilibrium reversibly (Warr et al., 2008). Therefore a reference state must be defined and is expressed as the state of thermodynamic equilibrium which has the same temperature, pressure and chemical composition of the environment that surrounds the system (Serrenho et al., 2012). For example, the maximum work produced by a fuel is given by the chemical work obtained in his combustion (Serrenho et al., 2012; Warr et al., 2008).

Unlike energy, exergy can be destroyed and lost, during the conversion processes (Warr et al., 2008). In other words, exergy is not a conserved property and can be destroyed by irreversibilities as a consequence of the second law of Thermodynamics (Moran & Shapiro, 2004).

Just like energy, exergy has three stages of flow: the primary exergy, final exergy and useful work. These are equivalent to primary energy, final energy and useful energy respectively (Serrenho et al., 2012).

To measure the performance of a given system we usually calculate its efficiencies. There are two types of efficiencies: energy efficiency - or fist-law efficiency – and the exergy efficiency – or second-law efficiency (Ford et al., 1975; Serrenho et al., 2012).

Energy (or 1st law) efficiency measures the performance of a system and can be described by the following equation (Moran & Shapiro, 2004):

$$\eta = \frac{Desired\ energy\ transfer}{Relevant\ energy\ input} \quad (1)$$

For example, when analyzing a power cycle, this efficiency is the ratio between the work produced by the cycle and the heat input by the cycle. In this case, we get $0 < \eta < 1$. This value could never be equal to 1, i.e., not all the energy that's supplied by heat can be converted to work (Moran & Shapiro, 2004).

We can see that the 1st law efficiency can have some inconvenience (Ford et al., 1975):

(i) The maximum value depends on the system and on the temperatures of the hot and cold sources. This value can be greater (e.g. heat pumps), equal or less than 1.
(ii) It doesn't include adequately the role of the second-law of thermodynamics.
(iii) It is difficult to interpret when its generalize to systems where the output desired is a combination of work and heat.

Exergy (or 2nd law) efficiency is defined in the same manner that the energy efficiency, but instead of using the concept of energy, it uses the concept of exergy (Moran & Shapiro, 2004):

$$\varepsilon = \frac{Desired\ exergy\ transfer}{Relevant\ exergy\ input} \quad (2)$$

It measures for each process the distance from the theoretical ideal process. It presents higher values as lesser exergy is destroyed in a process (Serrenho et al., 2012). In other words, it is a measure of performance relative to the optimal performance permitted by both the first and second laws of thermodynamics (Ford et al., 1975).

The second-law efficiency can be reformulated as (Serrenho et al., 2012):

$$\varepsilon = \frac{\begin{matrix} Minimum\ amount\ of\ work \\ required\ to\ produce\ the\ desired\ energy\ transfer \end{matrix}}{\begin{matrix} Maximum\ amount\ of\ work \\ that\ could\ be\ produced\ from\ the\ relevant\ energy\ input \end{matrix}} \quad (3)$$

The numerator is the same used in the first-law efficiency. The denominator represents the theoretical maximum amount of work that could be produced with the energy input allowed by the second law of thermodynamics (Ford et al., 1975).

For example, if we want to calculate ε for a heat pump with a COP = 2 we use:

$$\varepsilon = \frac{W_{min}}{W_{max}} = Q_3 \frac{\left(\frac{T_0}{T_2} - 1\right)}{W_{in}} = \eta \left(\frac{T_0}{T_2} - 1\right) \quad (4)$$

where W_{min} is the amount of work required to extract Q_3 from a cool reservoir at T_3 following a Carnot cycle and $W_{max} = W_{in}$ because the energy input is work itself.

This efficiency has values between 0 and 1 and gives us a better idea of the quality or closeness to perfection of a given energy use (Moran & Shapiro, 2004; Serrenho et al., 2012). It could also be applied to a simple output device or to a multiple output complex system. For example, in a process involving heat and work, maximizing the efficiency is equivalent to minimizing fuel consumption (Ford et al., 1975).

3. Methodology

In this work, we used the same methodology applied in Serrenho et al., 2012. We did an extensive exergy accounting from 1971 to 2009 for Brazil, focusing on the final to useful transformations processes. Electricity and food for humans and feed for working animals will be taken into account in future work.

We used a three-step methodology for useful work accounting using energy data:

(A) Conversion of final energy to exergy. This conversion can be quite complex because it may depend on many variables. We used the method of exergy factors for different energy carriers, which are defined as the ratio of exergy over energy (Chen & Chen, 2009; Serrenho et al., 2012). Table 1 shows the exergy factors for each group of energy carriers.

Table 1- Exergy factors for energy carriers. Sources: Serrenho et al., 2012; Chen and Chen, 2006.

Coal and coal products	1.06
Oil and oil products	1.06
Natural gas	1.04
Combustible renewables	1.11

Final energy consumption data for each of these energy carriers were obtained from the IEA energy balances database.

(B) Allocation of each final exergy consumption to the respective useful work categories and **(C)** and the determination of useful work values. This is achieved by multiplying final exergy data by the 2nd law efficiency. The useful work categories are:

Table 2 - Second-law efficiencies by energy carrier and useful work. Source: Serrenho et al., 2012; Ford et al, 1975

Useful work \ Energy carrier	Natural gas	Coal and coal products	Oil and oil products	Combustible renewables
Mechanical Work	$\varepsilon = \frac{W_{out}}{\Delta H} \approx \eta$ (5)			
Transports	$\varepsilon_{gasoline} \approx \eta_{theoretical\ maximum} \prod_{i=1}^{6} \alpha_i$ (6) $\varepsilon_{diesel} \approx 1.25 * \varepsilon_{gasoline}$ (7)			$\varepsilon_{cr} \approx 0.8 * \varepsilon_{gasoline}$ (8)
Heat	$\varepsilon = \frac{Q_2}{B}\left(1 - \frac{T_0}{T_2}\right) \approx \eta\left(1 - \frac{T_0}{T_2}\right)$ (9)			

(i) <u>Mechanical work</u>: takes into account the final work of all kinds of mechanical work with the exception of transports, giving a special relevance to the stationary engines. The exergy efficiency is given by equation 5 of Table 2.

For this category we considered that the efficiency was equal to the efficiency of the boat engines (since we do not consider electricity), because these are also internal combustion engines but have a constant regime, i.e., they are less "polyvalent" that the motor vehicles which have several regimes (boot, acceleration, etc.) and therefore less efficient. If the fixed engine operates with gasoline, we considered a decrease in efficiency of 25% (Heywood, 1988).

(ii) <u>Transports</u>: includes all forms of transport using vehicles as diesel, gasoline, trains, planes and boats. The goal is to put something in motion so the useful work is the product of the force by displacement. The second-law efficiency is given by the equation 6 in Table 2 (those who perform Otto cycles), where $0 \leq \alpha_i \leq 1$, ∀I means the bias from real to ideal use settings an $\eta_{theoretical\ maximum}$ depends on the compression ratio and the specific heat ratio (Cp = $\frac{Cp}{Cv} \approx 1.4$):

$$\eta_{theoretical\ maximum} = 1 - \left(\frac{1}{\gamma}\right)^{\gamma - 1} \quad (10)$$

For diesel vehicles (eq. 7), we considered an increase of 25% in efficiency compared to the efficiency of the gasoline vehicles (Ford et al., 1975; Heywood, 1988). Regarding to vehicles moved only by ethanol, we adopted an efficiency of 80% of a gasoline engine, as we can see in equation 8 (Bastin et al., 2010).

(iii) <u>Heat</u>: includes all end uses where heat is needed in any process or device. The second-law efficiency is calculated by equation 9 of Table 2. T_0 is the environment temperature, T_2 is the temperature at which heat transfer occurs to provide heat Q_2 to a system, B is the final exergy and η is the first-law efficiency.

Environmental temperature data were obtained from INMET from 1971 to 2009. The first-law efficiency was calculated based in Schaeffer & Wirthshafter, 1992 and Chile's energy intensity for steel industry (IEEJ) data (APERC, 2000) – since this industry is one of the most important in Brazil and Chile is geographically next to it.

In table 3 we can see the assumed temperature at which heat occurs. We decided to split this category, since this efficiency is very sensitive to temperature, in the following sub-categories: high temperature heat – used in glass, steel and iron industries; medium temperature heat – widely used in various industrial processes, namely chemical and petrochemical; low temperature heat– includes water and space heating. We divided the sub-category of low temperature heat in three (Table 3) because the efficiency is more sensitive to temperature at low temperatures.

Table 3 - Temperatures adopted for all the heat sub-categories considered. Source: Serrenho et al., 2012; Ayres, Warr, 2010

Category		T_2 (ºC)
High temperature heat		500
Medium temperature heat		150
Low temperature heat	1	120
	2	90
	3	50

The second-law efficiency of this category depends mostly on temperature since that energy efficiency badly affects this value when compared with temperature T_2.

4. Results and discussion

Brazil has a very unique energy system. In figure 1 and 2 we can visualize the structure of primary energy production and consumption by source respectively. All the data were obtained on IEA.

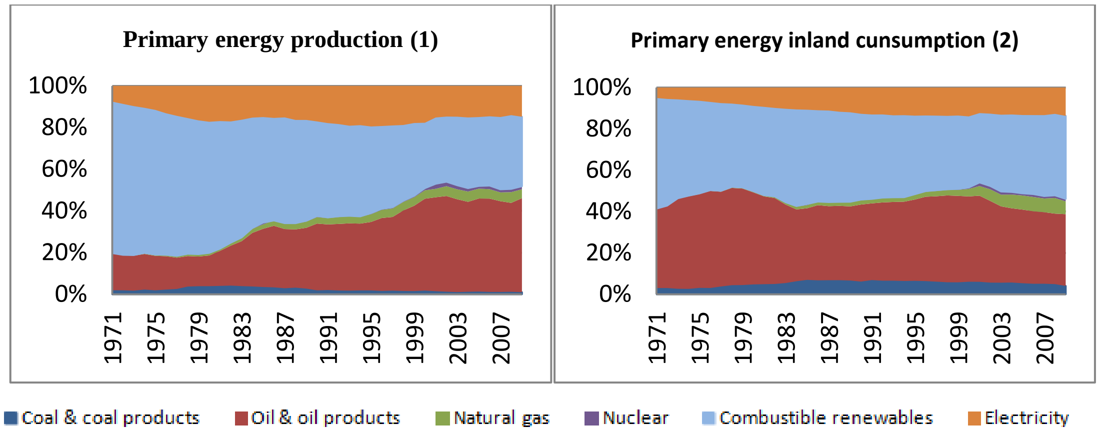

Figure 1 and 2 - Primary energy production and primary inland consumption in Brazil from 1971 to 2009

We can see some differences between primary energy consumption and production. Analyzing both figures, we notice that the two main primary energy sources in Brazil are oil and oil products and combustibles renewables.

The relative importance of combustible renewables has been decreasing relative to the other products, especially when compared with oil. This transition from wood to oil can be classified as an energy transition and took place between 1979 and 1985.

In the 70's, the production of oil was very limited. Afterwards, we can see a large increase of relative production and actually, Brazil considers itself "oil independent", i.e., it produces sufficient oil to achieve the proposed consumption requirements, thanks to offshore extraction.

We can see that coal has little relevance regarding energy production and consumption. This is due to the poor quality of coal in the country (high content of ashes). We notice a slight increase in 1973 (first oil crisis), achieving the maximum value in the ends of the 70's (second oil crisis). Coal is mostly used in the iron and steel industry.

Since 1979 we noticed a constant increase in production and a generalized consumption of natural gas resultant of energy policies that privileged this resource, not only on the production point of view but also on the consumption with natural gas imported from Bolivia (E & E, 2003).

Despite having some nuclear power plants, this resource is, still, not very well accepted by Brazilians. Hydroelectric power is the main source electricity production. We can see that the production of electricity has increased from 1971 to 1980 and tends to stabilize afterwards. Unlike the production, primary electricity consumption has always been growing in relative terms, making Brazil dependent on importation to satisfy its power needs (EPE, 2010).

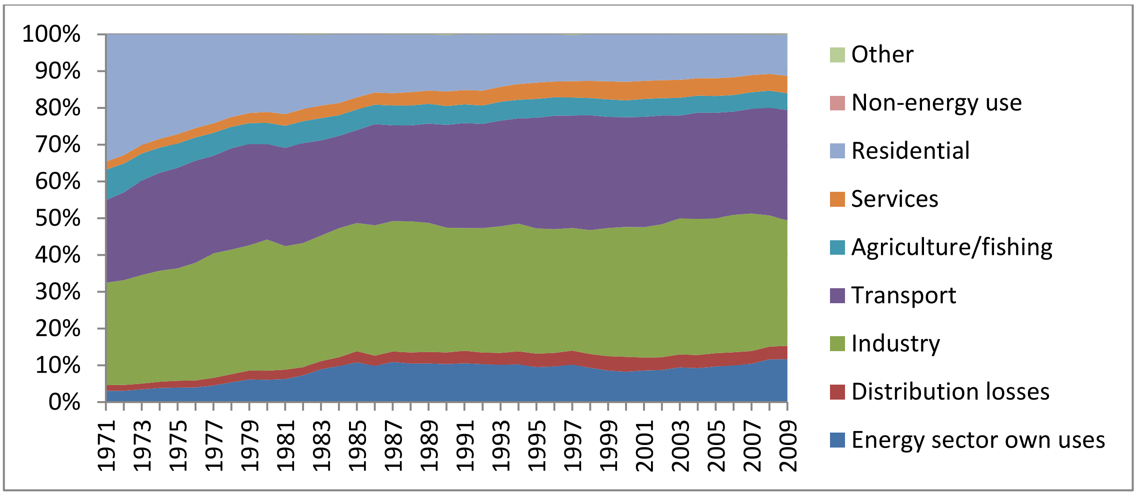

Figure 3 - Structure of final energy consumption by sector in Brazil from 1971 to 2009

In figure 3 we can observe final's energy consumption by sector in Brazil. Industrial and transport are the sectors that consume more final energy. These two have been growing constantly. In fact, only the residential sector and the agriculture sector (not so relevant) have been declining constantly in relative terms. The fact that the residential has been decreasing is due to the fact that in these years, Brazil is substituting wood, for electricity or natural gas for the same power purpose - cooking, space/water heating (E & E, 2003). These fuels have a higher energetic efficiency which allow for promote a lower amount of final energy consumption.

In energy sector own uses we can see a small rise between 1981 and 1987. This is due to the shift from oil to combustible renewable (meanly wood) for producing energy – because of the 2nd oil crisis in 1979. Since wood has a lower energy efficiency value we need to consume more to produce the same amount of energy.

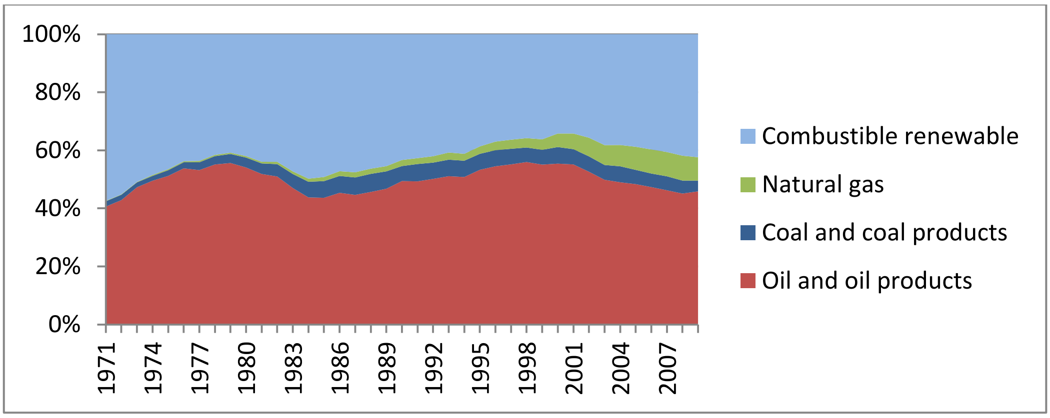

Figure 4 - Structure of final exergy consumption by source in Brazil from 1971 to 2009

Figure 4 demonstrate the structure of final exergy consumption (note that electricity is not included because these are preliminary results). We can see that it follows the same tendency of primary energy, i.e., in the 70's there was a higher consumption of combustible renewables than oil – due to both oil crisis – after that, oil was always the main resource. However, around 2003, there was an increase of combustible renewable consumption. This was due to the utilization of flex vehicles – vehicles with engines that moves with gasoline or ethanol.

The following figures represent final exergy (5) and useful work (6) consumption.

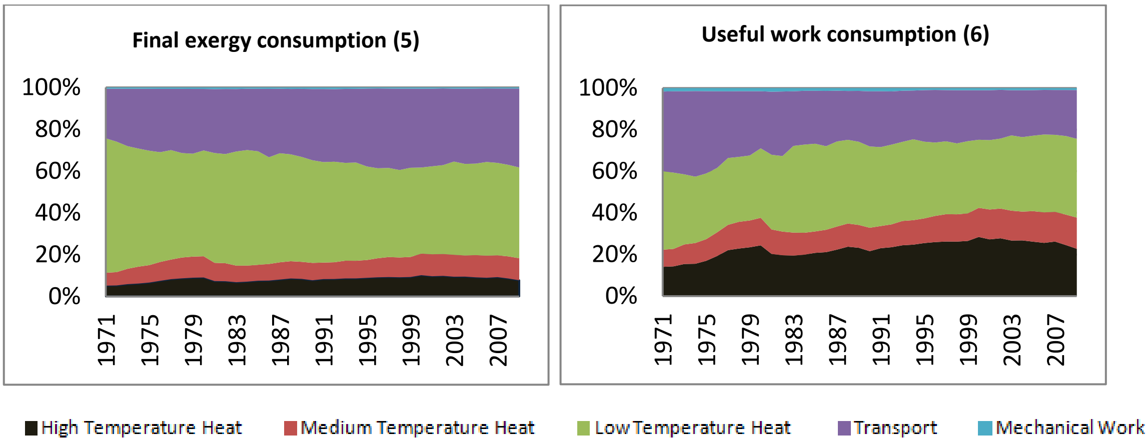

Figure 5 and 6 - Structure of final eergy and useful work in Brazil from 1971 to 2009

For the energy carriers defined in the methodology, we can observe that low temperature heat is the most common use in Brazil, in the point of view of final exergy and useful work. In the beginning of the 70's, low temperature heat was the category that consumed more useful work but it was not the category that contributed more to useful work. The reason for that is that at the time, the processes of low temperature heat were mostly of low temperature heat 3 (T_2 = 50 ºC), where second-law efficiencies are substantially lower once those depend largely on temperature, the higher the temperature is, the greater is the efficiency. Later, this low temperature heat became mainly low temperature heat 1 and 2. That is why the consumption of useful work regarding low temperature heat has been constantly increasing. For the same reason, high temperature heat is more relevant in useful work terms than in final exergy terms, due to its higher exergy efficiency (Ford et al., 1975; Serrenho et al., 2012).

In the same figures, we notice a bigger difference between final exergy and useful work in the category of transports since 2003/2004. The reason was the implementation of flex vehicles. These have a lower first and second law efficiencies compared with gasoline or ethanol engines. Despite this fact well known by the scientific community (Bastin et al., 2010), Brazil prefers decreasing oil consumption rather than using more efficient gasoline engines to fulfill the Kyoto protocol.

In figure 7 we can see the aggregated conversion of final to useful exergy in Brazil between 1970 and 2009. The efficiency value has been growing among the years. However it has grown very little (less than 10%), because Brazil maintained its energy setup, privileging low temperature heat and transport instead of high and medium temperature heat uses – which have higher efficiencies. Brazil also privileged the same energy carrier, mostly oil products and combustible renewables. We conclude that the aggregated efficiency is rising mainly as a result of technological changes and that is the reason for its limited growth.

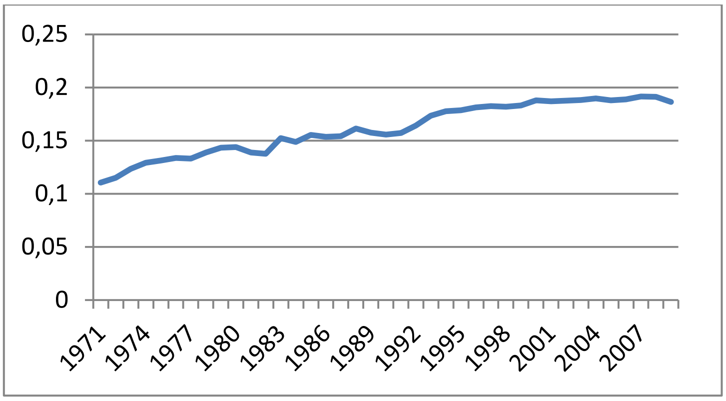

Figure 7 - Aggregated second-law efficiency in Brazil from 1971 to 2009

5. Conclusions and future work

Brazil has a very unique energy system where combustible renewables have great relevance but still, as in most countries, oil is the main energy source with highest consumption.

The results obtained express the exergy tendency use of Brazil from 1971 to 2009. Low temperature heat is the preferential use due to the fact that Brazil have many combustible renewable, which cannot be used in process with high temperature where they are limited by their heating value. The other and main reason is the Brazilian use patterns that favors low temperature heat processes because despite the industrial sector were, most of the years, the single largest final exergy consumption, the sum of residential, agriculture and services sectors – which have mainly low temperature heat uses – were always very big consumers of final exergy.

In future work, we will compare Brazil with Portugal regarding energetic behavior. These two countries are completely different regarding size, resources, population, wealth and economic perspectives – but there are historical connections and specific knowledge regarding Portugal that make this comparison very interesting and possibly very fruitful. For that, electricity and food for humans and feed for working animals will be taken into account. Also, the following categories of work will be added: light, muscle work and other electrical uses.

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Measuring the Impact of Renewable Energy Sources on the Optimal Generation Mix: An Application to the Iberian Electricity Market

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Abstract

In the last few decades, electricity markets have undergone extensive reforms. A process of liberalizing the electricity markets has been implemented by several countries, reducing the incumbents' market power. Thus, generation and retail are open to competition, and transmission and distribution remain regulated. Furthermore, the need to comply with the targets set by the Kyoto Protocol has disseminated the renewable energy sources, such as wind power. Therefore, it is important to study what the impact of a renewable source like wind power will be on the optimal generation capacity mix, assuming producers can invest in other technologies and the wholesale market is open to competition. In this article, we assume two alternative generation technologies – wind and combined cycle gas turbines – as a simplifying assumption. We develop a two-stage model for the Iberian Electricity Market, where the choice of the capacity construction occurs in the first-stage, before electricity demand is known, and the optimal outputs and daily equilibrium prices are obtained in the second-stage, under the assumption that electricity demand does not exceed the installed capacity. Through the application of the model, it can be concluded that generators can be expected to increase their renewable generation capacity (wind power).

Keywords: Electricity Markets; Optimal Capacity Mix; Wind Power; Conventional Power.

JEL codes: D21; L94

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1. Introduction

Since its invention, electricity has become an indispensable good for each home and an essential input for industry in almost every economy. For many years, vertically integrated and state-owned monopolies were responsible for providing electricity to everyone.

However, this scenario has changed drastically in the last two decades. The formation of a less-regulated and more competitive electricity market is currently taking place in many countries. In the European Union, the first great step to a reorganization process of the electricity market began in 1996, with the Directive 96/92/EC, and since then several additional measures have been taken in order to achieve an Internal Electricity Market. To achieve this goal, the member states have reinforced their interconnections through the creation of regional markets. As a result, Portugal and Spain decided to create an Iberian Electricity Market (MIBEL[1]).

Following the steps of the UK and the Scandinavian countries in the reorganization process of their electricity markets, MIBEL provided a vertical unbundling of generation, transmission, distribution and retail supply. As a consequence, wholesale generation and retail were opened to competition, and the (incentive) regulation of transmission and distribution networks was established. The Iberian wholesale spot market was created, where the rules of a liberalized market prevailed. This is the market on which the present article focuses.

Having this in mind, we can argue that MIBEL is based on principles of a single price for the whole peninsula, free competition, transparency, equal access among stakeholders, and economic efficiency to consumer's benefit in both countries (Cruz, 2008; Domínguez and Bernat, 2007).

Several technologies can be employed to produce electricity. Nevertheless, the growing concerns of global warming and the scarcity of fossil resources have led to an increase of State measures to promote renewable energy sources. For example, the European Union has set the goal of satisfying 20% of electrical demand with renewable energy by 2020 (Europa, 2009); and for Portugal and Spain, the targets are 31% and 20%, respectively (Parlamento Europeu and Conselho Europeu, 2009).

In this, wind power has played a key role. According to GWEC (2012), "*the global wind power market grew by about 6% compared to 2010, and the 40.5 GW of new wind power brought on line in 2011 represents investments of more than €50 billion (about $68 billion)*". In Europe, new installed capacity of wind power reached 10,281 MW in 2011. Currently, the whole installed capacity of wind power in Europe is 96.6 GW. Even in Portugal and Spain, the wind power has had a significant growth. During 2006-2011 the installed capacity of wind power increased 169% in Portugal (from 1,517 MW to 4,081 MW) and 74% in Spain (from 11,521 MW to 20,733 MW). This growth allowed an important contribution of wind to power generation, reaching 18.6% for Portugal and 16.3% for Spain, in 2011 (REN, 2012a; REE, 2012). Concluding, we can sustain that the technology used to produce wind power is mature, competitive, and it is well spread in the global market.

[1] MIBEL is the Portuguese/Spanish acronym for the Iberian Electricity Market.

Since the electricity market has been subject to extensive reforms and wind power has experienced impressive growth, the following research question arises: what is the effect of well-developed renewable energy sources, like wind power, on the generation capacity mix of a competitive market, such as the Iberian wholesale electricity market?

Actually, this is a crucial question since both Portugal and Spain have already approved the reduction of subsidies to the generators of wind power. Therefore, the purpose of this study is to provide the necessary tools to understand the relationship between renewable energy sources and the optimal generation capacity mix in a liberalized, competitive market. Furthermore, since the literature on this specific topic is scarce, this article has as its secondary objective to contribute to filling this gap.

The methodology used was the following: after a literature survey focused on the impact of wind power on the generation capacity mix, we follow the article developed by Milstein and Tishler (2009) because, it allows for a better understanding of the market reality. To explore the connection between renewable energy sources and optimal generation capacity mix in a competitive wholesale electricity market, this article applies and solves the model developed by the aforementioned authors to the Iberian Electricity Market. To that end, we present a two-stage game of endogenous investments and operations in a competitive electricity market with wind and combined cycle gas turbine (CCGT)[2] technologies under demand and supply uncertainties. In the first-stage of the game, each generator decides on its capacity investment in order to maximize their expected profits. In the second-stage of the game, the generator selects its daily electricity production subject to its capacity availability, and the equilibrium prices are determined. The game is developed under a Cournot framework, and it is solved using *MATLAB* software.

The article proceeds as follows. Chapter 2 makes a literature survey about the research question. Chapter 3 presents the model. Chapter 4 applies the model to the Iberian Electricity Market and presents the main results. The last chapter concludes.

The main conclusion is that, in a competitive electricity market, when the generators can build both technologies, investment in wind power capacity is the optimal choice for the generators. This conclusion can eventually be developed for other renewable energy sources.

2. A Literature Review

The literature on the impact of renewable energy sources on the generation capacity mix is scarce. Indeed, the literature on wind power says little about how this power source may affect the generation capacity mix. Thus, as the main objectives of this article are to fill this shortcoming and answer to the research question, the literature survey will only focus on the main articles that address this specific issue.

[2] It should be noted that, the contribution of CCGT has become increasingly important in the electricity production. Indeed, in 2011, the installed capacity of CCGT accounted 20.3% of the total installed capacity and 21.3% of the total power generation (REN, 2012a; REE, 2012).

Some recent studies have started to approach this topic, as there are serious concerns either on the way electricity power planning will change and how the management of the electricity system will be changed.

The research question has been approached in two ways: some studies use the idea of the credit concept and others use the screening curve methodology. However, there is a set of studies that use other methods to address the same question. The different ways to address the problem will be explained below.

The Capacity Credit Concept

Wind power is an intermittent energy, where its output can vary drastically from day to day and along the 24 hours of a single day. Thus, to ensure the security of supply, total substitution of conventional power plants by wind turbines is improbable (Weigt, 2009a). Nevertheless, it is possible to achieve a safe reduction in the installed capacity of conventional power with a sufficient increase in the installed capacity of wind power. This gain in capacity reduction is usually called capacity credit.

Some of the main authors to look into this matter were Strbac et al. (2007). The authors developed a study which explores the costs and benefits of integrating wind power into the UK electricity market. The analysis concludes that wind generation only replaces a relatively small amount of conventional capacity. Thus, it is necessary to preserve a significant proportion of conventional capacity to ensure the security of supply.

Another important study was developed by Oswald et al. (2008). The study developed a model that analyzed the dynamic behavior, the volatility and the implications of 25 GW of wind on the UK power system. The authors concluded that, given that wind power is a volatile power source, the electrical system will need to maintain the fossil fuel plants to handle peak demand. Therefore, the ability of wind power capacity to replace fossil power capacity may be compromised, namely in peak demand situations.

Finally, Weigt (2009a) sought to analyze the reserve capacity and the impact of wind power on generation costs and market price in Germany. Regarding capacity replacement potential, and in accordance with the conclusions of all the referenced studies, the author concluded that an increase in the installed capacity of wind power does not allow for a significant reduction of the installed capacity of conventional power.

The Screening Curve Methodology

Besides the aforementioned method, the screening curve methodology can be used to study the impact of wind power on the generation capacity mix. This method is designed to determine the optimal baseload, intermediate and peaking capacities, and the system costs. According to Lamont (2008), an optimization problem is used to minimize the total generation cost and, simultaneously, to satisfy the loads in each hour. Thus, a load-duration curve is created showing the cumulative probability distribution over system loads during a year.

Nevertheless, the main problem is to discover the optimal capacity of the intermittent technologies, since determining the optimal capacities of the other technologies is relatively simple. For that, the capacity of the intermittent technologies should be considered as a negative load, i.e., subtract "the generation of a given intermittent capacity from the load in each hour to obtain a residual load for each hour" (Lamont, 2008, pp. 1210). Hence, the screening curve methodology can be applied through the construction of the load-duration curve for the residual load. After that, the non-intermittent optimal capacity that matches the residual load will be determined. However, this analysis does not determine directly the intermittent optimal capacity.

This method has been implemented by some authors. Lamont (2008) used a long-term model of theoretical equations, based on the screening curve methodology, to obtain the marginal costs of an intermittent technology as a function of its capacity factor. This method was used to show how the optimal capacity of non-intermitent technologies changes when the intermittent technologies are added to the California electricity system. The author finds that, in the long-term, the introduction of intermittent technologies will reduce the non-intermittent component of baseload capacity.

Sáenz de Miera et al. (2008) applied a simulation analysis to study the impact of the introduction of wind energy on wholesale market prices in Spain. They use the previous method to determine the optimal capacities for each considered technology. The authors state that, there is a reduction of residual thermal demand when wind power is introduced, due to a shift down and to the left of the electricity demand curve. In turn, this alteration reduces the need for thermal power plants, because the baseload technologies operate longer than mid and peaking load technologies.

Green and Vasilakos (2011), used the concept of screening curves to make a market equilibrium model to analyse the changes of an introduction of large amounts of intermittent generation in the capacity mix. Regarding wind's impact on generation capacity, the authors find that the changes in the capacity mix are much greater than the changes in the electricity prices.

Recently, De Jonghe et al. (2011), concluded that the baseload capacities are replaced by mid-load capacities when there is a high penetration of wind power in the electrical system. To achieve this conclusion, a linear programming investment planning model based on screening curve method was developed.

Other Studies

Nevertheless, there are studies that do not use the concepts of capacity credit and the screening curve. Notwithstanding, they arrive at similar conclusions. One such study was undertaken by Rosen et al. (2007). The authors developed long and short-term models to estimate the effects of wind power in Germany, and they showed that the introduction of wind replaced conventional, mainly in baseload and mid-load production.

Bushnell (2010) used an equilibrium model of generating investment to study how the introduction of intermittent generation, such as wind power, would change investment in conventional thermal generation. He concluded that, in equilibrium, the amount of coal-fired baseload production decreases when wind is introduced in the generation capacity mix.

Lastly, Chao (2011) developed a simulation study to assessment renewable energy strategy and alternative pricing mechanisms through an updated economic model of pricing and investment in a restructured electricity market. He concluded that "the wind generation capacity generally substitutes the investment in combined cycle GT capacity but complements the investment in gas turbine units" (Chao, 2011, pp. 3951).

From this collection of papers we can draw the broad conclusion that, one way or another, whether to a greater or lesser extent, the introduction of renewable energies replaces conventional technologies. Nevertheless, all the studies are very static in their approach. Indeed, they do not take into consideration the dynamics of the generators' investment decision process. The generators face two decision moments: one when they decide which technology should they choose and what will be its capacity; and another when they face the uncertainty in demand. These two decision moments can influence the adoption level of intermittent and conventional technologies.

To address this shortcoming, Milstein and Tishler (2009) developed a dynamic two-stage game for the Israeli electricity market. In the first-stage, the generators built the generation capacity that maximized their expected profit; and in the second-stage the output is determined, where the market equilibrium ensures that market demand does not exceed the installed capacity. This model has as its main goal to assess the effect of the introduction of different generation technologies on the generation capacity mix and market prices. It should be noted that, this article is an extension of the article published by Tishler et al. (2008), where the authors only used one generation technology; and it is the predecessor of the work developed by Milstein and Tishler (2011), which combined the methodologies used in the previous articles, and more than one generation technology was introduced. Generally, Milstein and Tishler (2009) and Milstein and Tishler (2011) concluded that the introduction of generation technologies with lower marginal costs on the generation capacity mix will decrease the investment in generation technologies with higher marginal costs. This result is valid when the number of firms, which act in the market, increases, and when the capacity costs of generation technology with lower marginal costs decrease.

It should be noted that, the study developed by Milstein and Tishler (2011) is more appropriate to address the research question, because the authors include in their study the intermittency of the renewable energy sources. However, the complexity of the model, the lack of information and resources, forced the choice of a simpler model. Thus, the article developed by Milstein and Tishler (2009) will serve as the basis for the formulation of the model that will address our research question.

Bearing in mind the different methodologies applied to understand the impact of renewable energy sources on the generation capacity mix, the next chapter will describe the model used in this article.

3. The Model

In our model, we assume that only two types of generating technologies are available in the market: wind power, to be denoted W, and combined cycle gas turbine (CCGT), to be denoted C. All electricity demand is satisfied by both technologies. The oligopoly market is deregulated and comprises N identical firms that employ both technologies. Each firm will build generating capacity, which is then used to generate and sell electricity for a horizon of T days. This horizon will be 365 days (one year). The firms purchase all the electricity needed to satisfy the daily demand, in the MIBEL spot market. It should be noted that, the spot market only encompasses the day-ahead market, because the share of intraday market in the total transactions of the spot market is small. Therefore, it may be disregarded. For the sake of simplification, the electricity merit order and the intermittency of wind power will not be considered.

According to Ventosa et al. (2005), cited by Weigt (2009b), three types of models can be used to study the electricity markets: optimization, equilibrium, and simulation. Optimization models aim to maximize or to minimize a specific objective: a single firm's profit, subject to technical or economic constraints; besides, they allow the study of the whole market through welfare maximization or cost-minimizing approaches. The main advantage of these models is their capacity to use large-scale basis under several restrictions. Notwithstanding, the model's capacity is compromised, because pursuing a single objective makes the exploration of all market behavior difficult to achieve (Weigt, 2009b). Equilibrium models allow us to study market situations where there are several players in imperfect market setting. This way, the different players' strategic behaviors can range from the classic models of Bertrand and Cournot competition to sophisticated mathematical models like Supply Function Equilibrium (SFE) model. In these models, if there is a solution, it satisfies the Nash equilibrium condition. Therefore, the market participants will not change their decision, because they are playing their best strategy. Through this model, we can address several market players' profit maximization simultaneously. Finally, we can have Simulation models. These models are usually applied if the problem becomes too complex to use the equilibrium models. Normally, the type of models commonly used is the agent-based model, because it can bridge the fact that market participants base their decisions on historic information. Equilibrium models cannot do that (Weigt, 2009b).

However, several authors have employed the Cournot model to study the electricity market (e.g., Borenstein and Bushnell, 1998; Green, 2004; Murphy and Smeers, 2005; Newbery, 1998; Wolfram, 1999). Indeed, according to Borenstein and Bushnell (1998) the Cournot model seems to correspond to electricity markets much more closer than other models, such as the Bertrand model. The authors affirm that "*The Bertrand equilibrium is supported by the assumption that any firm can capture the entire market by pricing below others and can expand output to meet such demand. Since firms have increasing marginal costs of producing* *electricity at a point in time and since generation capacities present significant constraints in electricity markets, an assumption of Bertrand behavior is not tenable. Capacity constraints on generation are significant in both the medium-term – based upon investments in construction of new capacity – and the short-term, in which plants are rendered "unavailable" due to maintenance and other reliability considerations*" (Borenstein and Bushnell, 1998, pp. 5).

In the same way, Green (2004) argue that the incumbents' market power is justified by the fact that, even in a liberalized market, they frequently hold a high proportion of capacity, the imports are usually restricted by the limits on the transmission lines, the demand is inelastic, and the electricity cannot be stored. The terms "*Economic withholding*" and "*Physical withholding*" are usually used to describe how the generators can exploit their market power. The first term tell us that a power plant will only offer its output when the market price reaches a level which covers, at least, its costs. On the other hand, the second term means that the plant's output is not made available to the market at any price. These strategies would raise the price received by the other power plants that are not withheld from the market and, consequently, they would increase the incumbents' profits. The behavior developed by the incumbents is usually studied, in economics, through the Cournot model, where the firm decides how much output to sell in each time period, and the prices are set by the intersection of the demand curve with this quantity.

Furthermore, Green (2004) states that the Cournot model seems empirically inappropriate to study the electricity markets organized according to the Uniform Price Auction (UPA)3, such as MIBEL. However, the model could be used for to address this case, because the generators are not required to offer all of their capacity to the market in each period.

With this in mind, the Cournot model will be adopted as oligopoly equilibrium model and all producers will make their choices based on its conjecture.

3.1. The two-stage model

Following the methodology used in Milstein and Tishler (2009), the daily electricity demand is given for a typical Cournot demand function:

$$P_t = a - bQ_t + \varepsilon_t \tag{3.1}$$

And, the electricity price and output on day t are represented by P_t and Q_t, respectively, where Q_t is given by:

$$Q_t = \sum_{i=1}^{N} (Q_{it}^{W} + Q_{it}^{C}) \tag{3.2}$$

[3] In an UPA market the selling bids are ordered by increasing prices and the demand bids are ordered by decreasing prices. This ordering results in two aggregated curves for the supply and demand of energy. Thus, the market clearing price is achieved by the intersection of these curves. In other words, the last accepted selling bid (the bid that defines the system marginal price) will pay all the selling bids (or all the demand bids) at lower prices (Nogueira *et al.*, 2003).

Parameters Q_{it}^{W} and Q_{it}^{C} give us the production on day t of the *i*-th firm that uses technology W and C, respectively. Regarding parameters a and b, they are positive known constants ($a > 0, b > 0$), and the parameter ε_t is a random variable that contains all those which are not explicit in the model but that may affect prices, like weather for example. This way, we can define ε_t as a random variable that measures the effect of presence or absence of wind under the daily electricity demand. These conditions are revealed to producers on day t. On the other hand, this random variable is associated to $f(\varepsilon_t)$ - the probability density function of ε_t – which is known by the firms when they choose their capacity. It is also assumed that the availability of wind and ε_t are independent, reflecting the assumption that demand is driven by temperature, much less so by daily wind conditions, i.e., the demand for electricity only depends on the variation of temperature. Finally, it is also assumed that $E\ (\varepsilon_t) = 0$ and $Var\ (\varepsilon_t) = \sigma^2$.

Regarding the total production costs, the annual production cost of *i*-th firm employing wind or CCGT technology (using a generator K_i^W or K_i^C MW of capacity) can be defined as:

$$C_i(K_i^W, Q_i^W) = \theta^W K_i^W + c^W Q_i^W \tag{3.3}$$

$$C_i(K_i^C, Q_i^C) = \theta^C K_i^C + c^C Q_i^C \tag{3.4}$$

Note that, Q_i^W and Q_i^C give us the annual wind and CCGT production by firm *i*, respectively, and its formula is:

$$Q_i^W = \sum_{t=1}^{T} Q_{it}^W \tag{3.5}$$

$$Q_i^C = \sum_{t=1}^{T} Q_{it}^C \tag{3.6}$$

Finally, the terms θ^W (θ^C) and c^W (c^C) denote the capacity cost in €/MW-year and the marginal cost in €/MWh for technology W (technology C). As the wind technology exhibit high capacity costs and zero marginal costs and the CCGT technology have low capacity costs and high marginal costs, it will be assumed that $c^C \gg c^W \cong 0$, and $\theta^C < \theta^W$. The parameters c^C, c^W, θ^C and θ^W are known constants and $c^W < a + \varepsilon_t$[4].

[4] This assumption is commonly assumed when it sets the Cournot model. For more information see Gibbons (1992).

The decision process of the market players is made in a two-stage game, as follows:

- **Stage 1:** each of the *N* firms decides on its investment in capacity (K_i^W and K_i^C), so as to maximize its expected profits over T days. The capacities of the other *N-1* firms, the probability function of ε_t, and wind conditions are taken as given.
- **Stage 2:** as the firms have information about the parameter ε_t and wind conditions on day *t*, each firm will decide how much quantity of electricity will be produced, so that its daily operating profit can be maximized. As the firms' decision is based on the Cournot conjecture, the quantity produced by the other *N-1* firms and the capacity of all *N* firms are taken as given. This stage is repeated *T* independent times.

It should be noted that, the capacity chosen in the first-stage of the game cannot be changed in the second-stage. This assumption brings model closer to market reality, since several years are required to build new power plants.

To solve this two-stage game and find the subgame-perfect Nash equilibrium[5], the backward induction is used. This way, the second-stage of the game is solved in the first place, and then, the obtained solutions (the reaction functions[6]) are used to solve the first-stage of the game.

In our case, the daily electricity production of each firm is obtained by solving the operating profit maximization problem of the *i*-th firm in stage 2, conditional on ε_t, and it is given by:

$$\begin{aligned} \max_{Q_{it}^C, Q_{it}^W} \pi_{it} &= (P_t - c^C)Q_{it}^C + (P_t - c^W)Q_{it}^W \\ s.t.\ & Q_{it}^C \leq K_i^C, Q_{it}^W \leq K_i^W \\ & Q_{it}^C \geq 0,\ Q_{it}^W \geq 0 \\ & i = 1,\dots,N \end{aligned} \tag{3.7}$$

When the solutions of the second-stage are found, the optimal capacities can be determined; the *i*-th firm uses the second-stage reaction functions to solve the profit maximization problem of the first-stage, given by:

$$\max_{K_i^C, K_i^W} E\left[\sum_{t=1}^{T}(\pi_{it}|K_i^C, K_i^W)\right] - \theta^C K_i^C - \theta^W K_i^W, \qquad i = 1, \dots, N \tag{3.8}$$

3.2. The Theoretical Formulation of Optimal Solutions

As mentioned above, to solve this two-stage game the backward induction method is needed.

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[5] According to Gibbons (1992), the Nash equilibrium assumes that each player plays his best response, given the conjecture that it has about the other players' strategies. However, when we have a dynamic game with imperfect competition, we must define the concept of subgame-perfect Nash equilibrium. Thus, Selten (1965) says that *"a Nash equilibrium is subgame-perfect if the players' strategies constitute a Nash equilibrium in every subgame"* (Gibbons, 1992, pp. 124), i.e., if each player plays his best response in every subgame.

[6] The reaction function gives us the best strategy for each firm *i*, given the conjecture that the firm was formed on the rivals' strategies.

Beginning with the second-stage maximization problem, described by equation (3.7), the optimal solutions are shown in Milstein and Tishler (2009).

These authors solve the maximization problem using Karush-Kuhn-Tucker (KKT) formulation, because the maximization problem involves inequality constraints and a set of nonnegativity constraints. When this happens, the KKT conditions are usually used to solve the problem (Simon and Blume, 1994).

To do so, the Lagrangian must be defined:

$$L\left(Q_{it}^{C}, Q_{it}^{W}, \lambda_1, \lambda_2, \lambda_3, \lambda_4\right) = (P_t - c^C)Q_{it}^{C} + (P_t - c^W)Q_{it}^{W} - \lambda_1\left(K_i^C - Q_{it}^{C}\right) - \lambda_2\left(K_i^W - Q_{it}^{W}\right) + \lambda_3 Q_{it}^{C} + \lambda_4 Q_{it}^{W}, \qquad i = 1, \dots, N \tag{3.9}$$

Once the Lagrangian is written, the KKT conditions are given by:

$$\begin{array}{llll}
\multicolumn{4}{l}{\frac{\partial L}{\partial Q_{it}^{C}} = 0 \Leftrightarrow P_t - c^C - \lambda_1 + \lambda_3 = 0 \Leftrightarrow a - b(N+1)Q_{it}^{C} - b(N+1)Q_{it}^{W} + \varepsilon_t - c^C - \lambda_1 + \lambda_3 = 0} \\
\multicolumn{4}{l}{\frac{\partial L}{\partial Q_{it}^{W}} = 0 \Leftrightarrow P_t - c^W - \lambda_2 + \lambda_4 = 0 \Leftrightarrow a - b(N+1)Q_{it}^{C} - b(N+1)Q_{it}^{W} + \varepsilon_t - c^W - \lambda_2 + \lambda_4 = 0} \\
\lambda_1\left(K_i^C - Q_{it}^{C}\right) = 0 & \lambda_1 \geq 0 & K_i^C - Q_{it}^{C} \geq 0 & \\
\lambda_2\left(K_i^W - Q_{it}^{W}\right) = 0 & \lambda_2 \geq 0 & K_i^W - Q_{it}^{W} \geq 0 & \\
\lambda_3 Q_{it}^{C} = 0 & \lambda_3 \geq 0 & Q_{it}^{C} \geq 0 & \\
\lambda_4 Q_{it}^{W} = 0 & \lambda_4 \geq 0 & Q_{it}^{W} \geq 0, & i = 1, \dots, N
\end{array} \tag{3.10}$$

The Nash equilibrium is obtained when the conditions defined in equation (3.10) are simultaneously satisfied. The authors present nine possible solutions $(Q_{it}^{C*}, Q_{it}^{W*})$ for the Nash equilibrium, of which, only four solutions simultaneously satisfy the KKT conditions[7]. Together, these four solutions constitute the Nash equilibrium. They are the following:

$$(Q_{it}^{C*}, Q_{it}^{W*}) = \begin{cases} \left(0, \dfrac{a - c^W + \varepsilon_t}{b(N+1)}\right), & if\ c^W - a < \varepsilon_t \leq c^W - a + b(N+1)K_i^W \\ (0, K_i^W), & if\ c^W - a + b\,(N+1)K_i^W < \varepsilon_t \leq c^C - a + b(N+1)K_i^W \\ \left(\dfrac{a - c^C + \varepsilon_t}{b(N+1)} - K_i^W, K_i^W\right), & if\ c^C - a + b\,(N+1)K_i^W < \varepsilon_t \leq c^C - a + b(N+1)K_i^W + b(N+1)K_i^C \\ (K_i^C, K_i^W), & if\ \varepsilon_t > c^C - a + b(N+1)K_i^W + b(N+1)K_i^C \end{cases} \tag{3.11}$$

For a given value of the capacity costs (θ^C or θ^W), if the marginal cost of technology **C** (c^C) is much greater (much lesser) than the marginal cost of technology **W**, only the technology **W** (**C**) will be available in the market. On the other hand, the CCGT power plants will only enter in

[7] For simplicity, the remaining five solutions of the maximization problem of equation (3.7) are not presented, as they do not meet all the necessary conditions of the Nash equilibrium. For more information see Milstein and Tishler (2009, pp. 63-65).

the market if the electricity demand is sufficiently high and all wind plants are at full capacity. Thus, when the total capacity of all *N* firms is less than the Cournot's optimal solution, due to the large realization of ε_t (when the demand for electricity rises), we have $Q_{it}^C = K_i^C$ or $Q_{it}^W = K_i^W$. This way, each firm will choose their output on day *t* equal to their capacity investment. When this happens, our daily electricity demand is given by $P_t = a - b(K_i + K_{-i}) + \varepsilon_t$, where $K_{-i} \equiv \sum_{j\neq i}^{N} K_j$ is the aggregate capacity of the other *N-1* firms (Milstein and Tishler, 2009; Tishler et al., 2008).

Once the second-stage optimal solutions are found, the first-stage maximization problem can be solved. To do so, equation (3.11) should be substituted into the expected operating profit equation of the *i*-th firm on day t, given by:

$$E\left[\sum_{t=1}^{T} (\pi_{it} | K_i^C, K_i^W)\right] = \int_{c^W - a}^{\infty} [(P_t - c^C)Q_{it}^C + (P_t - c^W)Q_{it}^W] f(\varepsilon_t) d\varepsilon_t \tag{3.12}$$

After the substitution of uniform distribution[8] on equation (3.12), the *i*-th firm's profit-maximization capacities, K_i^{C*} and K_i^{W*}, are obtained[9]:

$$K_i^{C*} = \frac{2(\beta - \alpha)\theta^W/T - \left[c^C - c^W + \sqrt{2(\beta - \alpha)\theta^C/T}\right]^2}{2b(N+1)(c^C - c^W)} \tag{3.13}$$

$$K_i^{W*} = \frac{(\beta + a - c^W)^2 - (\beta + a - c^C)^2 - 2(\beta - \alpha)(\theta^W - \theta^C)/T}{2b(N+1)(c^C - c^W)} \tag{3.14}$$

The solutions show us that, the optimal investment capacity of technology **C** (**W**) increases when the marginal cost of the technology **C** (**W**) and the capacity cost of technology **C** (**W**) decreases, *ceteris paribus*.

This way, and according the authors, the solutions of the model can be summarized in three points (Milstein and Tishler, 2009):

a) A unique Nash equilibrium exists in the second-stage of the game, given by the equation (3.11).
b) The optimal first-stage solution exists if and only if the following condition holds:

$$\sqrt{2(\beta - \alpha)\theta^C/T} < \frac{(\beta - \alpha)(\theta^W - \theta^C)/T}{c^C - c^W} - \frac{c^C - c^W}{2} < \beta + a - c^C \tag{3.15}$$

---

[8] According to the authors, it may be boring but not difficult to obtain the expressions of the optimal capacities in an implicit form. However, *"extensive simulations show that the optimal capacities obtained under the assumption that $f(\varepsilon_t)$ is uniform or normal are very similar, practically identical, to those obtained for the true (data-generating) distribution, provided the true distribution is not too asymmetric"* (Milstein and Tishler, 2009, pp. 13). Thus, the first-stage maximization problem will be solved through the assumption that $f(\varepsilon_t)$ follows a uniform distribution.

[9] The solutions are detailed in Milstein and Tishler (2009, pp. 66-67).

c) If the prior condition holds, the total capacity of the industry is bounded from above and the price spikes are independent of the number of firms. That is,

$$N \times (K_i^{C*} + K_i^{W*}) < \left(\beta + a - c^C - \sqrt{2(\beta - \alpha)\theta^C/T}\right)/b \tag{3.16}$$

Since the model was fully formulated and the optimal solutions were found, we can accept the model as valid and apply it to our case. The application of the model to the particular case, and its results and main conclusions will be presented in the next chapter.

4. Data and Empirical Results

The solutions of the prior section will be applied to the Iberian data to illustrate their real world relevance. The main goal of this article is to study the effect of the introduction of renewable energy sources on the MIBEL generation capacity mix. However, the countries in MIBEL (Portugal and Spain) are different in their market's dimension and structure. On the other hand, MIBEL could work under market splitting scheme, which occurs when each country defines their supply and demand aggregated curves, and the clearing prices for both two zones are determined by the intersection of these curves. In this case, the two areas are treated separately. This situation only occurs if there is traffic in the interconnection, in the same direction, that is greater than the available commercial capacity. Thus, it is important to study those markets individually.

Furthermore, one of the great objectives behind the creation the Iberian Market is the increase of the efficiency in electricity markets and the utilization of renewable energy sources. Thus, it is expected that, having reached this goal, the use of conventional power, like CCGT, can be reduced. Therefore, the application of the model is suitable because it will confirm if the reduction is true or not.

The year 2011 was chosen because it gives us a relative distance from the start of MIBEL and it is also the year in which the majority of the necessary data to develop the model are available. However, the data of the marginal and capacity costs belong to year 2010, due to the unavailability of updated data and the need of consistency of information. Nevertheless, this assumption does not invalidate the analysis, because the time difference is small.

To apply the model, the parameters of the demand function (*a* and *b*) need to be estimated. For that, the daily data for electricity prices (P_t) and daily averages of hourly electricity outputs (Q_t) for the different markets were collected from official pages of OMIE (2012) and REN (2012b). Regarding the Portuguese case, the renewable energy outputs do not enter on the spot market, so these data are not available in OMIE's official page. They were collected from REN's website. It should be noted that the energy dispatched to the grid does not always come from the wholesale market. The electricity can be traded through bilateral contracts or intraday market. However, for the sake of simplification, it is assumed that all renewable energy collected from REN's website will be available in the spot market for trading. This assumption brings model closer to the future market reality.

The estimation of *a* and *b* parameters was obtained through the price elasticity. The program used for the estimation of the price elasticity was *Eviews*, where the OLS (ordinary least squares) method was applied. An exponential regression model was used to estimate the price elasticity. This way, if the equation $\log(Q_t) = \beta_1 + \beta_2 \log(P_t) + u_i$ is estimated by OLS, the price elasticity is given by the value of β_2, since $\beta_2 = \frac{\Delta Q_t}{\Delta P_t} \times \frac{P_t}{Q_t}$. Having this in mind, $a = \overline{P_t} + b\overline{Q_t}$ and $b = -\frac{\overline{P_t}/\overline{Q_t}}{\delta}$, where, $\overline{P_t}$ is the price average, $\overline{Q_t}$ is the mean of daily averages of hourly electricity output, and δ is the price elasticity. Through the descriptive statistics of the prices and daily averages of hourly electricity output, and the price elasticity, parameters *a* and *b* were calculated. It should be noted that, sometimes, MIBEL works under market splitting scheme. When this happens, two different prices are created for each country. For this reason, the MIBEL price average represents the daily arithmetical average of the price between Portugal and Spain. The results are presented in table 1.

Table 1: The values of the parameters of the demand function for MIBEL, Portugal, and Spain

	MIBEL	Portugal	Spain
$\overline{P_t}$ **(€/MWh)**	50.1878	50.4531	49.9217
$\overline{Q_t}$ **(1000 MWh)**	26.7422	5.9328	20.8093
δ	-0.0727	-0.1744	-0.0332
a	740.2853	339.8245	1552.8169
b	25.8056	48.7746	72.2222

Source: elaborated by the author

To validate the applicability of this method to estimate the demand parameters, the values exposed in the article of Milstein and Tishler (2009) will be used. According to the authors, using the average price of 66.4$/MWh, a price elasticity of -0.25 and a mean of daily averages of hourly electricity output of 5.75 (1000 MWh), the estimates are: *a=332.0* and *b=46.2*. However, they do not explain how these values are calculated. Nevertheless, if these data are applied to the equations of the parameters of demand function, it is proved that the estimates of *a* and *b* are, indeed, *a=332.0* and *b=46.2*. Thus, it can be concluded that our method, used to estimate *a* and *b*, is in accordance with the article.

Another variable of demand function, which needs to be estimated, is the ε_t. They are obtained solving the equation $\varepsilon_t = P_t - a + bQ_t$.

The OLS method could be used to estimate the parameters of demand function and the values of the random variable. However, to apply this method in the estimation of the parameters of a regression, it is necessary that the expected value of the ε_t must be zero and its variance must be a constant, the values of ε_t must be independent, and finally, ε_t must follow a normal distribution. The first two conditions are confirmed by the assumptions of the model.

However, it was assumed that $f(\varepsilon_t)$ follows a uniform distribution. This way, the OLS method cannot be applied to the model (Guimarães and Cabral, 2011).

Once calculated the parameter ε_t, we are able to find the values α and β (note that $f(\varepsilon_t) \sim U[\alpha, \beta]$). Thus, they were calculated assuming the descriptive statistics of ε_t presented in table 2, and that $\alpha = \mu - \sqrt{3} \times \sigma$ and $\beta = \mu + \sqrt{3} \times \sigma$.

Table 2: The descriptive statistics of ε_t *and the values* α *and* β *for MIBEL, Portugal, and Spain*

	MIBEL	Portugal	Spain
Mean	0	0	0
Standard Deviation	84.6547	33.8781	196.0578
α	-146.6262	-58.6786	-339.5821
β	146.6262	58.6786	339.5821

Source: elaborated by the author

Regarding the values of the capacity ($\theta^C$and θ^W) and marginal (c^C and c^W) costs, there is little updated information about them. To fill this shortcoming, a study published, in 2010, by the Danish Energy Agency and Energinet.dk is used. The study named *"Technology Data for Energy Plants"* has as its main goal the publishing of a report that systematizes the technological and investment characteristics of the representative power plants.

This report shows that, the investment cost of a CCGT power plant is 0.64 M€/MW[10]. Using a 10% discount rate[11] over 25 years yields an annual cost of 0.0640978 M€/MW or 64,097.8 €/MW. If we assumed that, the fixed operation and maintenance (O&M) costs represent about 99.96% of the total O&M costs[12], we have an annual fixed O&M cost of 36,777.2832 €/MW. Adding this cost to the previous, we obtain a CCGT capacity cost (θ^C) of 100,875.0832 €/MW. Regarding the marginal cost of a CCGT power plant, the average price of natural gas for Portugal and Spain was about 29.40 €/MWh, in 2010 (EUROSTAT, 2012). If we add the variable O&M costs of 0.00168€/MWH to the natural gas price, we obtain a marginal cost of a CCGT power plant (c^C) equal to 29.40168 €/MWh (Danish Energy Agency and Energinet.dk, 2010).

Assuming an investment cost of 1.4 M€/MWh and considering a 10% discount rate over 20 years, the annual investment cost of a wind power plant is 0.1494941 M€/MW or 149,494.1 €/MW. Adding this annual cost to the fixed O&M cost, equal to 113,834.448 €/MW, it is obtained a capacity cost of wind power (θ^W) of 263,328.548 €/MW. The marginal cost of wind

[10] In the face of the actual adversity, it was assumed the worst scenario.
[11] The discount rate is based on a 12 months Euribor rate equal to 1.353%, in 2010, a high country risk measured by the interest rates of the treasury certificates (5.40% for the Portuguese treasury bonds with a maturity of 10 years and 4.57% for the Spanish treasury bonds with a maturity between 10 and 30 years, in 2010); and assuming a risk aversion perspective. The value for the discount rate it will be applied to the MIBEL, Portuguese, and Spanish markets (Euribor-EBF, 2012; Banco de Portugal, 2012; Tesoro Público, 2012).
[12] According to ACIL Tasman (2008), in the developed countries, the fixed and variable O&M costs represent 99.96% and 0.04% of the total O&M costs, respectively.

power (c^C) is commonly assumed to be equal to zero (Danish Energy Agency and Energinet.dk, 2010). For the sake of simplification, these values will be used in the three markets.

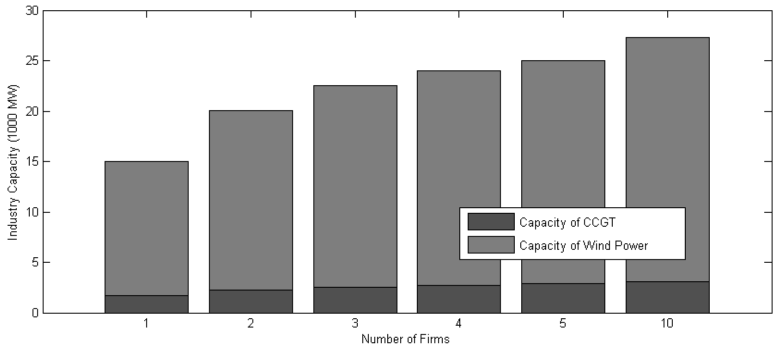
Regarding the number of firms present in the electricity market, the analysis will consider a *N*=1,2,3,4,5,10. The choice of these values can be explained by the fact that the electricity market is an oligopoly where the level of market concentration is high. Thus, in a near future it is improbable that more than five major firms act in the market. To fill this shortcoming, a case for *N*=10 is considered.

With all the parameters estimated, the model can be solved and its solution can be found. The software program used to solve the model was *MATLAB*.

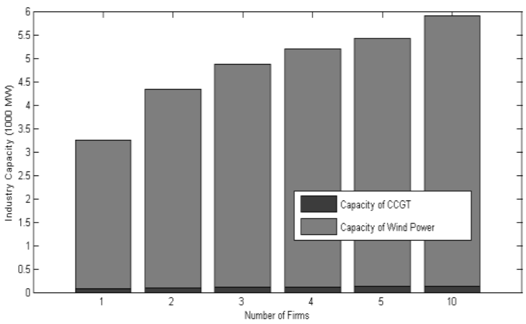
Figure 1 shows the optimal industry capacity for MIBEL, Portugal and Spain markets as a function of the number of firms which act in the electricity market.

Figure 1: Optimal industry capacity for MIBEL, Portugal, and Spain, 2011

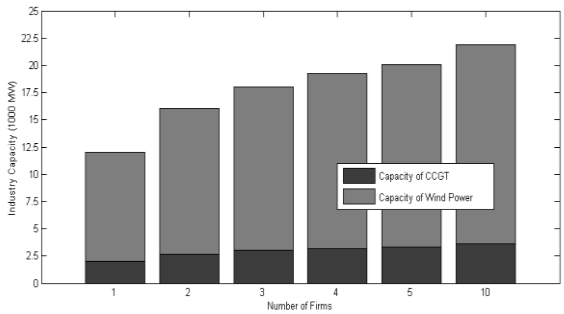
MIBEL



Portugal



Spain



Source: elaborated by the author

As the economic theory suggests, the optimal capacity of each firm is reduced as the number of firms increases, but in the whole, the industry capacity increases. This statement is valid for the three markets.

However, the optimal industry capacity cannot exceed the theoretical bound defined by equation (3.16). As it was explained in prior chapter, an optimal first-stage solution exists if and only if the equation (3.15) holds. Applying the different parameters in the equation, it is confirmed that it is valid for the considered markets. If this happens, the total industry capacity is bounded from above by equation (3.16), and its value is 30,000 MW for MIBEL, 6,500 MW for the Portuguese case, and 24,000 MW for the Spanish case. This phenomenon happens because, it is expected that the equilibrium electricity prices decrease and the quantities demanded increase with the entry of new firms on the electricity market.

It should be noted that, these bounds are lower than the actual installed capacity in the Iberian Market and in its constituting markets. Indeed, in 2011, Portugal and Spain reached a total installed capacity of 18,901 MW and 100,576 MW, respectively. Thus, MIBEL had a total installed capacity of 119,477 MW, in the same year (REN, 2012a; REE, 2012). Nevertheless, two corrections need to be made. In the first place, the study does not consider all the quantities, which enter in the electricity market. The quantities traded through bilateral contracts or in the intraday market do not matter for this study. In the second place, the bound of the optimal industry capacity is likely to be much smaller in a deregulated market than in a regulated one. According to Milstein and Tishler (2009), in a regulated market it is common that the regulatory entity sets electricity prices during the year. This happens, for example, with the feed-in tariffs applied to electricity generation from renewable energy sources. Unlike Israel, where the electricity market is entirely deregulated, this kind of supports still exists in Portugal and Spain. Thus, when the regulatory entity sets the electricity prices, the generators do not have the price mechanism to respond to changes in electricity demand over the day and during the year. This way, and taking into account the electricity price announced by the regulator, the installed capacity in a regulated electricity market is very close to the maximum value of the hourly demand over the year plus reserves. So, the value of the bound in a regulated market is superior.

Figure 1 also shows that, the Portuguese optimal industry capacity is much lesser than the Spanish optimal industry capacity, since the Portuguese electricity demand is smaller than the Spanish one. It is also confirmed that, independently of the number of firms, the optimal capacity of wind power is much greater than the optimal capacity of CCGT. This conclusion is valid for the three markets.

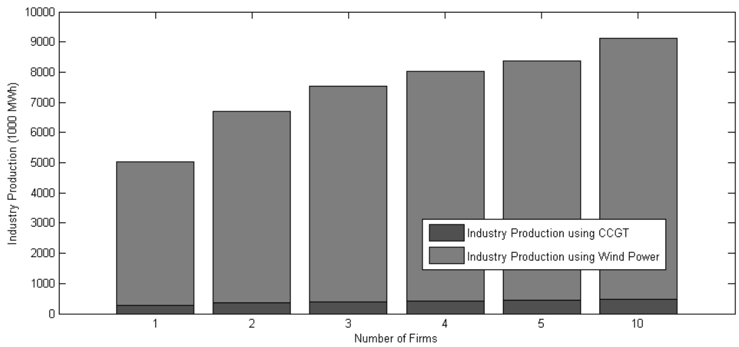
Therefore, it is shown that the optimal capacity of wind power represents 97.69% and 83.39% of the total industry capacity for Portugal and Spain, respectively. Thus, the optimal capacity of wind power in MIBEL reached 88.64% of the total industry capacity. This value is lower than the Portuguese one, due to low percentage of the Spanish optimal capacity of wind power. Indeed, the model shows us that Portugal should invest more capacity in wind power than in CCGT power.

Having this in mind, and in accordance with Bushnell (2010), Milstein and Tishler (2009, 2011), Sáenz de Miera *et al.* (2008), and Weigt (2009a), it can be concluded that the introduction of installed capacity of wind power will reduce the installed capacity of conventional power, like CCGT, since the need of building capacity of conventional power to satisfy the demand is reduced. Naturally, when the firms can employ both technologies, the generator will invest in technology with lower marginal costs. Thus, the share of technology **W** in total capacity of the industry will be greater. This conclusion can be extended to other renewable energy sources. Nevertheless, and as Oswald *et al.* (2008) and Strbac *et al.* (2007) say, a significant proportion of installed capacity of conventional power must be preserved, due to security of supply.

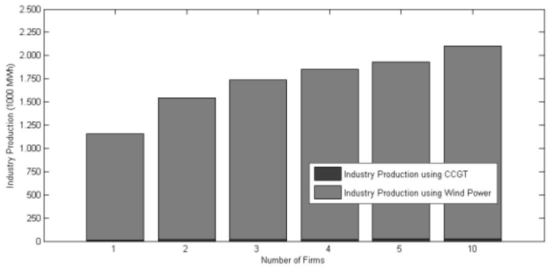
Figure 2 presents the optimal industry production for MIBEL, Portugal and Spain markets as a function of the number of firms which act in the electricity market.

Figure 2: Optimal industry production for MIBEL, Portugal, and Spain, 2011

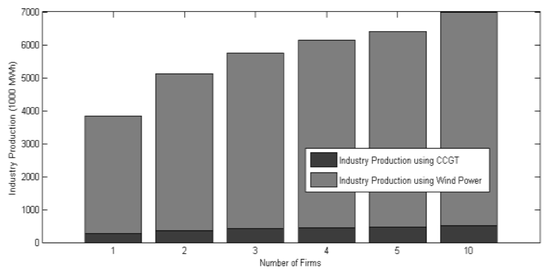
MIBEL



Portugal



Spain



Source: elaborated by the author

The conclusions of these graphs are analogous to those, which were taken in the prior figure, since their evolution pattern is very similar.

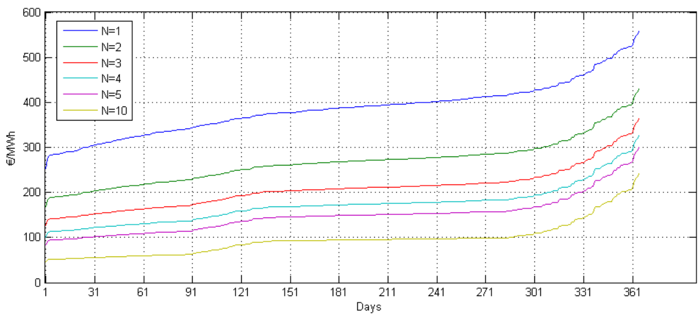
As it can be seen by figure 2, the Portuguese optimal industry production is much lesser than the Spanish one. In Portugal, the industry production using CCGT power plants reached 1.12%, against 7.21% held by Spain. Due to this low value, the MIBEL optimal industry production using CCGT only reached 5.21%. Regarding the wind power, it is shown that in MIBEL, Portugal and Spain, the share of wind power in the total of production is 94.79%, 98.88%, and 92.79%, respectively. These conclusions do not depend on the number of firms.

The common sense suggests that electricity demand fluctuate wildly over the day and during a year. Thus, to satisfy the demand, the construction of new capacity could be a solution. Nevertheless, this new capacity requires time and money, and likely, it would be idle most of the times. This way, the capacity already installed has to serve the daily demands. When a peak demand, which exceed the available capacity, occurs, the generators let the electricity price soar, with the aim to cut the excess of demand. Therefore, the price spike of electricity could be a substitute to evaluate the excess on generation capacity.

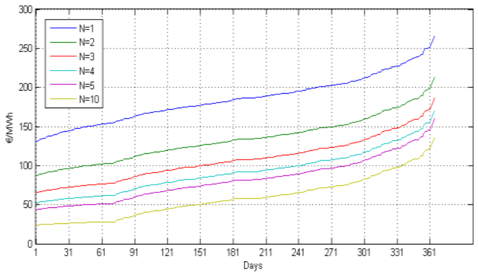
Figure 3 presents the distribution of the equilibrium electricity prices for the 365 days of 2011, for the three markets. The prices are organized in ascendant order subject to quantity demand. Thus, on day 1 the demand reaches its minimum value and on day 365 it reaches its maximum value.

Figure 3: Distribution of the electricity prices during the year 2011, for MIBEL, Portugal, and Spain

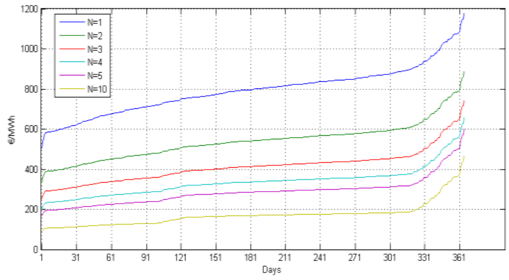
MIBEL



Portugal



Spain



Source: elaborated by the author

Analyzing the figure, it is confirmed that, when the number of firms increase, the price levels decrease in the three markets. On the other hand, Spain and consequently MIBEL have higher price levels than those recorded in Portugal. It should be noted that these prices are very stilted, because in our study the merit order is not to be considered. If the merit order were included in this study, the wind power would enter first in the grid due to its zero marginal costs, and the rise in prices would be lower than those that are shown by the figure.

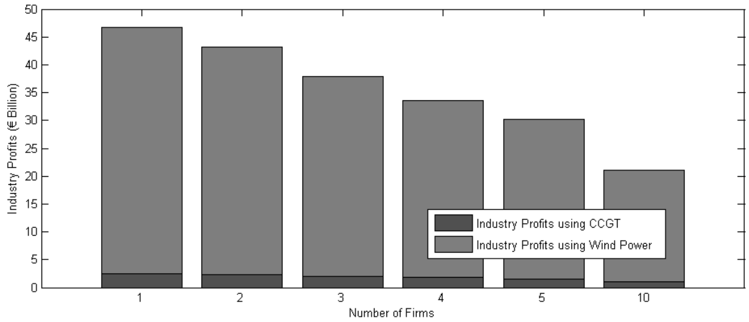
On the other hand, and in accordance to Tishler *et al.* (2008), the figure shows that the frequency of price spikes does not depend on the number of firms in the market. Thus, even if a competition policy to promote the entry of new firms to mitigate price volatility is applied, it is still unlikely that the frequency of prices spikes will change.

The figure also shows that MIBEL, Portuguese and Spanish electricity markets produce at full capacity during 22.5%, 79.7%, and 12.6% of the year, respectively. Once at full capacity, the electricity prices increase at a faster rate until their maximum. By the explanation mentioned above, the price spikes occur when the demand exceed the available capacity. This means that, in Portugal, the optimal system does not have sufficient capacity to satisfy the demand most of the times. The Spanish system is the most efficient. These results prove that, for the generators, it is more profitable to let the prices spike than to build new capacity.

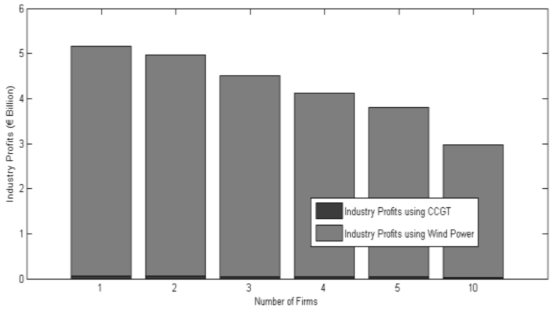
Figure 4 shows the industry profits for MIBEL, Portugal and Spain, in 2011.

Figure 4: Industry profits for MIBEL, Portugal, and Spain, 2011

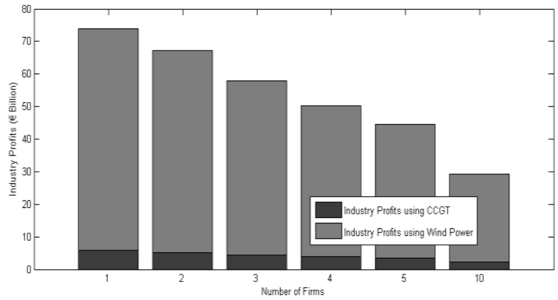
MIBEL



Portugal



Spain



Source: elaborated by the author

Generally, it can be concluded that, when the number of firms increase, the profits of industry tend to decrease, the share of CCGT on the industry profits decreases, and the share of wind power on the industry profits increases. Thus, it can be concluded that the CCGT power is the technology less profitable. These conclusions are valid for the three markets.

The reason for this behavior is simple: the marginal costs of technology **C** are much higher than those of technology **W**, so when the firms can construct both technologies they will reduce the use of technology **C**. Thus, and according to Milstein and Tishler (2009), the generators tend to eliminate the weaker product from the market.

As expected, the main results of this work closely follow the main conclusions drawn by Milstein and Tishler (2009). Thus, it can be concluded that, when the generators can operate two technologies, the introduction of wind power replaces the choice of investments in conventional power (CCGT), in MIBEL and in each country that constitutes it. This conclusion shows that, the investment in new renewable capacity will be the most efficient choice.

4. Conclusion

The main goal of this article was to provide and to apply a methodology to understand the relationship between renewable energy sources and the optimal generation capacity mix in a competitive market.

The literature on this important topic is scarce. The Iberian Electricity Market (MIBEL) was chosen due to the urgency and importance of obtaining more knowledge about this market's functioning. Thus, a literature survey on this specific research topic was performed, followed by the selection of the model.

This work is based on the methodology developed by Milstein and Tishler (2009) because this model mimics the real world decision processes in a competitive electricity market. A two-stage model was developed under Cournot conjecture, where the Nash equilibrium of the optimal endogenous generation capacity and the optimal outputs are deducted. The capacity to be built is determined in the first-stage, when electricity demand is unknown, and the outputs are determined in the second-stage, when daily demand is revealed.

This work shows that in both countries the investment in renewable capacity would be greater than the investment in conventional capacity when wind power is considered in the investment choices of the generators. It should be noted that wind power was chosen in this study from among all the available renewable technologies as it has been one of the fastest growing renewable technologies over the last several years. These results prove that despite the decline in State support to electricity production in renewable energy, the generators would invest more in wind power capacity than in combined cycle gas turbine (CCGT) capacity. An analogous result is obtained regarding optimal industry production. Just as the majority of investment in installed capacity is in wind power, so too the share of wind power in the total of optimal industry production is greater than the share of CCGT power. This result is valid for MIBEL and its constituting countries, Portugal and Spain. Regarding equilibrium prices, it was confirmed that in MIBEL electricity generation would be at full capacity during 22.5% of the year. In Portugal and Spain, this percentage is 79.7% and 12.6%, respectively. These results show that there is inadequate investment capacity in Portugal, unlike Spain. Thus, it can be concluded that, it is more profitable to generators to let the prices spike than build new capacity, which would otherwise be idle during most of the year. Lastly, conventional power is less profitable. This way, and in accordance with the first conclusion, the generators would invest in wind power capacity.

Therefore, in a competitive electricity market, where each firm can choose between two technologies to construct and operate, the generators tend to eliminate the weaker product from the market, i.e., there is a reduction in the use of CCGT power technology. This result is very important because it gives the regulatory entity the necessary understanding that the less valuable technologies would likely be reduced.

On the other hand, it was proved that, in Portugal, the generators prefer to let the price spike, when the peak demand exceeds the availability capacity, than invest in new installed capacity. With this in mind, the regulatory entity must provide the necessary conditions to promote the investment in new capacity for the most profitable technology – wind power. Thus, it is important to provide the financial incentives to electricity production from renewable energy sources, despite wind power being the optimal choice to produce electricity.

These conclusions can be extended for others renewable technologies.

There were difficulties in harmonizing the data from different sources and countries, yet this was ultimately done satisfactorily. Future work will seek to work upon a more sophisticated model where intermittency as well as different generating technologies are considered. Indeed, if more technologies were considered and the intermittency was included, it should be possible to measure, with more precision, the effect of the introduction of wind power on other production technologies.

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Electricity cost optimization in a renewable energy system

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Abstract

The variable electricity output of the renewable energy sources (RES) power plants, such as wind and hydro power technologies, is seen as an important challenge for the electricity system managers.

This paper addresses the problem of an electricity system supported mainly on hydro, thermal and wind power plants, presenting a short-term model planning. A binary mixed integer non-linear optimization model for one year planning with hourly time step is described and applied to a system close to the expected Portuguese electricity scenario for the year 2020.

The main objective of this paper was to analyze the impact that different levels of installed wind power and hydropower have in the operation of thermal power units. Besides that, the analysis of results demonstrate the influence that the characteristics of the seasons of the year has on the renewable power units electricity generation and by this way on the total production cost of the system.

1 Introduction

Nowadays, the increasing use of new technologies such as wind power, characterized by production of variable output and frequently not subject to dispatch and benefiting from feed–in tariffs creates new challenges to the electricity power management. The promotion of the use of renewable energy sources (RES) for electricity generation is one of the possible greenhouse gas mitigation measures [Delarue et al., 2009] and has been supported by important incentives. On the contrary, the large thermal and hydropower groups need to compete in the market for dispatch.

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According to De Jonghe et al. [2012], large-scale wind power development affects short term operation of the electricity system, as well as the optimal generation technology mix since wind increase significantly the variability of generation. The volatility of wind power into the grid will enforce thermal generators to ramping to compensating supplying disruptions or to operate at low load conditions. According to Troy et al. [2010], increasing variability and unpredictability added to the power system due to wind curve characteristics will frequently originate that thermal units will experience an increasing number of startups, ramping and periods of operation at low load levels. In line with this Alvaro et al. [2011] support that, with the increase of wind power generation all over the world, the integration of wind power generation in electricity power systems needs to be carefully performed and requires new concepts in operation, control and management. In their study, a joint operation between a wind farm and a hydro-pump plant is addressed having into account the uncertainty of the wind power forecast.

Other concern that is usually addressed to RES technologies such as wind and hydro is the difficulty on their availability forecast. Different studies have focused on this thematic. Wang. et al. [2009] have study the impact of wind power forecasting on the unit commitment problem and economical dispatch. A set of different scenarios to deal with wind uncertainty were considered, transforming the problem into a stochastic one. Despite the complexity usually associated to the stochastic problems that usually leads to better results, the authors concluded that a deterministic method combined with an increased reserve requirement can produce results that are comparable to the stochastic case. In Vardanyan and Amelin [2011] a survey of short term hydro power planning with large amount of wind power in the system is presented. In their study some conclusions were underlying. They have concluded that research when uncertainty is considered is not fully explored and when considered can significantly increase problem size, which may require more advanced solution algorithms and techniques to bring problem size down and make it solvable.

It is well known that the principal aim of power planning, whether it is applied to long term planning horizon or to short term horizon, is to minimize the operation cost of the system allowing to fulfil a forecasted demand. Optimization models for short-term electrical power generation scheduling are therefore seen as useful and powerful tools to decision makers.

Short-term electrical power generation scheduling also known as unit commitment (UC) problem is essential for the planning and operation of power systems. The basic goal of the UC problem is to properly schedule the on/off states of all the units in the system. Further on, the optimal UC should meet the predicted load demand, plus the spinning reserve requirement at every time interval minimizing the total cost of production [Senjyu et al., 2003]. Şima Uyar et al. [2011] describe the short-term electrical power generation scheduling as an optimization problem, in which optimal startup and shutdown schedules need to be determined over a given time horizon for a group of power generators under operational constraints. The objective remains the minimization of the power generation costs meeting the hourly forecasted power demands. Following this idea, Zhang et al. [2011] focused on the variations in operating cost caused by integration of an increasing amount of wind power in thermal generation systems. According with the simulation results the authors concluded that wind power brings considerable cost increase on thermal generation. Furthermore, when wind power is integrated in the grid, more flexible generation with higher cost are dispatched in peak load regulation, units starts and stop more often and more money is spent on ramping costs, increasing the average cost of the system.

Many other studies addressing the short-term electrical power generation scheduling are well documented in literature with emphasis on the changes that occur in the operation of the thermal units due to increase of wind penetration on system and on the the market prices (see for example Traber and Kemfert [2011] and Troy et al. [2010].

The objective of this work is to analyze the impact that different levels of installed wind and hydro power have in the operation of thermal power units. For that an optimization model considering a short–term horizon planning was used.

This paper is organized as follows. Section 2 describes the proposed model formulation. In Section 3 a realistic case study close to the Portuguese system is addressed, and the results are analyzed. Finally, conclusions are stated in Section 4.

2 Model Formulation

The formulation followed in this work for the unit commitment problem in a system with high penetration of wind and hydro power is described in detail in this section. The model assumes a set of different fossil fuel units mostly comprised between coal and gas. In what concern to hydro power units, the model assumes two different types such as: the large hydro power units with reservoir and the run–of–river units. Pumping units were also also included in the model. Due to the increase complexity of the model no individual set for wind power units was considered. Instead, the model assumes all the individual wind power units as one.

2.1 Objective function

The proposed model formulation takes into account the economic cost, originating one objective functions to be considered. This objective function is set up by the sum of the variable costs of the electricity system. The variable costs, encompass the variable Operation and Management (O&M) costs, fuel and pumping cost, CO_2 emission allowance costs and shutdown and startup costs for each group. The objective function is measured in € and is defined by:

$$\sum_{t\in T}\sum_{j\in J}\left[C_{t,j}+Su_{t,j}+Sd_{t,j}\right]+\sum_{t\in T}\left[CVOM_{h_d}\times phd_t\right]+\sum_{t\in T}\left[CVOM_{h_r}\times phr_t\right]+ \sum_{t\in T}\left[(Cp_p\times ppump_t)+(CVOM_p\times ppump_t)\right]+\sum_{t\in T}\left[(pwind_t\times CVOM_e)\right] \quad (1)$$

where T is a set of the time period (in hours) considered in the model, J is a set of all groups of thermal power plants included in the system, $C_{t,j}$ is the total cost of thermal power groups (€), $Su_{t,j}$ is the startup cost of thermal power groups (€), $CVOM_{h_d}$ is the O&M cost of hydropower plants with reservoir (€/MWh), phd_t is the power output of hydro power plant with reservoir in hour t (MWh), $CVOM_{h_r}$ is the O&M cost of run–of–river power plants (€/MWh), phr_t is the power output of run–of–river power plant in hour t (MWh), Cp_p is the cost of pumping (€/MWh), $ppump_t$ is the power output of pumping power plant in hour t (MWh), $CVOM_p$ is the

O&M cost of pumping power plant (€/MWh), $pwind_t$ is the power output of wind power plant in hour t (MWh) and $CVOM_e$ is the O&M cost of wind power plants(€/MWh).

The costs of thermal power groups considered in objective function above encompasses the fuel cost of each group, the O&M cost, the emissions allowance cost and the startup and shutdown costs. Those can be defined by equations (2), (3), (4) and (5).

$$C_{t,j} = \left[F_j + CVOM_j + (CO_{2_j} \times EC)\right] pt_j \tag{2}$$

$$Sd_{t,j} = CSd_j \times (v_{t-1,j} \times (1 - v_{t,j})) \tag{3}$$

$$Su_{t,j} = ColdS_j \left(v_{t,j} \times (1 - v_{t-1,j})\right) \times \prod_{n=1 \to N_j} 1 - v_{t-n,j} \tag{4}$$

$$Su_{t,j} = HotS_j \left(v_{t,j} \times (1 - v_{t-1,j})\right) \times \left(1 - \prod_{n=1 \to N_j} 1 - v_{t-n,j}\right) \tag{5}$$

where F_j is the fuel cost of group j (€/MWh), $CVOM_j$ is the O&M cost of thermal power group j (€/MWh), EC is the CO_2 emission allowance cost (€/ton), CO_{2_j} is the CO_2 emission factor of type j power group (ton/MWh), CSd_j is the shutdown cost of thermal power group j, $v_{t,j}$ is the binary variable that is 1 if thermal power group j is on in hour t or 0 if it is off, $ColdS_j$ is the cost of the cold startup of power group j (€), N_j is the time necessary for a cold startup (h) and $HotS_j$ is the cost of the hot startup of power group j (€).

2.2 Constraints

The set of adopted constraints for the unit commitment problem usually includes constraints derived from physical processes, demand requirements, capacity limitations and legal/policy impositions. These constraints are equations that impose conditions to the model formulation, defining values of the decision variables that are feasible Hobbs [1995].

2.2.1 Demand Constraint

To ensure the reliability of the system, the production of all power plants should meet the total system load at each hour of planning period. Thus, the demand must be equal to the total power output from power plants plus the special regime producers power output minus pumping consumption. The mathematical formulation of this constraint is

$$\sum_{j \in J} pt_{t,j} + phd_{t,h_d} + phr_{t,h_r} + pwind_{t,e} - ppump_{p,j} + Psrp_t = D_t \quad \forall t \in T \tag{6}$$

where D_t is the demand in hour t of planning period (MWh) and $Psrp_t$ is the generation output of all special regime producers (except large hydropower plants and wind power plants) including co-generation in each t hour of respective planning period (MWh).

2.2.2 Thermal Power Capacity Constraints with Ramp Considerations

Power capacity constraints ensures that all power groups included in the model will not produce more than respective group capacity for each hour of the planning period. Indeed, the power output will be less or equal to the power group capacity. A minimum output of 35% of capacity for coal and gas thermal power groups is considered due to its technical characteristics. Furthermore, startup and shutdown ramp constraints were also considered to ensure a more reliable system representation. Mathematical formulation of these constraints is

$$\overline{p_{t,j}} \leq \overline{P_j}\left[v_{t,j} - (v_{t,j} \times (1 - v_{t+1,j}))\right] + (v_{t,j} \times (1 - v_{t+1,j})) \times Sdr_j \tag{7}$$

$$\overline{p_{t,j}} \leq pt_{t-1,j} + Ru_j \times v_{t-1,j} + Sur_j \times (v_{t,j} \times (1 - v_{t-1,j})) \tag{8}$$

$$\overline{p_{t,j}} \geq 0 \tag{9}$$

$$\overline{p_{t,j}} \geq pt_{t,j} \tag{10}$$

$$\underline{P_j} \times v_{t,j} \leq pt_{t,j} \tag{11}$$

$$pt_{t-1,j} - pt_{t,j} \leq Rd_j \times v_{t,j} + Sdr_j \times (v_{t-1,j} \times (1 - v_{t,j})) \tag{12}$$

$$pt_{t,j} \geq 0 \tag{13}$$

where $\overline{p_{j,t}}$ is the maximum power generation of group j in time t (MWh), $\overline{P_j}$ is the maximum capacity of thermal group j (MW), Sdr_j is the shutdown ramp limit of group j (MWh), Ru_j is the ramp up limit of group j (MWh), Sur_j is startup ramp limit of group j (MWh), $\underline{P_j}$ is the minimum capacity of thermal power group j (MW) and Rd_j is the ramp down limit of group j (MWh) Arroyo and Conejo [2004].

2.2.3 Minimum up and down time of thermal power groups

Minimum Up and Down time constraints enforce the feasibility of system in terms of proper technical operation of units. Once a shutdown is verified the group must remain off for a certain period of time as well as if an startup happens, the group must remain working over a certain time period. Equation (14) and (15) ensure then operation feasibility in terms of minimum up and minimum down time constraints respectively.

$$\sum_{i \in i \leq UT_j} v_{t+i,j} \geq UT_j \times (v_{t,j} \times (1 - v_{t-1,j})) \tag{14}$$

$$\sum_{i \in i \leq DT_j} 1 - v_{t+i,j} \geq DT_j \times (1 - v_{t,j}) \times (v_{t-1,j}) \tag{15}$$

where UT_j is the minimum up time of thermal group j and DT_j is the minimum down time of thermal group j.

2.2.4 Large Hydro Constraints

For the large hydro power plants with reservoir, constraints regarding the expected storage and production capacity for each hour of planning period are considered into the model. The following equations relate the reservoir level for the hour t in terms of the previous reservoir level, inflows and consumption. Two sets of constraints appear due to the need of consider an initial reserve for the first hour of the planning period.

$$reserve_t = Inflows_t + (\eta_p \times ppump_t) - phd_t + Ir \qquad t = 0 \tag{16}$$

$$reserve_t = Inflows_t + (\eta_p \times ppump_t) - phd_t + reserve_{t-1} \qquad \forall t \in T \setminus \{0\} \tag{17}$$

where $reserve_t$ is the reservoir level on hour t of the planning period, $Inflows_t$ is the hydro inflow on hour t of the planning period, Ir is the initial reserve of reservoir on hour 0 of planning period and η_p is the efficiency of pumping units.

Additional upper and lower bounds must be used to define maximum and minimum reservoir levels as well as the maximum power output of these units that must be less or equal to groups capacity. The following set of equations represent these constraints.

$$reserve_t \leq reserve_{max} \tag{18}$$

$$reserve_t \geq reserve_{min} \tag{19}$$

$$phd_{h_d,t} \leq \overline{P_{h_d}} \tag{20}$$

where $reserve_{max}$ and $reserve_{min}$ are the maximum and minimum reservoir level allowed, respectively and $\overline{P_{h_d}}$ is the maximum power capacity of hydropower unit with reservoir.

The next set of constraints makes the production of run-of-river power plants equal to the installed power, taking into consideration the availability of these units. This type of plants are characterized by its reduced storage capacity.

$$phr_t = \phi_{h_r,t} \times \overline{P_{h_r}} \tag{21}$$

where $\phi_{h_r,t}$ is the run–of–river units availability in hour t that is strongly dependent of seasonality of each season.

2.2.5 Pumping Constraints

For the mathematical formulation of the operation of hydropower plants with pumping capacity, two reservoirs must be taken into account. The upper one storages water from inflows and from pumping itself, while the lower one storages water already used for electricity generation that later may be pumped again to the upper level. Again two set of constraints are necessary to model the initial pumping reserve for the first hour of planning period.

$$Preserve_t = phd_t - (\eta_p \times ppump_t) + PIr \qquad t = 0 \tag{22}$$

$$Preserve_t = phd_t - (\eta_p \times ppump_t) + Preserve_{t-1} \qquad \forall t \in T \setminus \{0\} \tag{23}$$

where $Preserve_t$ is the reserve of the pumping storage hydro power plant in hour t, PIr is the initial reserve of lower reservoir for instance t = 0.

The set of three next constraints representing the upper and lower bounds on the pumping reservoir and the maximum output production of pumping units, must also be included to ensure reliability of system. These are represented by the following constraints.

$$Preserve_t \leq Preserve_{max} \tag{24}$$

$$Preserve_t \geq Preserve_{min} \tag{25}$$

$$ppump_{t,p} \leq \overline{P_p} \tag{26}$$

where $Preserve_{max}$ and $Preserve_{min}$ are respectively the maximum and minimum capacity of lower reservoir and $\overline{P_p}$ is the max capacity of pumping groups.

2.2.6 Wind constraints

This constraint ensures wind power generation capacity to be equal to the total installed power taking into account the wind availability. This constraint is set as an equality assuming that wind power is not subject to dispatch, making use of the feed-in tariffs and has priority access to the grid. Wind constraint is described by

$$pwind_{t,e} = \phi_{t,e} \times \overline{P_e} \tag{27}$$

where $\overline{P_e}$ is the maximum capacity of wind power units (MW) and $\phi_{t,e}$ is the wind availability in hour t.

2.2.7 Security constraints

Power units outages although not being frequent must be considered and prevented. These outages have different reasons for happen consisting essentially on the power units breakdown and stoppages for maintenance. Furthermore suddenly increase of power consumption that may occur must be taken into considerations. Equation 28 represent this security constraint for each moment t.

$$\sum_{j\in J}\left(\overline{P_j}-pt_{t,j}\right)+\sum_{h_d\in H_d}\left(\overline{P_{h_d}}-phd_{t,h_d}\right)+\sum_{h_r\in H_r}\left(\overline{P_{h_r}}-phr_{t,h_r}\right)\geq D_t\times\alpha \tag{28}$$

where α is the parameter that will ensure the reliability of the system and usually represent 10%.

3 Model implementation and results analysis

3.1 Case study

The optimization model previously described was designed with the final aim of being used for a typical unit commitment problem for the analysis of a mixed hydro-wind-thermal power system. For this case study, a typical system encompassing all the electricity power generation technologies referred above, was taken into consideration. The particular case of the Portuguese electricity system was then selected, as representative of an example of this technology mix.

The Portuguese electricity system comprises essentially large thermal and hydro power plants in two different regimes: the ordinary regime production (ORP) encompasses thermal and large hydropower plants and the special regime production (SRP) encompasses renewable energy sources except large hydropower plants. Besides that, the investment in new technologies, essentially wind power, is increasing due to environmental and social concerns along with the need to reduce the external energy dependence. According to WWEA [2011] in 2011, Portugal occupied the tenth position on world in wind power capacity with 3960 MW installed, from which, 260 MW installed during the first half of 2011. This corresponds to 21% of total installed power of Portuguese national system and 17% of the total production [REN, 2012]. According to [REN, 2011] this increasing trajectory is expected to keep on at least until 2022 even despite of the decrease in 3% verified in the global consumption. In what concerns to ORP, in 2011, a reduction of 27% of total hydropower production was observed totaling 10808 GWh, with an hydraulic productivity index (HPI)[1] of 0.92, against 14869 GWh of 2010 with an HPI of 1.31. On the contrary, thermal power groups production experience an increase of 12%, totaling 19435 GWh against the 17299 GWH of 2010. This variability is quite informative of the changes on production that variable output units, highly dependent of climate conditions, can bring to the system.

Weather conditions and the seasonality will influence the power output in each year and consequently, will have an impact on electricity system operation and on the thermal power units

[1]Ratio between the hydropower production during a time period and the hydropower production that would be expected for the same period under average hydro conditions

performance. Figure 1 and 2 demonstrates the variability of the wind and run–of–river hydro production for January and August[2]. As may be observed the production of both wind and hydro power plants is much higher during winter (in January) than during summer (in August), due to the availability of the underlying resources. In fact in 2011, during the winter, RES production represented approximately 66% of the total electricity demand but during summer this share was only 24%. This demonstrates the need to analyze the short term scheduling of the electricity system considering a large share of RES.

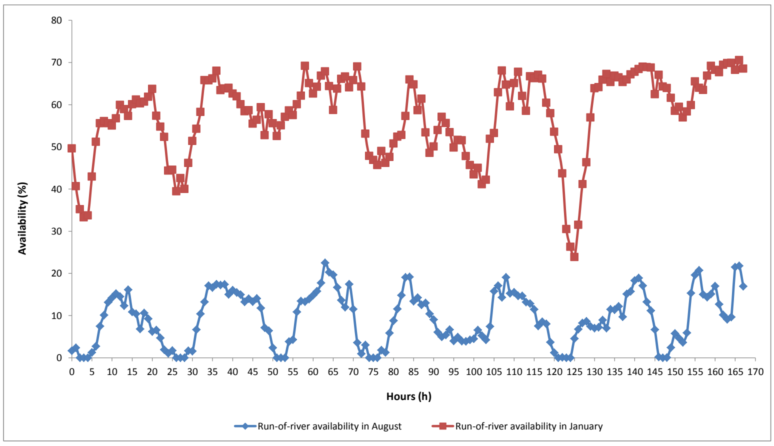

Figure 1: Hourly production of run–of–river power units in January and August 2011 weeks [Own elaboration from REN data]

In order to reduce the complexity of the analysis, a closed system was assumed and the imports and exports were not accounted in the optimization process. This way, the analysis will look for optimal electricity plans to meet the internal demand at minimum generation cost.

3.2 Simulation process

According to De Jonghe et al. [2012], although Linear Problems (LP) models have been successful because of their ability to model large problems, mixed integer programming must be used when binary variables are associated with investment projects or non-convexities, such as minimum run levels and minimum up– and downtimes.

Therefore, on the previously described model, equations (1)–(28) represent a mix integer non-linear optimization problem (MINLP) with 16633 continuing variables, 5208 integer variables, 48889 equation constraints, 579261 non-linearities and 183592 nonzeros modeled in GAMS [2011] code. The AlphaECP solver was selected to obtain the numerical results reported herein. The numerical results were obtained in a Microsoft Windows operating system using a 2.3GHz Pentium i5 computer with 4GB of memory.

[2]Availability used as a proxy of the variability of the resource measured as power output/ maximum capacity

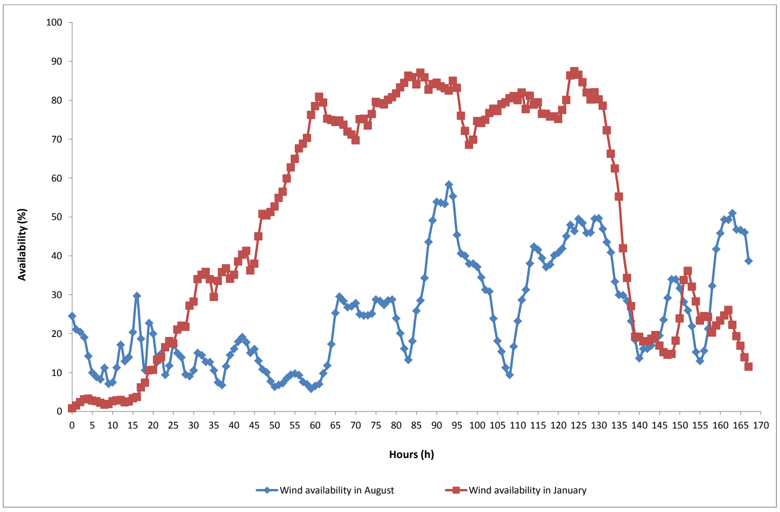

Figure 2: Hourly production of wind power units in January and August 2011 weeks [Own elaboration from REN data]

Table 1: Installed power system (Source: REN website)

	Technology	Number of power groups	Installed Power per technology (MW)
Thermal Power	Coal	8	1820
	Gas	15	4033
	Fuel	8	1145
Total	-	31	6998
Hydropower	Run-of-rivers	-	2583
	Large hydropower units	-	2649.8
Total	-	-	5232.3
Wind Power	-	-	3960
Pumping	-	-	1053.3

A single-objective problem with yearly time horizon and hourly time step was considered for a short–term electricity power generation scheduling, UC problem, in a system with different wind and hydro power penetration levels. Besides the installed wind power, the model assumes a set of different fossil fuel units mostly comprising coal and gas and two different types of hydro power technologies, the large hydropower units with reservoir and the run–of–river units. Note that hydro pumping units were also also included in the model. The simulation was conducted assuming four different scenarios in 2020. Both table 1 and table 2 describe the case study in terms of installed power and scenarios used. In the case described on table 2, scenarios were created having into account an increase in the wind power installed capacity as well as different values for the installed hydro power.

As addressed above, the behavior of a electricity system comprising high penetration of renewables will be strongly influenced by the climatic conditions and different seasons. In table 3 the average values of availability and demand that characterize each season of year since 2009 for the Portuguese power system are presented. Analyzing this table is possible to conclude that, the demand tends to be higher in the winter. Curiously, it is in this season that hydro and wind

Table 2: Case study scenarios

	Wind power (MW)	HPI)
Scenario 1	3960	2583
Scenario 2	3960	2635
Scenario 3	6000	2583
Scenario 4	6000	2635

availability is also higher. On the contrary it is in the summer that both hydro and wind power availability are lower. On the other hand, apart winter, wind power tend to be approximately equal in the remain seasons. Moreover, the electricity demand in summer is close to the demand in Autumn and even higher than the demand in the spring, which due to the lower hydro availability can create additional difficulties in the scheduling of the power system.

Table 3: Season characteristics of the Portuguese electricity system 2009–2011 (Source: Own elaboration using REN data)

	2011			2010			2009		
	Demand (MW)	Hydro availability	Wind availability	Demand (MW)	Hydro availability	Wind availability	Demand (MW)	Hydro availability	Wind availability
Winter (week 1)	6349.4	51%	31%	6515.2	61%	37%	6136.4	39%	28%
Spring (week 2)	5496.9	33%	22%	5536.1	47%	26%	5293.3	17%	21%
Summer (week 3)	5575.4	11%	23%	5830.3	18%	18%	5522.0	10%	20%
Autumn (week 4)	5684.4	24%	29%	5979.4	23%	31%	5837.6	17%	34%
Average/year	5776.5	30%	26%	5965.3	37%	28%	5697.3	21%	26%

Due to the complexity of the model, this work uses for the parameters, the data of 4 typical weeks, corresponding each one to one week of each season of the year. The objective was to obtain the total costs of the system, and to analyze the technology commitments over a year planning horizon for all scenarios presented in table 2. For simplicity reasons and to turn the model feasible it was assumed that the behavior of each week would repeat itself over the entire season being the final result the costs of the four seasons. The predicted wind and hydro power output was obtained from the hourly availability factor, which allowed to take into account the uncertainty and seasonality of wind and hydro power.

3.3 Numerical results

The results obtained for all scenarios are presented in Table 4. It is possible to conclude that for an increase of both wind and hydro power, the nominal cost of the system tend to decrease as expected. Comparing Scenario 1 and Scenario 3, it is possible to see a reduction of 19% on the estimated annual cost of the system. Consequently, the same happens when considering the week production cost for all weeks. For example, for both weeks 1 of scenarios 1 and 3 a reduction from 8.12 €/MWh to 6.40 €/MWh, which corresponds to a decrease of 21%, have occurred. This reduction can be explained by the increase of electricity generation provided by wind power, characterized by no fuel costs and lower cost of operation and maintenance when comparing with fossil fuel traditional generation units. Figure 3 and figure 4 demonstrate exactly the decrease of thermal power units production between scenario 1 and scenario 3 due to increase on wind capacity.

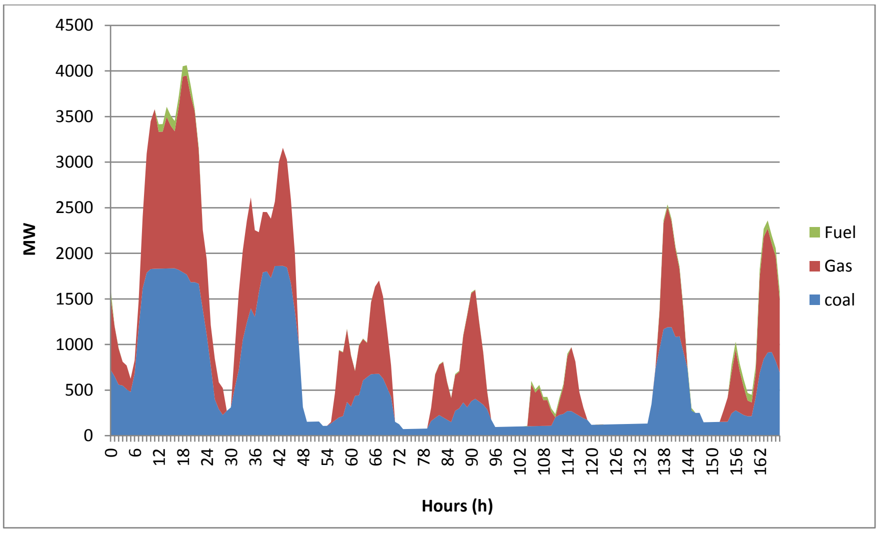

Figure 3: Hourly production of thermal power units for scenario 1 in week 1

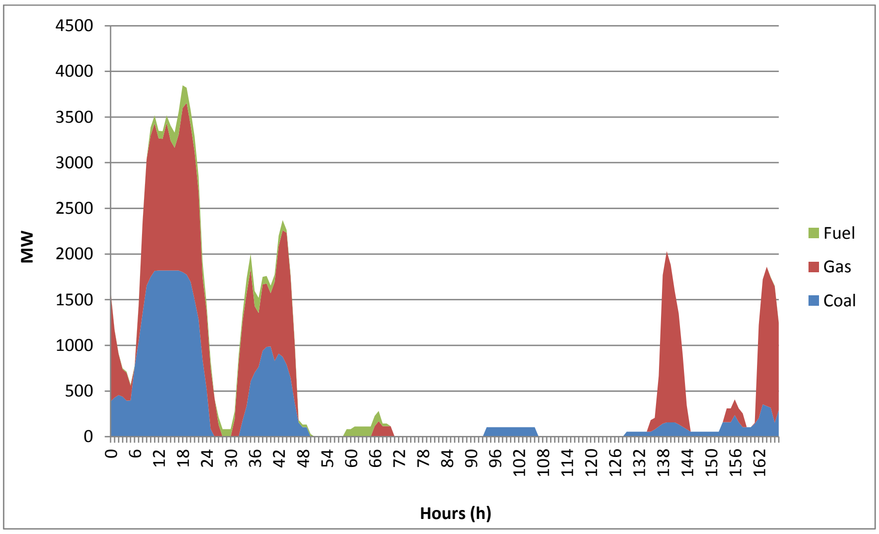

Figure 4: Hourly production of thermal power units for scenario 3 in week 1

Table 4: Optimal objective functions solutions

	Cost (€)	Marginal Cost (€/MWh)	Startups	Annual Cost (€)
		Scenario 1		
Week 1 (Winter)	10.687.227,3	8.12	126	598.142.031,0
Week 2 (Spring)	10.913.487,7	8.87	139	
Week 3 (Summer)	15.131.014,9	13.78	162	
Week 4 (Autumn)	13.113.439,3	11.94	137	
		Scenario 2		
Week 1 (Winter)	9.305.384,1	7.07	123	557.245.252,1
Week 2 (Spring)	9.685.254,7	7.87	137	
Week 3 (Summer)	14.765.659,2	13.44	148	
Week 4 (Autumn)	12.680.806,3	11.55	131	
		Scenario 3		
Week 1 (Winter)	8.469.366,1	6.40	87	484.615.702,6
Week 2 (Spring)	8.520.375,6	6.91	125	
Week 3 (Summer)	12.526.010,3	11.40	150	
Week 4 (Autumn)	10.868.889,8	9.90	108	
		Scenario 4		
Week 1 (Winter)	7.382.641,9	5.56	78	453.708.508,2
Week 2 (Spring)	7.527.755,3	6.10	90	
Week 3 (Summer)	12.220.708,2	11.13	146	
Week 4 (Autumn)	10.677.936,9	9.72	124	

Furthermore, is possible to verify that for all scenarios considered, the production costs of week 1 and week 2, are lower than those costs for week 3 and week 4, even week 1 and 2 having an higher demand, characteristic of these seasons. During spring and winter the wind and hydro availability is higher which reduces the number of expecting working hours of thermal power plants. This allows reducing the operating cost of the system, along with the number of start–ups and consequently the costs of the system become lower. This cost reduction is even more evident for higher wind and hydro power scenarios. Considering week 2 as example, comparing both scenarios 2 and 4 it is possible to verify a reduction on the cost production from 7.87 €/MWh to 6.10 €/MWh which represents a reduction of 22%.

In fact, during weeks 3 and 4 when wind and hydro availability is lower, thermal power unit need to compensate the lack of RES electricity production expected. This is specially visible in figures presented in B. In particulary, in figure 7 is possible to observe that a reduction in wind an hydro power production would result in an increase in production of thermal power units and an increase of startups and shutdown as evidenced in table 4. This behavior is followed by week 4 as shown in figure 8, although with a lower number of startups.

Interestingly, is possible to verify that the variability of RES availability influence significantly the number of startups and shutdowns of the system. A presents an example of the first 24 hours of the commitment of thermal unit in week 1 and 3, both from Scenario 1.

4 Conclusions

This paper analyzes the Short-term electricity power generation scheduling also known as unit commitment problem. For this, one optimization model was presented and adapted to the characteristics of the system under study. A deterministic programming model was proposed aiming to support the short term power generation scheduling, taking into account economic concerns. Once deterministic, the model assumes perfect knowledge of the demand and technical restrictions and costs over time. The model usefulness as a decision support tool or for the analysis of RES strategies was demonstrated for a case study. However it may be easily adapted to other cases with similar characteristics, allowing to design and analyze the interaction between the elements of the electricity system and the seasonality of the underlying renewable energy sources.

From the solution of the optimization model and assuming the described departing conditions, the results indicate that as the production levels of RES (wind and hydro power) increase the overall marginal cost of the system tend to decrease. These results can be easily explained because the costs of operation and maintenance of RES are very low when comparing to traditional fossil fuel generation units.

Another important aspect is the fact that for all the scenarios, the lower production cost are always achieved during the winter week. Although this week presents the higher electricity demand it is also the one with higher wind and hydro availability. On the contrary, during the summer weeks both the wind and hydro availability are lower leading to higher thermal power production and so, causing an increase on the marginal costs of the system. This demonstrates the impact and importance of analyzing the seasonal behavior of resources and consumption during electricity power planning.

The main results of the analysis put in evidence the importance of both wind and hydro power as strategic technologies to reduce the marginal cost of the system. Future work will address the need of a deeper analysis of the impacts that variations of wind power production has in the production of hydro power. Furthermore, it will also be of great interest to study a better way to deal with the efficiency of traditional thermal power units, which translates into the relationship between its load factor and fuel consumption.

Acknowledgements

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A Appendix

Table 5: Commitment of thermal power units in 2020

	Scenario 1, week 1 – hourly time step (24 h)																								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Carriço														1	1	1	1	1	1	1	1	1	1	1	
FigueiraFoz																		1	1	1	1	1	1		
Setubal3	1																								
Setubal4													1	1	1	1	1	1	1	1	1				
Tunes1																									
Tunes2	1	1	1																						
Tunes3															1	1	1	1	1	1	1	1	1		
Tunes4																									
Ribatejo1	1																		1	1	1	1	1		
Ribatejo2											1	1	1	1	1	1	1	1	1	1					
Ribatejo3	1	1	1																	1	1	1	1	1	
Sines1								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Sines2	1	1						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Sines3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Sines4							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Energin									1	1	1	1	1	1						1	1	1	1	1	
Lares1	1	1						1	1	1	1	1					1	1	1	1	1	1	1	1	
Lares2																				1	1	1	1	1	
Soporgen1										1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Soporgen2									1	1	1	1	1	1	1	1	1	1	1	1					
Pego1									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Pego2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
Pego3							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Pego4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Tapada1	1	1	1	1	1					1	1	1	1	1	1	1					1	1	1	1	
Tapada2	1									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Tapada3									1	1	1	1	1	1	1	1	1	1	1	1	1	1			
PegoCC1									1	1	1	1	1	1	1	1	1	1	1	1					
PegoCC2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		

Table 6: Commitment of thermal power units in 2020

	Scenario 1, week 3 – hourly time step (24 h)																								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Carriço									1	1	1	1	1												
FigueiraFoz		1	1	1	1	1	1					1	1	1	1	1	1	1	1	1	1	1	1	1	
Setubal1																		1	1	1	1	1	1	1	
Setubal2								1	1	1	1	1	1	1	1	1	1	1	1	1					
Setubal3											1	1	1	1	1	1	1	1	1						
Setubal4																									
Tunes1			1	1	1	1	1	1	1	1	1														
Tunes2	1	1	1	1	1																				
Tunes3				1	1	1	1	1	1	1	1	1													
Tunes4																									
Ribatejo1	1									1	1	1	1	1	1	1	1	1	1	1	1	1			
Ribatejo2	1	1	1	1												1	1	1	1	1	1				
Ribatejo3	1																	1	1	1	1	1	1	1	
Sines1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Sines2								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Sines3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Sines4									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Energin										1	1	1	1	1								1	1	1	
Lares1									1	1	1	1	1	1	1										
Lares2		1	1	1	1	1					1	1	1	1	1										
Soporgen1																						1	1	1	
Soporgen2				1	1	1	1	1	1	1	1	1	1	1	1	1									
Pego1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Pego2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Pego3			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Pego4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Tapada1	1						1	1	1	1	1	1													
Tapada2																					1	1	1	1	
Tapada3																		1	1	1	1	1	1	1	
PegoCC1							1	1	1	1	1	1										1	1	1	
PegoCC2																									

B Appendix

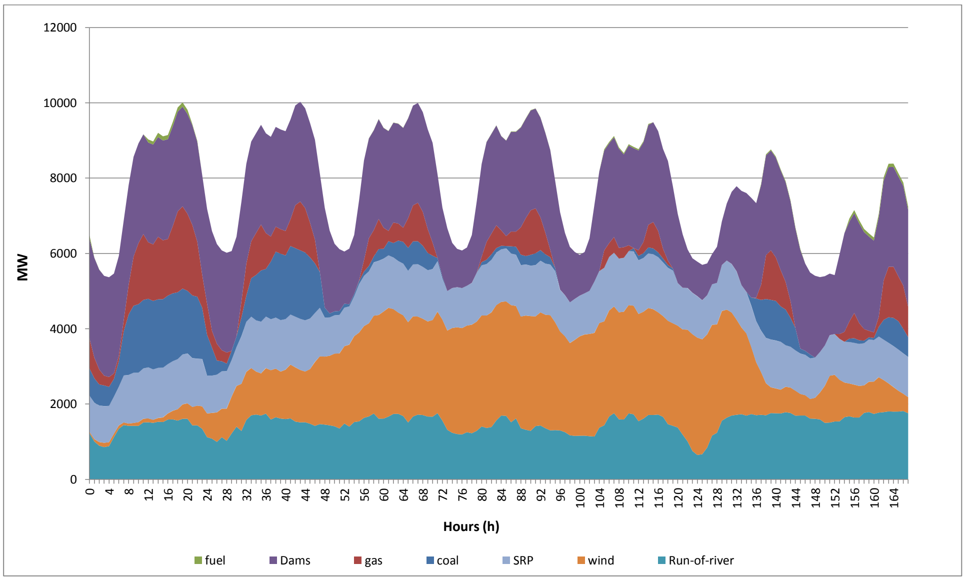

Figure 5: Power production for Scenario 1 in a Winter week

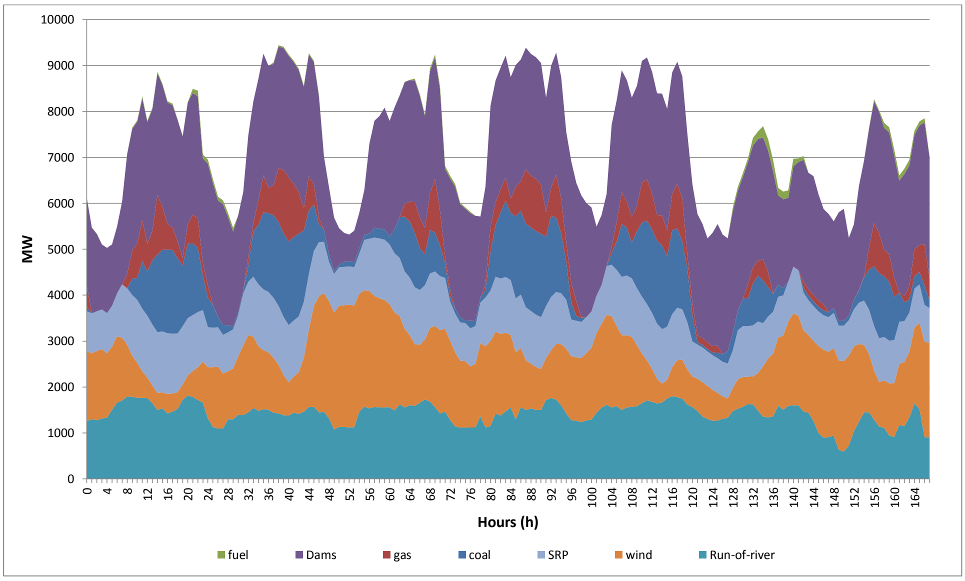

Figure 6: Power production for Scenario 1 in a Spring week

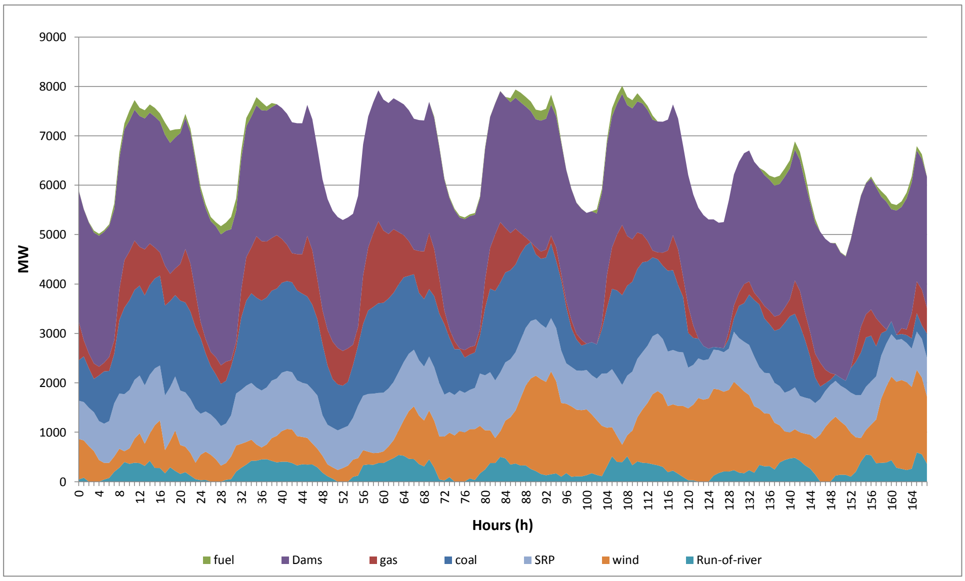

Figure 7: Power production for Scenario 1 in a Summer week

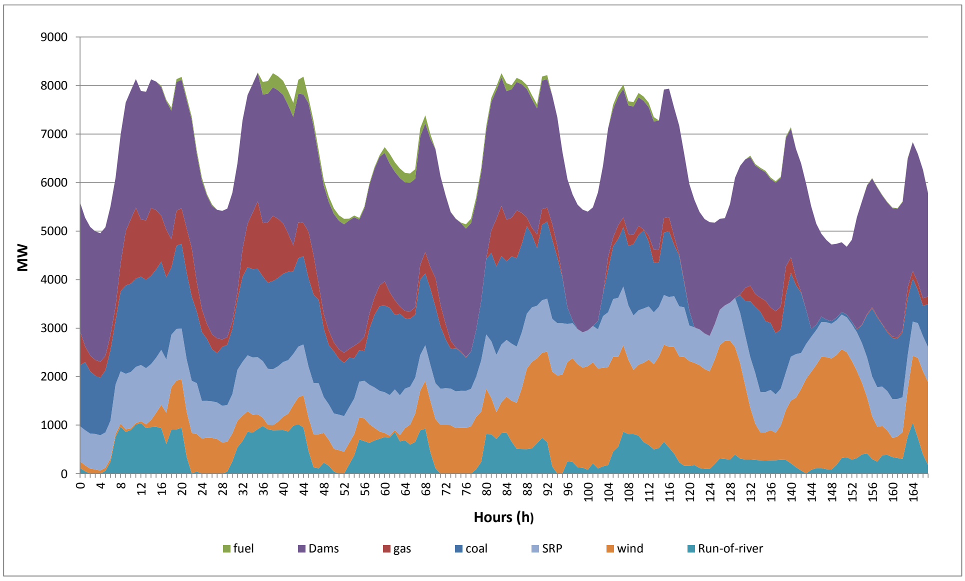

Figure 8: Power production for Scenario 1 in a Autumn week

DAY 9 - 16:30		
Room 642 - Energy Efficiency 1		
Efficiency of the introduction of electric buses in public transport fleet	Marko Slavulj[1]; Davor Brčić[1]; Ljupko Šimunović[1]	[1]Faculty of Transport and Traffic Sciences University of Zagreb
An Economic Model For Waste to Heat District Greenhouse Heating	Mehmet Basak[1]; Suleyman Hakan Sevilgen[1]	[1]Yildiz Technical University
Knowing electricity end-uses to successfully promote energy efficiency in buildings: a case study in low-income houses in Southern Brazil	Arthur Santos Silva[1]; Fernando Luiz[1]; Ana Carolina Mansur[1]; Abel Silva Vieira[1]; Aline Schaefer[1]; Enedir Ghisi[1]	[1]Federal University of Santa Catarina
Characterisation and Modelling of Energy Behaviours	Marta Lopes[1]; Carlos Henggeler Antunes[2]; Nelson Martins[3]; Maria São João Breda[4]; Paulo Peixoto[5]	[1]INESC Coimbra and ESAC; [2]INESC Coimbra and University of Coimbra; [3]University of Aveiro; [4]Institute of Cognitive Psychology, University of Coimbra; [5]Centre for Social Studies, University of Coimbra

Efficiency of the introduction of electric buses in public transport fleet

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Abstract

Aim of paper is to evaluate the effectiveness of the introduction of electric buses in the fleet of public transport. The research was done in the case of Zagreb Electric Tram who is the main operator of public transport in the city of Zagreb (Croatian capital). Through the conducted analysis it can be concluded that the introduction of electric buses instead of old buses that have Euro1 and Euro2 norms is justified from an economic and environmental point of view.

Keywords: Public transportation system, Electric Bus, Cost–benefit analysis, Zagreb

JEL classification codes: JEL: R42

1. INTRODUCTION

Cost–benefit analysis is a general method for comparing benefits and costs of proposed projects. As its name implies, it focuses on economic effects; thus it is not by itself a complete decision mechanism (Small, Verhoef, 2007). Nevertheless it can incorporate many factors that are sometimes considered non-economic just as: air pollution, noise, and risk of injury and death. Cost–benefit analysis need not be restricted to long-term investments. It can be applied to routine maintenance activities or to major rehabilitation projects, both of which have shown greater potential than new roads in many less-developed nations. It can be applied even to operational policies under consideration such as air-pollution standards, road pricing, or transit subsidies.

In the private sector of the economy, investment decisions are relatively simple, at least in principle. Although such goals as providing jobs, improving living standards, and promoting new technology may be considered, profit maximization is usually the dominant, sometimes the exclusive, goal. The main criterion for an investment is thus based on projected costs and revenues.

In the public sector, evaluation of projects, particularly those involving investments in infrastructure with long-term benefits, is considerably more complicated. While the maximum financial effectiveness of the investment is an important goal, many other goals must be considered and often given more importance than the monetary one. The goals of public project planning usually include such elements as providing essential public services (mobility), improving economic vitality and environmental quality in the city, achieving in the long run a desirable urban form and quality of life, etc.

2. ABOUT ZAGREB MUNICIPAL TRANSIT SYSTEM

Zagreb Municipal Transit System or ZET[1] (Zagrebački Električni Tramvaj) is a branch of the Zagreb Holding specialized for passenger transportation in the city of Zagreb and one part of the Zagreb County. It uses buses, trams and cable car to organize a transportation of students and also provides special transportation to people with disabilities. It is exclusively owned by the city of Zagreb and it is mainly financed through its budget.

It was founded in 1891 as the Horse Tram Association, which was the forerunner of the joint stock company established in 1892-Zagrebački tramvaj (Zagreb Tram), Zagrebački Električni tramvaj (Zagreb Electric Tram) established in 1909, and Zagrebački Električni Tramvaj (Zagreb Electric Tram) Ltd. The City Assembly of Zagreb made a decision on the 20th of December to pass the founding rights and shares of ZET Ltd. and other 22 companies owned by the city of

[1] http://www.zet.hr/

Zagreb to The City Housing and Public Utility Services Ltd., which took over the role of Holding. Since the 1 of July 2006 ZET is a branch of the Zagreb Holding.

ZET, aside from its primary function, passenger transportation, in more than one century of its existence, greatly influenced the development of Zagreb, and this influence continues to grow by covering important day routes people take in Zagreb and suburban areas with its extensive tram and bus system. However, ZET continues to follow the city development and connects many newly built districts, and together with the City District Councils adapts the routes and stations to address the needs of citizens.

Thanks to financial support of the city and citizens of Zagreb many projects came through in the last couple of years which contributed to substantial progress in the development of public transit system. So far 70 new, modern, low-floor trams were purchased and the delivery of the second series which includes 70 low-floor trams is scheduled for March 2008. During 2009. was acquired and 214 low-floor buses.

Following the environmental standards, in the year 2007 ZET started to use biodiesel in public transportation vehicles, and from 2008. used compressed gas.

3. METHODS FOR EVALUATING EFFECTIVENESS

The profitability of an investment project is observed here in from the economic flow determined by fixed prices (to avoid the impact of inflation within the project lifetime).

The adequacy of an investment is perceived using several methods used in practice:

a) Payback period method
b) Net present value method
c) Internal rate of return method.

a) Payback period

Payback period in refers to the period of time required for the return on an investment to "repay" the sum of the original investment. For example, a $2000 investment which returned $1000 per year would have a two year payback period. The time value of money is not taken into account. Payback period intuitively measures how long something takes to "pay for itself." All else being equal, shorter payback periods are preferable to longer payback periods. Payback period is widely used because of its ease of use despite the recognized disadvantages described below.

Disadvantages:

- Ignores the time value of money
- Requires an arbitrary cutoff point

- Ignores cash flows beyond the cutoff date
- Biased against long-term projects, such as research and development, and new projects.

b) Net present value method

Exploring profitability of an investment project using this method includes the calculation of the investment project net present value as a sum of the economic flow annual net revenues expressed as values in a starting year of a project. NPV is determined using the formula:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+k)^t} \qquad (1)$$

where,

NPV = Net present value
R_t = The net cash flow
r = Discount rate
t = The time of the cash flow

Three possible cases NPV is:

- When NPV is greater than zero it means that the discounted value of future cash flows is greater than your initial investment and you would be getting an even higher return than you desire.
- When NPV is zero it means that the discounted value of future cash flows equals your initial investment and you would be getting exactly the return you desire.
- When NPV is less than zero (a negative number) it means that the discounted value of future cash flows is less than your initial investment and you would be getting a lower return than you desire.

Relative net present value determines effects of a project per invested value. It is calculated using the following formula:

$$RNPV = \frac{NPV}{Io} \qquad (2)$$

where,

RNPV = Relative net present value
NPV = net present value
Io = total invested values during the project lifetime.

c) Internal rate of return method

Internal rate of return (IRR) method defines the discount rate that reduces the net present value of a particular investment to zero.

IRR:

- Helps measure the worth of an investment
- Allows the firm to assess whether an investment in the machine, etc. would yield a better return based on internal standards of return
- Allows comparison of projects with different initial outlays
- Set the cash flows to different discount rates.

4. RESEARCH RESULTS

Through the measure of purchasing electric buses ZET is plan to renew bus fleet. Buses that are specified in the Table 1 should be replaced with 10 electric buses that would pass the same annual mileage (1,025,976 kilometers). Investment cost of electric buses is 2.47 million euros (247,000 euros per bus[2,3]).

[2] http://chinaautoweb.com/2011/03/byd-k9-electric-bus-to-be-tested-in-denmark/
[3] http://www.byd.com/news/news-1-114.html

Table 1 General data about some diesel buses in ZET fleet

Garage number	Average annual mileage	Year of production	Euro standards	KW	Fuel consumption litres/100km
501	5,46	1995	EURO 1	220	67.25
502	17,268	1995	EURO 1	220	67.53
503	13,86	1995	EURO 1	220	69.86
504	16,152	1995	EURO 1	220	67.84
505	19,92	1995	EURO 1	220	51.98
506	35,028	1996	EURO 2	220	59.79
507	38,22	1996	EURO 2	220	56.65
508	57,216	1996	EURO 2	220	58.89
509	132	1996	EURO 2	220	63.24
510	17,796	1996	EURO 2	220	65.03
511	61,968	1996	EURO 2	220	59.38
512	-	1996	EURO 2	220	-
513	-	1996	EURO 2	220	-
514	-	1996	EURO 2	220	-
515	52,548	1996	EURO 2	220	64.26
516	77,76	1997	EURO 2	220	62.85
517	34,128	1997	EURO 2	220	64.07
518	68,388	1997	EURO 2	220	60.44
519	50,496	1997	EURO 2	220	59.92
520	78,564	1997	EURO 2	220	55.41
521	62,652	1997	EURO 2	220	56.89
522	78,936	1997	EURO 2	220	59.73
523	86,412	1997	EURO 2	220	60.04
524	88,176	1997	EURO 2	220	55.04
525	64,896	1997	EURO 2	220	61.61
Total	1,025,976				61.26

Source: ZET

Savings on reducing fuel consumption on an annual basis is significant and this amounts is 679,800 euros. The calculation is based on the difference in price of diesel fuel (1.32 €/liter - average for the first six months of 2012. in Croatia) which use buses that are currently in traffic and the price of electricity (price of one kilowatt hour in Croatia is 7.46 euro cent with VAT and consumption[4] of electric buses is 1 kWh per mile). Savings on maintenance costs are calculated as the difference between the cost of maintaining diesel buses and electric buses (electric bus maintenance cost throughout the lifetime is 23% of the purchase price, while the diesel bus maintenance cost is 100%).

[4] http://www.byd.com/auto/ElectricBus.html.

Table 2 Total benefit - Electric Bus

	Savings in maintenance costs (€)	Savings in reducing of the fuel consumption (€)	Savings in reducing emissions (€)	Total benefit (€)
0				
1	13,600	679,800	33,000	694,400
2	13,600	679,800	33,000	695,400
3	13,600	679,800	33,000	696,400
4	13,600	679,800	33,000	697,400
5	13,600	679,800	33,000	698,400
Total	68,000	3,399,000	165,000	3,632,000

Table 3 Emission factors for urban buses

Pollutant	The average value [grams / km]
CO	7.97
CO_2	1.275
HC	0.728
NO_x	13.51
SO_2	0.073
PM	0.769

Source: Cherry, Weinert and Xinmiao, Y., 2009.

Table 1 Savings in reducing emissions

	CO (g/km)	CO_2 (g/km)	HC (g/km)	NO_x (g/km)	SO_2 (g/km)	PM_{10} (g/km)
tons	8.177	1,308	0.747	13.861	0.075	0.789
Price €/per tonne	4	25	2	7.7		156.9
Total €	33	32,703	1.5	107	0	124

Source: For prices per tonne - Piao, J., et. al., 2009.

Savings in reducing emissions based on average values of emission factors (Table 3) for urban buses EURO 2 standards is presented in Table 4. The annual saving is 33,000 euros.

Table 2 The net present value for the measure of introducing electric buses

Year	Cost (€)	Benefit (€)	Δ = B - C	NPV (€)
0	2,476,000		-2,476,000	-2,476,000
1		726,400	726,400	648,600
2		726,400	726,400	579,100

3		726,400	726,400	517,000
4		726,400	726,400	461,600
5		726,400	726,400	412,200
Total	2,476,000	3,632,000	1,156,000	142,500

Relative net present value is:

$$RNPV = \frac{142{,}500}{2{,}476{,}000} = 0.0576$$

Table 3 Payback period for electric buses

Year	Cost (€)	Benefit (€)	Δ Cumulative
0	2,476,000		-2,476,000
1		726,400	-1,749,600
2		726,400	-1,023,200
3		726,400	-296,800
4		726,400	429,600
5		726,400	1,156,000

Net present value (Table 5) is 142,500 euros and the return of investment is in the fourth year. Internal rate of return is 14.3%.

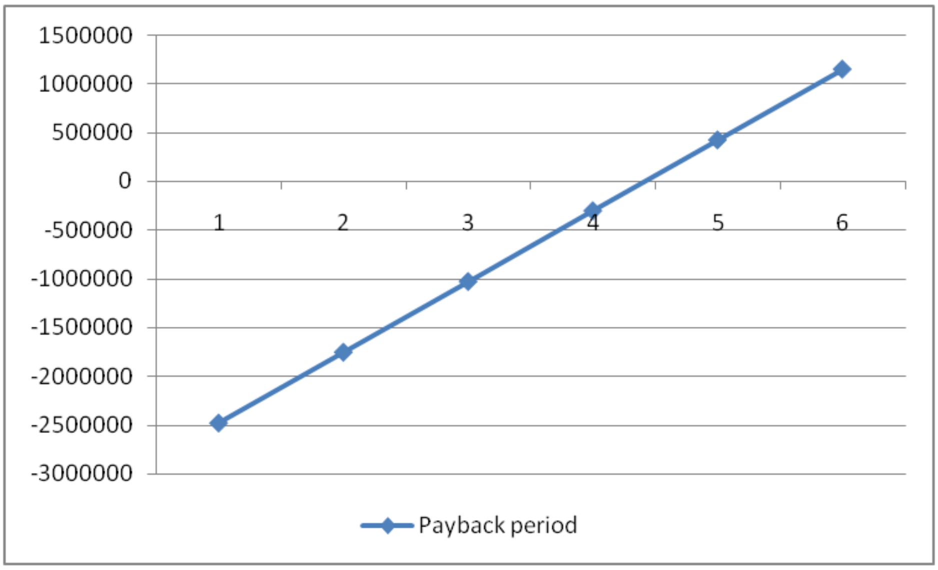

Figure 1. Payback period for electric buses (Graph)

5. CONCLUSION

Smart operators investigate all costs and benefits before making major purchase decisions. Prior to buying a car you want accurate information on its fuel, maintenance, repair and insurance costs. Similarly, is with electric buses. Consumers need accurate and comprehensive information when making personal travel decisions, communities need accurate and comprehensive information on all significant impacts when making transport policy and planning decisions (Litman, T., 2011).

Through the conducted analysis in this paper it can be concluded that the introduction of electric buses instead of old buses that have Euro1 and Euro2 norms is justified from an economic and environmental point of view.

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An Economic Model For Waste to Heat District Greenhouse Heating

Greenhouses are widely used in horticultural applications especially in cold climates. By means of climatic factors and increasing fuel prices, greenhouse heating becomes a vital issue. Renewable sources such as biomass and passive heating applications like using north wall are currently used applications. Heating greenhouses with a waste heat source is another alternative. In this paper we present an economic method for heating greenhouses with waste to heat applications in order to calculate the parameters that effect the economical viability of the system. A sensitivity analysis also executed and shown on graphics.

Keywords: greenhouse, district heating, waste heat

Knowing electricity end-uses to successfully promote energy efficiency in buildings: a case study in low-income houses in Southern Brazil

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Abstract

The objective of this paper is to show the importance of measuring electricity end-uses in order to promote energy efficiency in low-income houses in Southern Brazil. Sixty low-income houses were surveyed, and data of socioeconomic variables, electricity use, and usage pattern were measured and obtained. The data were statistically treated and confidence intervals were assigned to obtain representative electricity end-uses and usage patterns. The results showed that the electric shower has the greatest electricity end-use, i.e., 33.5 to 40.3%, followed by the refrigerators, with end-use of 27.4 to 33.1% with 90% non-parametric confidence interval. Usage patterns were obtained for appliances and lighting for each room and also for the electric shower. For the average usage pattern of all appliances and lighting, the usage power fraction never exceeds 20%. The results of this study will provide basis for determination of guidelines for low-income houses and government programmes for energy efficiency, rational use of energy and renewable energy.

Keywords: Low-income houses, electricity end-uses, electricity usage pattern, Southern Brazil.

JEL Classification Code: D1

1. Introduction

Energy is a key resource for social and economic development worldwide. However, the economic growth may lead to an expansion of lifestyle aspirations, which, in turn, increases energy consumption and associated impacts (Chung-Sheng *et al*., 2012).

The Brazilian electricity consumption has been increasing over the last decade. For instance, in the residential sector, such consumption increased from 72,670.0 GWh in 2002 to 113,328.0 GWh in 2011. Nowadays, the residential sector represents 23.6% of the total electricity consumption in Brazil (Brasil, 2012a). Therefore, there was an increase of 55.6% of the total electricity consumption for the residential sector over the last decade, approximately 5.6% per year.

The energy consumption in residential buildings depends on the activities carried out by occupants, which refers directly to the household energy end-use (Bin and Dowlatabadi, 2005). Therefore, several studies addressing the electricity end-use of residential buildings have been undertaken in Brazil (Jannuzzi and Schipper, 1991; Almeida *et al*., 2001; Ghisi *et al*., 2007). These studies can contribute to the development of strategies to enhance the energy efficiency in residential buildings.

In general, the wealthier people are, the more energy they will consume. According to Druckman and Jackson (2009), an increase in socioeconomic levels leads to an expansion of the energy consumption pattern and associated environmental impacts due to the enhancement of comfort, recreation and leisure. Ghisi *et al*. (2007) found this same trend for Brazilian houses, where wealthier families have had larger electricity consumption than poorer families. In the last decade, the Brazilian minimal wage raised from R$200 to R$622 (Brasil, 2007; Brasil, 2011), which has probably contributed to the growth of the total electricity consumption in the residential sector nationwide.

In this context, the Brazilian government has been developing programmes to improve the energy efficiency at low-income houses. In order to improve such programmes, it is important to know the electricity end-uses and usage patterns of Brazilian low-income houses.

The objective of this paper is to show the importance of measuring electricity end-uses in order to promote energy efficiency in low-income houses in Southern Brazil.

2 Method

In order to estimate the electricity end-uses and usage pattern, the following steps were carried out: (1) Data collection, (2) Data treatment, and (3) Data analysis.

2.1 Data collection

Data collection was undertaken through household interview surveys using questionnaires and monitoring equipment to register the electricity consumption of each electrical appliance, for summer and winter seasons.

2.1.1 House selection

Sixty low-income houses were randomly surveyed in the metropolitan region of Florianópolis, Southern Brazil. Low-income houses were classified in accordance with national laws and guidelines on Social Housing (e.g. PMF, 2011) as families with total monthly wage of R$1,866.00 (€687.20 in January 2013).

2.1.2 Questionnaires

Three questionnaires were used during the household interview surveys: (1) socioeconomic questionnaire; (2) electricity end-use questionnaire; and (3) electricity usage pattern questionnaire.

In the socioeconomic questionnaire, the number of occupants, and total and per capita income were collected.

In the electricity end-use questionnaire, the characteristics of each electrical household appliance were determined, including: type, model, power consumption, and the room in which the equipment is placed. The household monthly electricity consumption recorded by the local energy utility during the last 12 months was also obtained.

In the electricity usage pattern questionnaire, the usage pattern of each electrical appliance was estimated by interviewing householders. The questionnaire was structured as to allow the collection of data on an hourly basis, in which the duration of each usage event was estimated in seconds or minutes for each hour of the day. The usage patterns of electrical appliances were estimated for both summer and winter seasons.

2.1.3 Monitoring equipment

The electricity consumption of electrical appliances was measured during a minimum period of two weeks in each household. For this purpose, two meters were used: (1) PowerBall T8 and (2) CEM 1000.

The PowerBall T8 meter was employed to determine the total usage time and total electricity consumption of electrical appliances during the monitoring period. This meter was used to monitor electrical appliances rated up to 2.2 kW, including, but not limited to: fridge, freezer, washing machine, microwave, television, computer, fan, iron, coffee machine, hair dryer.

Electric shower heads were not monitored using this meter, because their power can range up to 8.0 kW.

Equation 1 was used to determine the electricity consumption of electric shower heads, considering the manufacture power rating and the usage time pattern estimated by householders.

$$EC = P \times \int_0^t T \, dt \quad (1)$$

Where *EC* is the electricity consumption (kWh); *P* is power rating (kW); *T* is the usage time (h); *t* is the evaluated period (days).

The CEM1000 meter was used to measure the electrical characteristics of lamps, including: instantaneous power, power factor, voltage and current. This equipment was not used to register the electricity consumption over the monitoring period, but rather to define the instantaneous power rating. Therefore, the electricity consumption of light bulbs was estimated using Equation 1, considering the instantaneous power rating measured and the usage time pattern estimated by householders.

2.2 Data treatment

Data treatment was performed so as to determine representative values and confidence intervals of electricity end-uses and usage patterns estimations. Three analyses were carried out: (1) electricity usage patterns and end-uses; (2) electricity consumption validation analysis; and (3) confidence intervals.

2.2.1 Electricity usage patterns and end-uses

Hourly usage patterns and electricity end-uses were calculated for each electrical appliance using the usage pattern estimated by the householders and obtained through questionnaires, and the average power rating. This last parameter was determined using Equation 2.

$$AP_a = \frac{EC}{T} \quad (2)$$

Where $\mathrm{AP_a}$ is the average power rating for each appliance (kW); EC is the electricity consumption over the monitoring period (kWh); T is the usage time over the monitoring period (h).

Equation 3 was used in order to determine the hourly electricity consumption pattern.

$$ECH_a = AP_a \times T_h \quad (3)$$

Where ECH_a is the electricity consumption of an appliance for each hour of the day (kWh); AP_a is the average power rating (kW);T_h is the usage time for each hour of the day (h).

The total average daily electricity end-use for each appliance was calculated using Equation 4.

$$ECD_a = \int_0^{24} EC_h \quad (4)$$

Where ECD_a is the total daily average electricity consumption (kWh); EC_h is the electricity consumption for each hour of the day (kWh).

The monthly electricity consumption for each appliance was estimated multiplying the total daily average electricity consumption by 30.42 days (365 days divided per 12 months). The total monthly electricity consumption at households was determined using Equation 5.

$$ECM_t = \int_{i=1}^{n} ECM_a \quad (5)$$

Where ECM_t is the total monthly electricity consumption (kWh); ECM_a is the monthly electricity consumption for each appliance (kWh); n is the number of appliances.

The electricity end-use of each appliance was calculated using Equation 6.

$$E\%_a = \frac{ECM_a}{ECM_t} \times 100 \quad (6)$$

Where $E\%_a$ is the electricity end-use for each appliance (%); ECM_a is the monthly electricity consumption for each appliance (kWh); ECM_t is the total monthly electricity consumption (kWh).

2.2.2. Electricity consumption validation analysis

The estimated electricity consumption for each house was compared with monthly electricity consumption recorded by the local energy utility. When the difference between estimated and recorded total electricity consumptions was greater than 20%, the house was excluded from the sample. After the excluding process, 53 houses were left to perform the electricity end-use and usage pattern analyses.

2.2.3. Confidence intervals

Parametric and non-parametric statistical analyses were performed so as to determine the confidence intervals of electricity consumption patterns and average installed power in each room.

For the parametric statistical analysis, Student's t-test was used assuming the sample was normally distributed. For non-parametric statistical analysis, Wilcoxon rank sign test was undertaken assuming the sample was not normally distributed, but rather symmetric according to the median.

The Wilcoxon rank sign test is employed to estimate confidence intervals for median values of small samples. According to Siegel (2006), this test describes well behavioural variables, such as usage patterns. In comparison to the Student's t-test, the Wilcoxon test compares the difference between median values rather than the difference between mean values. The analyses were carried out with MiniTab 16 Statistical Software.

Using data from electricity end-use estimations, the uncertainties of their mean and median values were calculated using a confidence interval of 90%.

2.3 Data Analysis

The data analysis was carried by determining the usage pattern schedules for rooms and electrical appliances.

The electrical appliances in the same room were grouped in order to determine the average daily usage pattern schedule. The usage pattern was considered ranging between 0 and 1 for events representing non- and full- power usage, respectively. These average schedules were weighted by both their average power and their share on the total electricity consumption of each house, in order to determine the representative schedules. The usage pattern schedule for each electrical appliance was undertaken using the Wilcoxon confidence interval of 80%, due to the large variability in the data, associated with the average installed power.

3. Results

The final results of the analysis performed in this research are presented in this section, which were divided by electricity end-uses and usage pattern.

3.1. Electricity end-use

Table 1 shows the electricity end-uses for the houses with a 90% confidence interval by Wilcoxon's test. The outlier values were disregarded and the ranking is based on the median of the sample. The "other" end-use refers to appliances that individually do not contribute as a representative end-use and also exhibits large variability on the sample.

Table 1– Median electricity end-uses for the whole year with 90% confidence interval with non-parametric test.

Value	Electric Shower	Refrigerator	Television	Lighting	Clothes Washer	Microwave	Other
Lower limit	33.5%	27.4%	8.4%	4.5%	0.7%	0.4%	8.0%
Median	36.8%	29.9%	10.2%	5.2%	0.9%	0.6%	10.5%
Upper limit	40.3%	33.1%	12.2%	6.1%	1.1%	0.9%	13.5%

According to Ghisi et al. (2007), the electricity consumption of electric shower represents 14 to 28% in summer and 26% in winter for the region sampled. The refrigerator features 33 to 34% in summer and 30% in winter.

According to Table 1, electric shower, refrigerators, television and lighting together represent from 73.8% to 91.7% of the total electricity consumption. The end-use results did not show significant difference between summer and winter seasons, and were generalized for the whole year.

There are some national programmes for energy efficiency promoted by state governments, energy utilities or private companies. In Midwest Brazil, for example, the energy utility performs donation of efficient refrigerators, compact fluorescent bulbs, and promotes the replacement of electrical conductors in the houses, benefiting so far, more than 32,000 low-income houses (Brazil 2012b). The estimated savings are 4,285.41 MWh per year and reduction of 536.48 kW on the peak load demand.

The National Institute of Metrology and Industrial Quality (INMETRO), through the Brazilian Labelling Programme, and the National Energy Utility (Eletrobras), and National Programme of Electricity Conservation (Procel), performs labelling of various equipment, including electric showers, refrigerators, televisions and light bulbs according to their energy efficiency. These energy efficiency labels are indicators that help buyers in the decision making process and encourage them to save electricity.

As for the electric shower, government programmes such as the Growth Accelerating Programme (PAC) have encouraged the use of solar water heating in low-income houses. Researches indicate appropriate solar fraction in most regions of Brazil, justifying their feasibility against the use of electric shower, reducing electricity consumption and peak load demand, with low payback (Naspolini and Rüther, 2011; Martins et al., 2012).

According to Ghisi et al. (2007), the electricity consumption in the bioclimatic zone where Florianópolis is located, ranges from 7.74 to 8.41kWh per day over summer and around 8.91kWh per day over winter. The data collected in the 53-house sample showed daily average of 7.23kWh and 7.79kWh, for summer and winter, respectively. The monthly average electricity consumption is 214 kWh and its median, 194 kWh. Wide variation on the data can be identified, with values ranging from 80 to 400 kWh per month. Figure 1 shows the frequency of monthly and daily absolute electricity consumption of the 53-house sample.

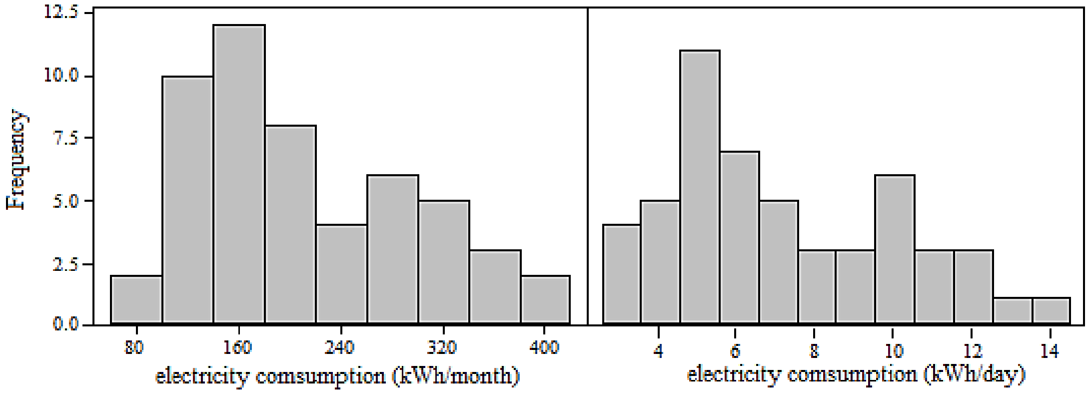

Figure 1 *– Electricity consumption of the 53-house sample in kWh per month and per day.*

3.2. Usage pattern schedules

Due to the great variability in the data regarding the appliances power and their usage pattern, the solution adopted was to create representative schedules for the 53 houses.

Figures 2 to 5 show representative usage patterns, summarized in a power usage fraction per room, which is a value from 0 to 1 indicating the partial power usage in each hour of the day. Figure 2 shows the usage patterns of all household appliances; Figure 3 shows the lighting usage pattern in each room and Figure 4 shows the usage pattern of electric shower, which is the largest electricity consumer of the sample. Figure 5 shows the average usage pattern in the sample, related to the sum of installed power with appliances and lighting, and it can be noticed that the fraction never exceeds 20%. This demonstrates the error that can be made in the scheduling process, in case of super-estimated power usage fractions; and also shows the simultaneity factor (potential power that can be turned on in the whole house, simultaneously).

It may be emphasized that the average values for each room in Figure 2 are shown without confidence intervals. Figure 3 shows median curves and Figure 4 shows the 80% confidence interval obtained by using the Wilcoxon test.

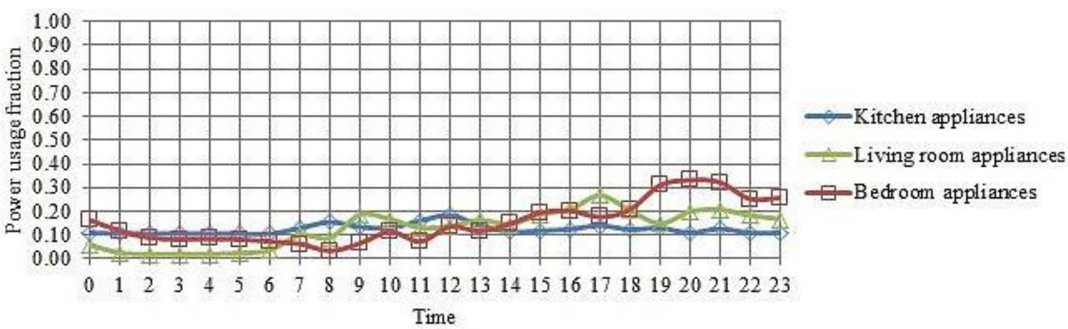

Figure 2 *– Household appliances usage patterns for each room (average values).*

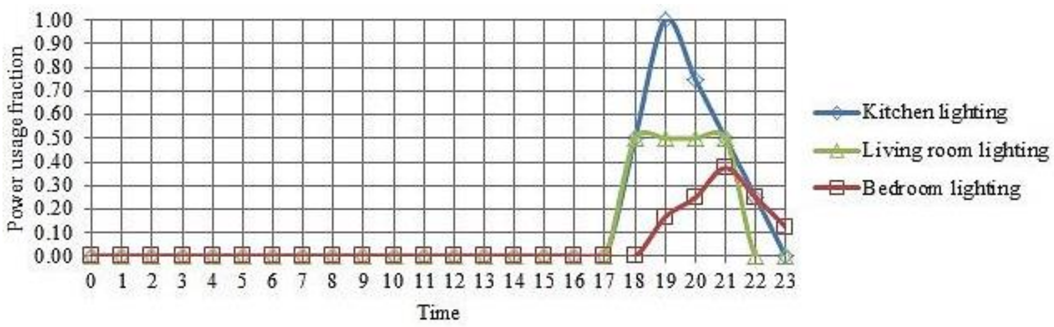

***Figure 3** – Lighting usage patterns for each room (median values).*

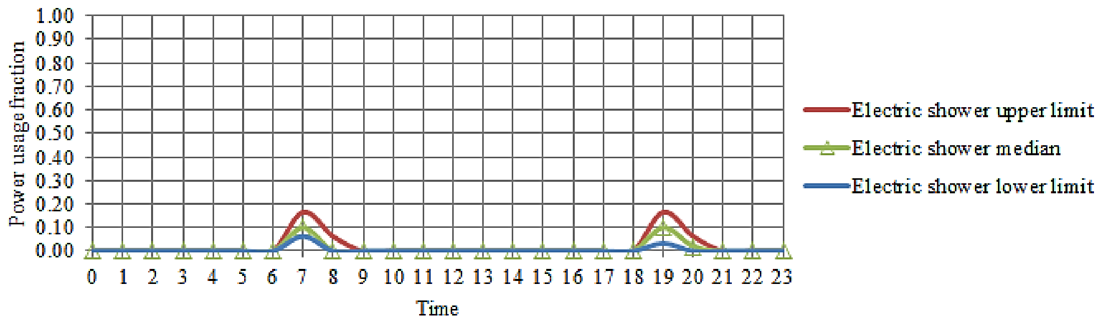

***Figure 4** – Electric shower usage patterns. The three curves represent the inferior and superior limit from the 80% confidence interval, and the median curve (median values).*

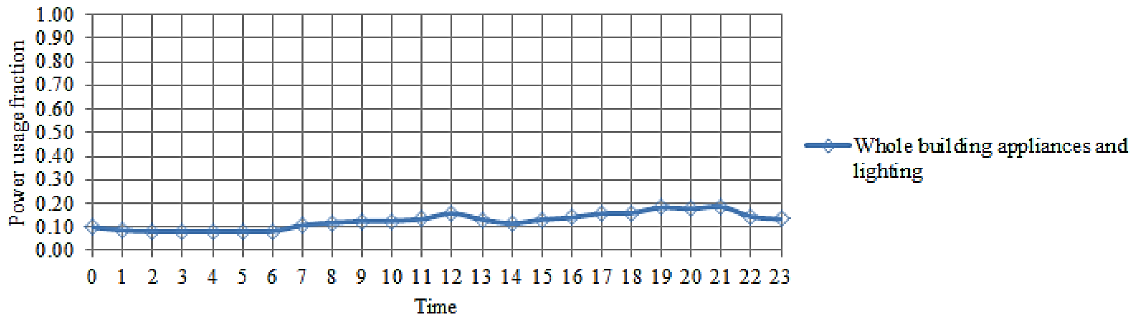

***Figure 5** – Appliances and lighting usage patterns for the whole building, in average values associated with the sum of the respective average power.*

The usage patterns shown in Figures 2 to 5 are associated with the installed power shown in Table 2, which presents the average installed power for each room of the 53 houses with 80% confidence interval, obtained using the t-test.

Table 2 –Average power for each room of the 53-house sample using the Student t-test with 80% confidence interval.

80% confidence interval	Electrical appliances (W)			Lighting (W)			Electric shower (W)
	Kitchen	Bedroom	Living room	Kitchen	Bedroom	Living room	
Lower limit	691.5	90.1	146.0	25.3	29.6	19.0	3062.0
Average	838.2	161.3	225.4	30.3	33.7	23.5	3298.0
Upper limit	984.9	232.5	304.6	35.3	37.9	28.0	3533.0

4. Conclusions

In this study, a sample of low-income houses in Southern Brazil was selected for the determination of electricity end-uses, with confidence interval. The importance of measuring electricity consumption and to perform appropriate interviews and quantification was shown, helping to obtain more realistic results.

The greatest electricity end-use found was the electric shower, followed by refrigerator, television and lighting, although other studies indicate differently for some regions of Brazil. The usage patterns obtained are useful for system sizing that can be proposed (such as solar water heating, photovoltaic system, air conditioning system) and for the quantification of future energy savings. Besides, the usage patterns help to assess the thermal performance of the building through thermo-energetic analysis, as they represent the occupant behaviour.

Through this method, it was possible to define the appliances responsible for larger electricity consumption in the low-income houses of Southern Brazil. Thus, it is possible to set goals to energy efficiency, such as investing in technologies of solar water heating and government programmes to encourage the use of energy-efficient appliances according to national laws and labels. However, these solutions are based on technical and economic feasibility, which can be different for each climate and solar radiation availability in the regions of Brazil, which indicates that more specific researches must be performed.

In general, the results shown herein will provide a basis for other studies, whose primary focus is the determination of guidelines for low-income housing, guiding and reinforcing government programmes for energy efficiency, rational use of electricity and renewable energy use.

Acknowledgements

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Characterisation and Modelling of Energy Behaviours

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Abstract

Energy behaviours represent a significant untapped potential for the increase of end-use energy efficiency in buildings. However, although there is extensive research on energy behaviours in the residential sector, there is a critical lack of characterisation and systematisation of energy behaviours influence on energy use. This paper aims at exploring the influence of energy behaviours on energy efficiency, by contributing to the characterisation and systematisation of energy behaviours in the residential sector and proposing an integrative modelling approach. In summary, energy behaviours are observed acts that lead to energy consumption and are usually categorised as investment, maintenance and usage behaviours. Energy behaviours are complex, shaped by many factors, not only individual but also contextual. Understanding the nature of energy behaviours is paramount not only to energy behaviours modelling, but also as preparation for behavioural change interventions, and ultimately to achieve more efficient energy behaviours and more effective energy efficiency policies.

JEL classification codes: Q49 – Energy / Other

1. INTRODUCTION

Recent evidence provided by the International Energy Agency (IEA) indicates that despite all efforts, energy demand and its related carbon dioxide (CO_2) emissions continue to increase, and low-carbon energy strategies such as energy efficiency will require widespread deployment in order to achieve the CO_2 emissions goals (OECD/IEA, 2011b, 2012).

Although energy efficiency levels have improved in the last years, the IEA and the European Union (EU) assume that there is still a significant untapped energy efficiency potential, namely in the building sector (CEC, 2006; OECD/IEA, 2012). The EU, in particular, estimates this potential up to 27% in the residential sector, exclusively associated with infrastructural and equipment investments (CEC, 2006; OECD/IEA, 2012). The IEA even exceeds this estimate by stating that energy efficiency investments in residential buildings could be responsible for a potential reduction of 63% of the buildings sector energy consumption (OECD/IEA, 2011a).

Energy consumption in residential buildings is highly influenced by local climates and cultures, but it depends mostly on individual users (OECD/IEA, 2008). Indeed, occupant behaviour is a major determinant of energy use in buildings, but the potential of energy savings due to behaviours is usually neglected, albeit being referred to be as significant as those from technological solutions (Jonsson *et al.*, 2010; Ürge-Vorsatz *et al.*, 2009). As the EU acknowledges, one reason for this may be that savings not related with equipment and infrastructural efficiency improvements are more difficult to quantify and hence habitually not considered (EC, 2010). Nevertheless, research on energy behaviours indicate that potential savings due to behaviour may reach 20%, although values differ up to 100% between different studies (Lopes *et al.*, 2012). Furthermore, although there is extensive research on energy behaviours in the residential sector, there is a critical lack of characterisation and systematisation of energy behaviours influence on energy use (Levine *et al.*, 2007).

Accordingly, this paper aims at exploring the influence of energy behaviours on residential sector energy efficiency by contributing to the characterisation and systematisation of energy behaviours. Furthermore, it proposes an integrative modelling approach using a cognitive mapping methodology. The work objectives are twofold: (1) supporting the planning and implementation of on-going field research on energy behaviour change; and (2) considering the complexity and interdisciplinarity of energy behaviours to create a common ground for experts working in this area, thus facilitating the integration of multidisciplinary knowledge and promoting more effective energy behaviours research.

The paper is organized as follows. In section 2 energy behaviours are defined, characterised and framed in the energy efficiency context. An energy behaviour model is presented in section 3. The main results are briefly discussed in section 4.

2. ENERGY BEHAVIOURS

Energy behaviours are observed acts that lead to energy consumption and are usually categorised as **investment**, **maintenance** and **usage behaviours** (Van Raaij & Verhallen, 1983). Investment behaviours are those involved in the purchase of new equipment, including the relative importance of the energy attributes of the products in the choice process. They are also commonly designated as efficiency behaviours (Black *et al.*, 1985; Breukers *et al.*, 2011; Gardner & Stern, 2002). Maintenance behaviours refer to behaviours involved in the repair, maintenance and improvements of energy consuming equipment or the building itself (Van Raaij & Verhallen, 1983). Usage behaviours refer to day-to-day usage of equipment in buildings and the building itself, and may be characterised by its frequency, duration, and intensity of use. This category includes habitual behaviours, which are automatic and routine behaviours through which individuals repeat and do things mechanically without conscientiously weighting the pros and cons (Fischer, 2008; Gynther *et al.*, 2011; Maréchal, 2010). Habitual behaviours may represent about 90% of energy-related human behaviour (Gynther*, et al.*, 2011). This kind of behaviour is frequently incorporated in the decision-making process since it releases mental resources that can be devoted to solve non-routine problems (Maréchal, 2010). Habits are usually formed and activated in the presence of specific conditions (context and goals) and after satisfactory previous repetitions of a given behaviour (Maréchal, 2010). However, in what concerns energy efficiency, although habitual behaviours are functional they may yield sub-optimal results since the context may have changed in the meantime and the behaviour may no longer be the most energy efficient one (Fischer, 2008). Usually, this type of behaviours does not change, unless a modification in the external circumstances occurs that breaks that routine behaviour (Fischer, 2008; Gynther*, et al.*, 2011). Usage-related behaviours that decrease the use of energy and contribute to achieve energy savings are also named curtailment (Black*, et al.*, 1985; Breukers*, et al.*, 2011; Gardner & Stern, 2002) or conservation behaviours (Ehrhardt-Martinez *et al.*, 2011; Kok *et al.*, 2011). Very often energy behaviours are studied together with non-energy related environmental behaviours (Gadenne *et al.*, 2011; Poortinga *et al.*, 2004; Stern, 2000; Thøgersen, 2006).

This paper is focused on the usage energy behaviours. This type of behaviours is activated when, as a result of daily activities and processes, energy services (heating, cooling, lighting and electrical appliances powering) are required as means to satisfy needs that ultimately lead to energy use (Figure 1 and Table 1). Thus, when addressing energy behaviours there are always two implicit dimensions: the behaviour itself and the associated energy consumption, which provides a quantified indicator of the energy behaviour (Lopes*, et al.*, 2012). Energy use patterns will then be a result of users' daily practices and activities and, therefore this dual dimension must always be considered when addressing energy behaviour issues.

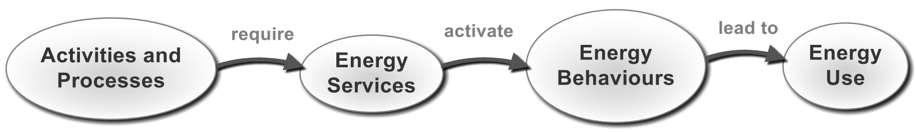

Figure 1 – Energy behaviours

At this stage, it is important to clarify the terms energy efficiency and energy conservation in the context of energy behaviours. Although both terms are commonly used, some authors argue that energy efficiency is related to investment behaviours while energy conservation is more adequate for referring to behaviours change that lead to energy savings (commonly addressed as conservation behaviours) (Oikonomou *et al.*, 2009). In this paper, the strict energy efficiency definition of reducing the final energy consumed while achieving the maximum energy services possible will be utilised, which may not be achieved only by the change of technologies but should involve the way they are used, i.e., energy behaviours (Lopes*, et al.*, 2012).

Examples of frequently cited usage energy behaviours in the residential sector are shown in Table 1. They were organised by energy services, such as lighting, food refrigeration and preparation, cleaning, information and communication technologies (ICT's), heating, ventilation and air conditioning systems (HVAC), and heating water.

Table 1 – Examples of usage energy behaviours in a residential environment.

Energy Service	Usage-related energy behaviours
Lighting	Turning off the lights when leaving an empty room Turning off all lights (or partially) when the sun light is sufficient Turning on only part of the lights in a room; if having dimming systems, adapting to light intensity
Food refrigeration	Controlling the temperature of the refrigerator /freezer; adjusting the temperature with seasons; adjusting the refrigerator temperature according to the quantity of food that it has stored Keeping the refrigerator door open only for short periods; do not opening the refrigerator door very often Putting cooled food into the refrigerator; unfreezing food in the refrigerator
Food preparation (cooking)	Unfreezing the food naturally before cooking it Putting the cover on the pot when cooking/boiling food; using the minimal water when boiling food/vegetables Turning the oven/hot plate off before ending cooking Using the microwave instead of the oven to cook the meals Keeping cooking appliances unplugged thus eliminating off power consumption Using off peak periods to cook meals
Cleaning	Starting the washing machine /dishwasher only when it is full Using energy saving programs at the washing machine /dishwasher; using lower washing temperatures/short programs Matching the clothes with equivalent characteristics Skipping the centrifuge function at the washing machine Using off peak periods to turn the washing machine /dishwasher on Unplugging the appliances in off mode thus eliminating off power consumption Drying the clothes outdoors/naturally; reducing the use of the tumble dryer Performing a manual dish pre-washing to enable a short washing program
ICT	Using appliances electricity-saving modes Do not setting the sound too loud or the screens too bright Turning appliances completely off, not leaving them in standby mode

	Switching off the appliances when nobody is using Unplugging the appliances in off mode thus eliminating off power consumption
HVAC	Adjusting (adding or removing) clothing Applying curtains or window blinds to prevent cold air from leaking out and sunshine from entering rooms Using natural ventilation Keeping the doors and windows closed between heated and not heated/cooled rooms; Reducing open time of door/windows Heating/cooling only rooms in use; turning off the thermostat in empty rooms Adjusting the thermostat temperature according to the season; Setting the thermostat to a lower temperature at night More members staying together in fewer rooms and turning on fewer air-conditioning Using off peaks periods to accumulate heat/cold Unplugging the appliances when off mode, thus eliminating off power consumption Turning off some minutes ahead of leaving out
Heating water	Reducing usage time of hot water (number and length of showers, etc.)

Adapted from (Abrahamse & Steg, 2009; Barr *et al.*, 2005; Dietz *et al.*, 2009; Ehrhardt-Martinez, *et al.*, 2011; Ek & Söderholm, 2010; Kok, *et al.*, 2011; Leighty & Meier, 2011; Mullaly, 1998; Ouyang & Hokao, 2009; Thøgersen & Grønhøj, 2010; Woods, 2008)

If analysed from an energy service point of view, the usage-related energy behaviours may be divided into five categories:

- **Efficient energy behaviours**. These energy behaviours occur when an energy service is activated with the minimum energy intensity and only for the required period of time. Examples include turning appliances on when entering a room and turning them off when leaving it.
- **Waste energy behaviours**. Energy wastage behaviours are opposite to efficient energy behaviours. The energy service is activated but not effectively utilised during that period. Examples include keeping appliances or lights on and leaving a room.
- **Energy service efficiency improvement behaviours**. These may represent the majority of daily energy usage-related behaviours. The energy service is activated, but the energy behaviour determines the amount of energy utilised for the same energy service quality. The energy behaviour controls and defines the equipment parameters, the load of the equipment, their programs or the use of passive heating or cooling strategies as complement to active strategies. Examples include: for the equipment parameterisation, adjusting the HVAC thermostat temperature; for the equipment load, starting the washing machine or dishwasher only when it is full; for the way of use, keeping the refrigerator door open for short periods of time; for passive strategies, using natural ventilation or light, or even adjusting clothing according to the temperature.
- **Economic efficiency improvement behaviours**. There are some energy behaviours that only influence the economic efficiency of the energy service, and not its energy efficiency. They consist of changing the time in which the energy service is activated, taking advantage of dynamic pricing. Examples consist of using off peak periods to use appliances.

- **Technology efficiency behaviours**. This behaviour category improves the intrinsic technology energy efficiency. Although the energy service is not activated, some technologies may have off-power or standby consumption. Hence, energy behaviours must be activated in order to eliminate this technology waste energy consumption, and surpass this technical limitation.

The unpredictable frequency by which users carry out these behaviours during their daily activities will influence the estimation of the overall energy behaviour efficiency. Increasing energy efficiency by changing energy behaviours will require properly targeting which behaviours to change, or even to improve. Further, it will demand a deep understanding of the factors that activate them.

3. MODELLING ENERGY BEHAVIOURS

Modelling is a central tool to modern science, management and policy making. By representing reality in a simplified yet meaningful manner, modelling helps to better comprehend reality and the systems' functioning, thus informing judgement and guiding problem solving (Moezzi & Lutzenhiser, 2010; Sterman, 2000). Further, being an iterative process of improvement, it involves continual questioning, testing and refinement of both formal and mental models (Sterman, 2000). In energy efficiency, for example, modelling is usually used for forecasting energy demand, predicting the adoption of new technologies and estimating the impacts of energy efficiency programs.

In this paper cognitive mapping is used to represent how energy behaviours relate with energy consumption. Cognitive mapping is a qualitative diagramming tool made of concepts linked by arrows which represent causal relationships (Özesmi & Özesmi, 2004). The concepts are represented by variables which may be measurable quantities or abstract qualitative concepts. This technique is usually applied in disciplines such as engineering, business management and political science helping to gain a better understanding of complex issues and supporting decisions. Cognitive maps presented in this paper are further structured by levels, according to their detail.

As previously mentioned, energy behaviours are activated when, as a result of the household daily activities and processes, energy services are required as means to satisfy needs, which ultimately lead to energy use. Energy resources (e.g. electricity, gas, fuel) provide the required energy services (Figure 2). All these components are influenced by several dimensions, such as household sociodemographic context, the building characteristics, the physical environment, the energy consuming equipment characteristics, behaviour determinants, and the socioeconomic environment (Figure 3).

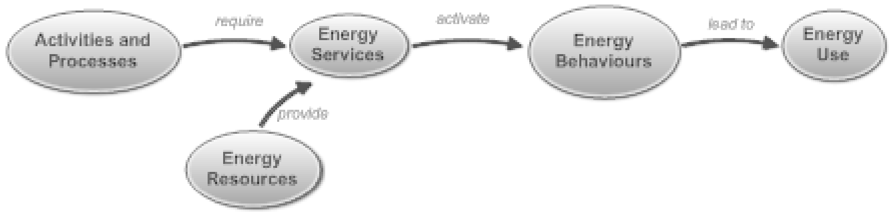

Figure 2 – Energy behaviours 1st level cognitive map

People daily activities are very diverse and comprise, in general, gainful work and study, domestic work, meals, personal care, travel, free time and sleep (EC, 2004). Most of these activities are performed at home and involves several processes that activate energy services (some of them energy intensive) such as food preparation, dish washing, cleaning, laundry, ironing, bathing, playing videogames, watching television, or even reading. These activities and processes will be influenced by the household sociodemographic context, such as its composition (e.g. number of individuals, age, sex, family relation, and marital status), lifecycle, level of education, income, professional activity, dwelling ownership, time spent at home, lifestyle (Cayla *et al.*, 2011; Hori *et al.*, 2013).

The magnitude and frequency by which energy services are activated will not only depend on the sociodemographic context, but are also influenced by the physical environment, the building and equipment characteristics.

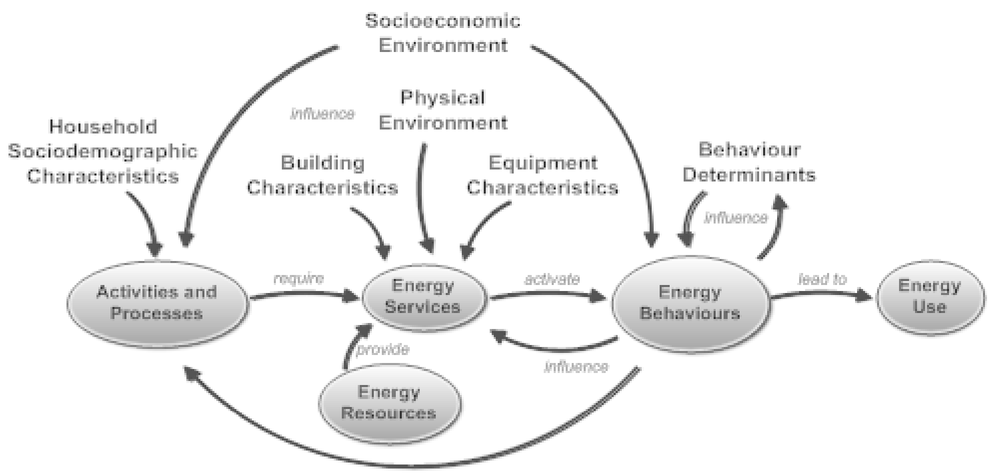

Figure 3 – Energy behaviours 2nd level cognitive map

Household energy use is closely related to the physical environment. Climate affects the level of energy services required to achieve a comfortable indoor temperature, and solar exposure influences both the thermal comfort as well as the lighting comfort (OECD/IEA & AFD, 2008). In fact, a considerable amount of energy is consumed for space heating, which reached a share of

53% of end-use energy consumption in residential buildings in the IEA19 in 2005, while lighting only accounted for 5% (OECD/IEA, 2008b).

Two major building characteristics influence the magnitude by which energy services are activated, thus leading to more or less energy consumption: the dwelling size and its energy efficiency. The bigger the dwelling, the more area needs to be cooled or heated, the more lighting power is required and more appliances need to be powered, thus leading to a higher magnitude of energy services activation, and consequently to a greater energy use. The energy efficiency of the building directly influences the indoor comfort environment, thus determining the level of energy services required. The most important parameters affecting buildings' energy efficiency are the thermophysical properties of the building envelope, directly related with the level of insulation (of roof, walls, windows and doors), and the passive architectural features such as orientation, the building form and optical characteristics that influence natural lighting (OECD/IEA & AFD, 2008). The better the level of insulation and passive architectural features, the better will the building energy efficiency be. Other characteristics such as the building age or the dwelling type (apartment, detached habitation, etc.) are directly related with the former variables.

Inside the buildings, the existing energy consuming equipment influence the level of energy use in two ways. On the one hand, the number of energy consuming equipment increase the magnitude of the energy services required, and consequently the level of energy use. On the other hand, the energy efficiency of that equipment reduce the amount of energy required to perform the energy services. Regardless of the improvements on energy efficiency standards, energy demand has substantially increased in the residential sector in recent years not only due to the rapid ownership of electricity consuming devices, especially small personal appliances and electronics (e.g. flat-screen televisions, cable TV reception and conversion boxes, mobile telephones and personal computers) (OECD/IEA, 2008, 2012), but also due to the individual and simultaneous use of these appliances.

The equipment use is a result of individual (or collective) needs during the household daily activities and processes, which lead to energy service activation and energy use. Energy behaviours mediate these relations. The more efficient energy behaviours are, the less amount of energy required to perform energy services. However, energy behaviours are complex and are influenced by many variables usually designated as behaviour determinants. At the personal level some include personal and social norms, beliefs, values, attitudes, intentions and perceived capabilities (Ajzen, 1991; Bagozzi et al., 2002; Bandura, 1991; Fishbein & Ajzen, 1975; Schwartz, 1977; Schwartz, 1994; Stern, 2000; Thøgersen & Ölander, 2002; Wilson & Dowlatabadi, 2007). Favourable attitudes towards energy efficiency promote intentions of performing efficient energy behaviours, and consequently their accomplishment. In turn, these promote positive attitudes in relation to energy efficiency. Personal moral norms and social norms also directly influence energy behaviours, particularly if users believe their actions will cause adverse consequence to others and feel responsible for that. Values affect beliefs, which in turn will also influence attitudes towards energy efficiency. Examples include altruistic values towards humans, such as freedom, honesty, and towards the biosphere, such as protecting the environment or unity with nature (Schwartz, 1994). The intentions of performing (or not) efficient energy behaviours are influenced by perceived capabilities, i.e.

the perception individuals have on the availability of necessary opportunities and resources to perform those behaviours (e.g., time, financial ability, skills, and cooperation with others).

On broader level, the surrounding socioeconomic environment also influences energy behaviours. The increase of energy prices, for example, increases energy expenditure, promoting higher energy awareness and literacy among householders, which in will turn favour energy efficient behaviours. In general, the increase of energy awareness and literacy created by bill increases and/or energy efficiency policies and behaviour change programmes also reinforce favourable energy determinants towards energy efficiency. Social pressure may also stimulate behaviour determinants (e.g. social norms) towards (or against) more efficient energy behaviours. A favourable economic context (such as economic growth) increases, in general, the need for energy services and consequently increases energy demand by rising the household financial ability and therefore their capacity to diversify and intensify household activities and processes. The exact reverse of this effect is nowadays being felt in some European countries.

Looking beyond the former influences on energy behaviours, it is also imperative to recognise energy behaviours feedback effects over other components of the model. For instance, not only energy behaviours are influenced by behaviour determinants, but may also influence, and even change, behaviour determinants (e.g. attitudes). Furthermore, energy behaviours may also directly restrict the household processes and activities as well as the magnitude of the energy service activation. For example, aiming to reduce energy consumption, and in order to perform the same activities, users may replace existing processes by others less energy intensive, reduce their frequency or even their magnitude. Finally, the socioeconomic context has a direct effect on the household sociodemographic characteristics (e.g. household income).

4. DISCUSSION

This paper characterised and systematised energy behaviours, and presented an evolving energy behaviour modelling approach uncovering multiple factors influencing the residential energy behaviour system.

In summary, energy behaviours are observed acts that lead to energy consumption, being usually divided into investment, maintenance and usage behaviours. Usage energy behaviours are activated when, as a result of daily activities and processes, energy services are required as means to satisfy needs, which ultimately lead to energy use. Accordingly, energy behaviours are bi-dimensional, since beyond the behaviour itself they imply associated energy consumption. Analysed from an energy service perspective, usage energy behaviours were categorised into additional categories, depending on the level of energy efficiency performed by energy behaviours, the behavioural intervention to overcome technology efficiency limitations and to improve the economic efficiency of the energy service.

The model presented in this paper identified multiple factors influencing residential energy behaviours and energy use, such as the household sociodemographic context, the building characteristics, the physical environment, the energy consuming equipment characteristics, personal behaviour determinants, and the socioeconomic environment. Energy behaviours are therefore a complex and multidimensional topic, shaped by individual and contextual factors that require for an interdisciplinary approach.

Although being still in a preliminary phase of development, the the cognitive mapping model presented in this paper allowed structuring the variables influencing energy behaviours and supported the planning and implementation of an on-going experimental energy behaviour research. Variables presented in this paper are being characterised and quantified using self-reported surveys and a smart electricity metering system and will be integrated into the model in a later phase. It is expected that the information gathered will allow establishing different users' profiles according to their energy behaviours. Furthermore, being part of a modelling process, this model does not constitute the ultimate version and will be further developed through the use of complementary modelling techniques including cognitive mapping and system dynamics. The characterisation, structuring and systematisation of energy behaviours revealed to be an essential phase in the modelling process.

In conclusion, understanding the precise nature of energy behaviours is paramount not only to energy behaviours modelling, but also to shaping policies for behavioural change interventions, and ultimately to achieve more efficient energy behaviours and more effective energy efficiency policies.

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DAY 9 - 16:30		
Room 613 - Market Power and Regulation		
Regulating International Gas Transport: Welfare Effects of Postage Stamp and Entry-Exit Systems	António Brandão[1]; Isabel Soares[1]; Joana Resende[1]; Joana Pinho[2]; Paula Sarmento[1]	[1]CEF.UP and Faculty of Economics of University of Porto; [2]CEF.UP. RGEA and Faculdade de Económicas. Universidad de Vigo
The impact of regulation, privatization and competition in gas infrastructure investments	Tiago Andrade[1]	[1]REN - Redes Energéticas Nacionais
Trading a Pumped Storage Hydro in a Liberalized Electricity Market with Increasing Degrees of Market Power	Fábio Teixeira[1]; Jorge Sousa[2]; Sérgio Faias[2]	[1]ISEL; [2]ISEL and Cie3/IST
The “Smart Paradox”: Stimulate the deployment of Smart grids with effective regulatory instruments	Vítor Marques[1]; Nuno Bento[2]; Paulo Morais Costa[3]	[1]ERSE, Portugal; [2]DINÂMIA´CET-IUL, ISCTE, Portugal; [3]Instituto Politécnico de Viseu, Escola Superior de Tecnologia e Gestão; INESC TEC – INESC Technology and Science

Regulating International Gas Transport:

Welfare Effects of Postage Stamp and Entry-Exit Systems

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Abstract

There is no consensus on the method to set transmission tariffs for natural gas. The *entry-exit* system is widely used in European markets because it iscost reflexive, it allows the network users to separate book of capacity for entry and exit points; beyond its pro-competitiveness characteristics. However, some authors defend the adoption of the *postage stamp* (where a single tariff is charged regardless of the origin of the gas), due to its simplicity. Our goal is to compare these two mechanisms of transmission tariff with respect to impacts on welfare. We find that the welfare effects depend crucially on the size of the internal market and incumbent firm's fixed costs. For large internal markets postage stamp regime leads to higher welfare when we assume that there are natural gas imports from abroad.

Keywords: Entry-exit tariffs; Natural gas; Postage stamp tariffs.

JEL Classification: L51, L95.

January, 2013

1. Introduction

European natural gas markets are undergoing substantial changes, namely due to the liberalization process, the demand expansion and the increasing importance of the imports (in particular of the liquefied natural gas, LNG). It is expected a decline of natural gas production in most of European countries (Gasmi and Oviedo, 2010). As a result, in response to demand imports increase (Cremer *et al.*, 2003; Gasmi and Oviedo, 2010). Another aspect that will facilitate imports concerns the reduction in transport costs in the last years (mainly for LNG), which "is one of the main driving forces for the growing globalization of natural gas markets" (Rosendhal and Sagen, 2009).

One fundamental question in discussion concerns the definition of the transmission tariffs. There are several systems to set the transport tariffs: *postage stamp*, *entry-exit*, *point to point*, *zonal tariff* or *capacity auctions* (Lapuerta and Moselle, 2002; Alonso *et al.*, 2010). Among these systems, the *postage stamp* and the *entry-exit* are the most used by European countries.

The *postage stamp* system implies the definition of a uniform tariff for a given capacity, independently of the entry and exit point of the network, or of the distance travelled by the gas. For a contracted capacity network users may change entry or exit points without signing a new contract. The main advantage of this system concerns the simplicity in its implementation. However, this mechanism displays no negligible disadvantages as the fact of not being cost reflective (because the tariff is independent on the location or distance) and do not allowing for cross subsidization.

According to the *entry-exit* system, the transmission tariff is split into two parts. More precisely, the *entry-exit* system allows network users to book capacity for entry and exit points separately, giving in this way more flexibility to their decisions. Moreover, this system encourages the development of notional points where gas is traded independently of its origin and the gas bought at one point can be delivered to any exit point of the system promoting the development of hubs (Alonso et al, 2010). Additionally, the tariff at an entry/exit point must be the same for all network users at that specific entry/exit point, ensuring in this way the non-discriminatory practice. Finally, another advantage of the *entry-exit* system relates to the ability of promoting trade, liquidity and gas to gas competition. Nevertheless, *entry-exit* system has some drawbacks, mainly resulting from the definition of two tariffs that might lead to higher fees in international transaction (the "pancaking" effect), which might reduce the incentive of cross-border transactions.

The European Commission and the Council of European Energy Regulators have a long-standing preference for the *entry-exit* system (CEER, 2002; Hunt, 2008; CEER, 2011), due to properties described above. Furthermore, the 3rd Package for natural gas (European Regulation no. 715/2009 of 13 July 2009 on conditions for access to the natural gas transmission network) establishes that, to enhance competition, it is crucial that gas can be traded independently of its location in the system.

In order to compare the welfare effects of different transmission tariffs systems, we propose a theoretical model which is based on the following assumptions:

(i) We consider two systems: postage stamp and entry-exit.
(ii) We consider an incumbent firm which is partially vertically integrated: production/imports/trade according to the 3rd Energy Package principles.
(iii) This incumbent holds a trading company that competes with an independent trader (without production technology) in the final consumers market.

(iv) We consider quantity competition in the final market. Natural gas market is well described by the Cournot model as competition take place through quantities between a small number of large players and the product is homogenous. In fact, this has been the assumption made in previous literature that analyses oligopolistic interaction in natural gas market (Golombek *et al.*, 1995; Golombek *et al.*, 1998; Mathiesen, 2001; Boots *et al.*, 2003; Jansen *et al.*, 2012 and the references therein).

(v) The marketer may buy the gas in the domestic market (from the incumbent firm) or from a foreign supplier.
(vi) We assume that the transmission tariff (from the incumbent to the marketer) is chosen by a domestic regulator, which approaches what happens in most of the European markets
(vii) Further, we assume that the objective of the regulator is to maximize social welfare.

The 3rd package establishes the unbundling principle for the natural gas market meaning that production and trade should be separate. However, until now we observe that many incumbent firms maintain production/import and trading activities into the same company. Indeed there are several examples where the production/import and trade operations are legally separated but the units that run these operations belong to the same holding company. Therefore, it is difficult to argue that they have independent strategies. This is the situation we represent in the model.

Related literature

Several authors have studied the European natural gas markets, but only few have specifically discussed the definition of transport tariffs.

An important branch of literature about the European natural gas market applies simulation models, as: the GASMOD (Holz *et al.*, 2008; Lise *et al.*, 2008), the GASTALE (Boots *et al.,* 2003), and the FRISBEE (Rosendhal and Sagen, 2009). These studies foccus on different features: Holz *et al.* (2008) study the supply structures; Lise *et al.* (2008) analyze the impact of demand uncertainty; Boots *et al.* (2003) investigate the role of gas trading companies in a context of liberalization and considering the existence of successive oligopoly. Boots *et al.* (2003) conclude that vertical integration should not be discouraged as it enhances welfare, due to the elimination of double marginalization. Rosendhal and Sagen (2009) investigate how lower transport costs for natural gas may affect the international gas markets. They conclude that counterintuitive results may happen: when transport costs are reduced, import prices and price differentials (between two import regions) may increase. These results largely depend on the transport distances and the choice of transport technology.

There is another branch of literature that analyzes the European natural market, but from a theoretical perspective. For example, Gasmi and Oviedo (2010) investigate the impact of the type of strategic interaction in downstream market. In particular, they compare three alternative models (Cournot, Stackelberg and no competition) with respect to the determination of the capacity transportation prices. Gasmi *et al*. (2004) analyze alternative regulatory policies that might be used with the purpose of reducing the effects of the exercise of local market power by gas suppliers.

Specifically about the transportation tariffs, Alonso *et al.* (2010) build a model to compute the entry and exit tariffs for the Spanish gas transport system in 2009. The authors conclude that the *entry-exit* system would be more efficient than the *postage stamp* system used in Spain at that time.

The paper is organized as follows. After the introductory section, the model is presented and solved in section 2 and the main conclusions are discussed in section 3.

2. The model

Consider a regional natural gas market, market *A*, where a marketer and a subsidiary of a vertically integrated firm (the incumbent firm) supply gas to final consumers.

The incumbent firm, *i,* produces gas at a constant marginal cost *c* and distributes it to final consumers at marginal cost c_m. It also supports a fixed cost, F_i, that can be interpreted as the initial cost of installing the gas tubes.

The marketer, *m*, sells gas to final consumers but it has no technology to produce gas. Therefore, it has to buy gas from another firm. The marketer can buy gas in the national market (from the incumbent firm) or import gas from a foreign supplier. By assumption, the marketer has zero fixed costs and its marginal cost is the sum of: (i) the price it pays (to the supplier) *per* unit of gas; and (ii) the marginal cost of distributing gas to final consumers. For simplicity, assume that the marketer's marginal distribution cost is equal to the incumbent's cost, c_m.

The foreign transmission firm, *e*, supports a marginal cost *c* to transport the gas to the marketer and fixed costs F_e.

The transmission tariff from the incumbent to marketer, P_i, is chosen by the national regulator; while the transmission tariff from the foreign supplier to the marketer, P_e, is set by the foreign regulator. Both tariffs are chosen in order to maximize social welfare of the corresponding country.

If the marketer acquires gas from the incumbent firm, it pays a unique tariff, P_i. If, instead, the marketer imports gas from the foreign supplier, the price of gas depends on the mechanism underlying the transmission tariff. We allow for two tariff mechanisms: (i) the *postage stamp*, under which the marketer pays one single tariff to the foreign supplier, independently of the final gas destination; and (ii) the *entry-exit system*, under which the marketer pays an *exit tariff* to the foreign supplier (for the transmission of gas until the entry point) and an *entry tariff* to the incumbent firm (for the use of the incumbent´s network transmission). The entry-exit system aims to be cost reflexive.

In the downstream market, the subsidiary firm and the marketer play Cournot competition. Assume that the two firms sell homogeneous goods. Let p denote the price of the gas to final consumers, which depends linearly on the total quantity. More precisely, $p=a-Q$ with $Q=q_i+q_m$, where q_i is the quantity sold by the incumbent firm and q_m is the marketer's quantity. By assumption, $a>c+c_m$.

The structure of the market is represented in Figure 1.

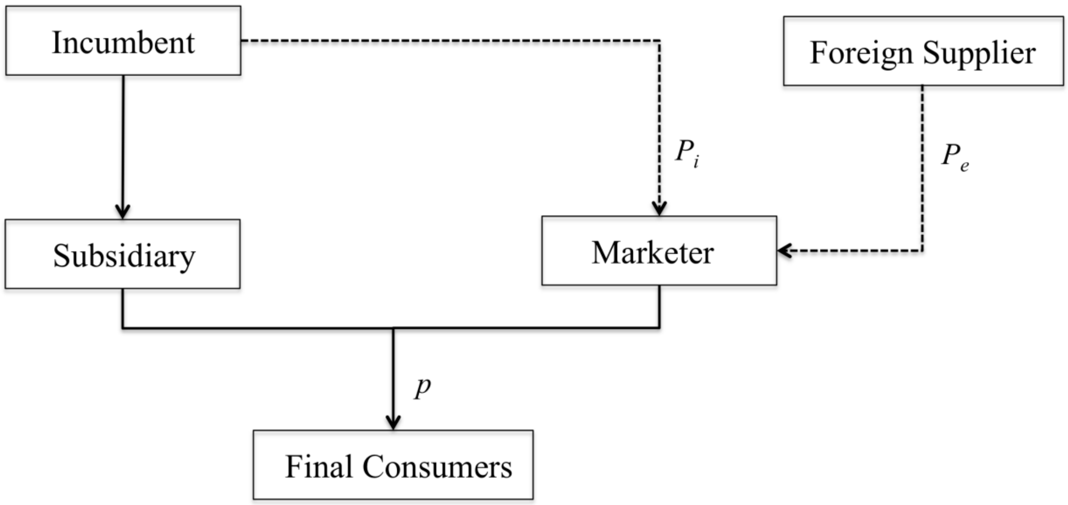

Figure 1. Market structure.

Our main goal is to compare the two tariff mechanisms, regarding the impact on social welfare of market *A*. To this end, we build a simple model, which can be described by the following three-stage game:

1st stage: Regulators set transmission tariffs, P_i and P_e;

2nd stage: The marketer decides whether to buy gas from the incumbent firm or from the external supplier;

3rd stage: The incumbent and the marketer choose the quantity to sell to final consumers, q_i and q_m.

Assume that either the incumbent or the foreign transmission firm have capacity to satisfy all the marketer's demand. As a result, in equilibrium, the marketer does not simultaneously acquire gas from both suppliers. To choose the supplier, the marketer compares the tariff in its home market, P_i, with the tariff in the foreign market, P_e. More precisely, if the foreign tariff is lower (resp. higher) than the national price, the marketer buys all the gas in the foreign (resp. home) market. Below, we analyze in separate the two tariff systems and the cases in which the marketer buys in its home market or abroad. Therefore, we need to study four possible scenarios.

2.1 *Postage stamp* system

2.1.1 Marketer buys abroad ($P_e < P_i$)

If the marketer buys all gas from the foreign supplier and the foreign regulator sets a *postage stamp* tariff, the profit functions of the incumbent and the marketer are, respectively, given by:

$$\pi_i^{Post} = \left(p - c - c_m\right)q_i^{Post} - F_i \qquad \text{incumbent firm}$$

$$\pi_m^{Post} = \left(p - P_e^{Post} - c_m\right)q_m^{Post} \qquad \text{marketer}$$

We solve the problem by backward induction. Let us start by solving the third stage of the game. In the final market, the incumbent and the marketer set quantities that maximize their individual profits (taking P_e^{Post} as given). Combining the firms' best reply functions, we obtain:

$$\begin{cases} \dfrac{\partial \pi_i^{Post}}{\partial q_i^{Post}} = 0 \\ \dfrac{\partial \pi_m^{Post}}{\partial q_m^{Post}} = 0 \end{cases} \Leftrightarrow \begin{cases} q_i^{Post}\left(P_e^{Post}; a, c, c_m\right) = \dfrac{a - 2c - c_m + P_e^{Post}}{3} \\ q_m^{Post}\left(P_e^{Post}; a, c, c_m\right) = \dfrac{a + c - c_m - 2P_e^{Post}}{3} \end{cases} \quad \textbf{(1)}$$

As the marketer does not buy gas from the incumbent, we do not need to care about the problem of the domestic authority. Let us, then, analyze the decision of the foreign regulator concerning the transmission tariff, P_e^{Post}. For simplicity, we ignore any activity of the foreign supplier in the foreign market. Therefore, maximizing welfare in the foreign market is equivalent to maximize the profit that the foreign firm makes by transporting gas to the marketer. As a result, the foreign regulator, taking q_m as given, sets the tariff P_e^{Post} that maximizes:

$$\pi_e^{Post} = \left(P_e^{Post} - c\right)q_m - F_e.$$

Substituting the expression for q_m^{Post}, obtained in (1), in the first-order condition of maximization of π_e^{Post}, we obtain the foreign tariff:

$$P_e^{Post}(a,c,c_m) = \frac{a+3c-c_m}{4}. \qquad \textbf{(2)}$$

Combining expressions (1) and (2), we obtain the equilibrium price in the final market:

$$p^{Post} = \frac{5a+7(c+c_m)}{12}$$

Consumer surplus in market *A*, with the *postage stamp* tariff, is equal to:

$$CS_A^{Post} = \frac{(a-p^{Post})(q_I^{Post}+q_m^{Post})}{2} = \frac{49}{288}(a-c-c_m)^2 \qquad \textbf{(3)}$$

Social welfare, W_A^{Post}, is defined as the sum of consumer surplus with the incumbent profit, $\pi_i^{Post} = \frac{25}{144}(a-c-c_m)^2 - F_i$, and marketer profit, $\pi_i^{Post} = \frac{1}{36}(a-c-c_m)^2$. Simple algebra leads to:

$$W_A^{Post} = \frac{107}{288}(a-c-c_m)^2 - F_i \qquad \textbf{(4)}$$

2.1.2 Marketer buys in the domestic market $(P_E > P_I)$

Suppose, now, that the foreign supplier charges a higher price than the incumbent firm. In this case, the marketer buys all the gas from the incumbent and the corresponding profit functions are:

$\pi_i^I = (p^I - c - c_m)q_i^I + (P_i^I - c)q_m^I - F_i$ incumbent firm

$\pi_m^I = (p^I - P_i^I - c_m)q_m^I$ marketer

Once again, we solve the three-stage game by backward induction. Let us start by taking the tariff in market *A*, P_i^I, as given. Deriving the first-order conditions corresponding to the maximization of profits in the final market and combining them, we obtain the best-reply functions of the two firms:

$$\begin{cases} \dfrac{\partial \pi_i^I}{\partial q_i^I} = 0 \\ \dfrac{\partial \pi_m^I}{\partial q_m^I} = 0 \end{cases} \Leftrightarrow \begin{cases} q_i^I\left(P_i^I; a, c, c_m\right) = \dfrac{a - 2c - c_m + P_i^I}{3} \\ q_m^I\left(P_i^I; a, c, c_m\right) = \dfrac{a + c - c_m - 2P_i^I}{3} \end{cases} \quad \textbf{(5)}$$

Substituting these values in the inverse demand function, $p^I = a - \left(q_i^I + q_m^I\right)$, we obtain the price of the gas in the final market as function of the tariff P_i^I:

$$p^I = \frac{a + c + P_i^I + 2c_m}{3}$$

Substituting expressions for price and quantities, given in (5), we obtain the consumer surplus in the domestic market:

$$CS_A^I = \frac{\left(a - p^I\right)\left(q_i^I + q_m^I\right)}{2} = \frac{\left(c - 2a + P_i^I + 2c_m\right)^2}{18}$$

Adding the profit of the incumbent and the marketer, we obtain the social welfare in market *A*, W_A^I. At the second stage, the national regulator sets the tariff, P_i^I, that maximizes W_A^I. Solving the corresponding first-order condition, $\dfrac{dW_A^I}{dP_i^I}$, we find the equilibrium tariff:

$$P_i^I = 2c - a + c_m \quad \textbf{(6)}$$

Substituting in the expression for social welfare, W_A^I, we obtain:

$$W_A^I = \frac{\left(a - c - c_m\right)^2}{2} - F_i \quad \textbf{(7)}$$

However, using (6) and the assumption that $a > c + c_m$, we conclude that the optimal tariff (charged by the incumbent to the marketer) is such that $P_i^I < c + c_m$. This implies that the incumbent makes losses when selling gas to the marketer. In addition, substituting (6) in the best-reply function of the incumbent, we conclude that $q_i^I = 0$. Therefore, the incumbent firm does not sell any gas to final consumers. As a result, the incumbent firm has losses. However, the marketer has positive profits (that more than compensate the incumbent's losses). Under this situation, and in order to maximize social welfare, the regulator sets a very low P_i^I. Then, from the regulator's perspective, it is preferable that the marketer sells all the gas to final consumers, as this firm bears an unitary cost of $P_i^I + c_m$, lower than the unitary cost of the subsidiary firm (which would be $c+c_m$). However, under this situation, the incumbent firm would fund the market activity which is not an acceptable result from the incumbent firm's perspective.

As the incumbent firm makes losses and supports fixed production costs, it is only willing to stay in the market if it receives some kind of subsidy. However, to consider the existence of such compensation would lead us to issues (e.g. social effects of the subsidy) that are out of the scope of this article. As a result, we propose an alternative way to determine the tariff P_i^I.

Substituting the best-response functions, obtained in (5), in the profit function of the incumbent firm, we obtain:

$$\pi_i^I = \frac{a^2 - 7ac + c^2 - 2ac_m + 7cc_m + c_m^2 - 9F_i + (5a + 5c - 5c_m)P_i^I - 5(P_i^I)^2}{9}$$

The incumbent firm is willing to stay in the market if $\pi_i^I \geq 0$. The incumbent's profit is zero with:

$$P_i^{I+} = \frac{a + c - c_m}{2} + \frac{3\sqrt{5}}{10}\sqrt{(a - c - c_m)^2 - 4F_i} \quad \vee \quad P_i^{I-} = \frac{a + c - c_m}{2} - \frac{3\sqrt{5}}{10}\sqrt{(a - c - c_m)^2 - 4F_i}$$

Expressions above are only admissible if:

$$F_i < \frac{(a - c - c_m)^2}{4} \qquad \textbf{(8)}$$

It is clear that P_i^{I+} is positive for sure. However, the signal of P_i^{I-} is not straightforward to know.

Lemma 1. If condition (8) is satisfied, then $P_i^{I-} < 0$.

Proof. The expression for P_i^{I-} is negative if and only if:

$$F_i < (a - c - c_m)^2 - 5c(a - c_m) = -\frac{3}{2}(a - c - c_m)^2 + \frac{5}{2}(a - c_m)^2 + \frac{5}{2}c^2$$

If the condition (8) is satisfied, than the last inequality is also satisfied since:

$$(a - c - c_m)^2 - 5c(a - c_m) > \frac{(a - c - c_m)^2}{4} \Leftrightarrow -7(a - c - c_m)^2 + 10(a - c_m)^2 + 10c^2 > 0$$
$$\Leftrightarrow 3(a - c_m)^2 + 14c(a - c_m) + 3c^2 > 0,$$

which is obviously satisfied.

$\square$

Therefore, assuming (8), the tariff charged by the incumbent firm (to the marketer) is:

$$P_i^I = \frac{a + c - c_m}{2} + \frac{3\sqrt{5}}{10}\sqrt{(a - c - c_m)^2 - 4F_i} \qquad \textbf{(9)}$$

Substituting this value in expressions (5), we find the quantities in the final market. Given these quantities, we find the consumer surplus and the profit of the incumbent and marketer. The expression for consumer surplus is:

$$CS_A^I = \frac{3}{20}(a-c-c_m)^2 - \frac{1}{20}\left[F_i + (a-c-c_m)\sqrt{5(a-c-c_m)^2 - 20F_i}\right], \tag{10}$$

while, for social welfare, it is:

$$W_A^I = \frac{a-c-c_m}{20}\left[7(a-c-c_m) - \sqrt{5(a-c-c_m)^2 - 20F_i}\right] - \frac{9}{10}F_i \tag{11}$$

2.1.3 Welfare comparison

Let us now compare the social welfare in the two cases: (i) the marketer buys the gas from the foreign supplier, W_A^{Post}, whose expression is given in (4); and (ii) the marketer buys the gas from the incumbent, W_A^I, whose expression is given in (11).

Proposition 1. Depending on the magnitude of the fixed production cost, the social welfare may be greater in the case in which the marketer buys the gas in the domestic market or abroad. More precisely:

- $W_A^I < W_A^{Post} \Leftrightarrow F_i \in \left]0, \frac{60\sqrt{37}-329}{144}\right[$.
- $W_A^I > W_A^{Post} \Leftrightarrow F_i \in \left]\frac{60\sqrt{37}-329}{144}, \frac{1}{4}\right[$.

Proof. With the postage stamp tariff, social welfare is greater in the case the marketer buys all gas in the domestic market if:

$$W_A^I > W_A^{Post} \Leftrightarrow -\frac{31}{1440}(a-c-c_m)^2 - \frac{\sqrt{5}}{20}(a-c-c_m)\sqrt{(a-c-c_m)^2 - 4F_i} + \frac{F_i}{10} > 0 \tag{12}$$

This inequality can be written as:

$$\frac{F_i}{(a-c-c_m)^2} > \frac{31}{144} + \sqrt{5\left[\frac{1}{4} - \frac{F_i}{(a-c-c_m)^2}\right]}$$

or, equivalently:

$$\left(\frac{F_i}{(a-c-c_m)^2}-\frac{31}{144}\right)^2>5\left(\frac{1}{4}-\frac{F_i}{(a-c-c_m)^2}\right)\Leftrightarrow\left(\frac{F_i}{(a-c-c_m)^2}\right)^2+\frac{329}{72}\frac{F_i}{(a-c-c_m)^2}-\frac{24959}{20736}>0$$

$$\Leftarrow\frac{F_i}{(a-c-c_m)^2}>\frac{60\sqrt{37}-329}{144}.$$

□

This is a quite intuitive result. When the incumbent firm has a high fixed cost it is quite important, from the incumbent firm's perspective and consequently from the social welfare perspective, to distribute this cost among large quantities sold to final consumers. And this is better achieved when the marketer buys from the incumbent firm.

2.2 *Entry-Exit* system

Consider now that there are entry and exit tariffs for the use of the transmission network. More precisely, if the marketer buys gas from the foreign supplier, it must pay a tariff for the use of the foreign network, *E*, and a tariff for the use of the national network, *I*. Therefore, the marginal cost of the marketer is $E+I$. Alternatively, if the marketer buys the gas from the incumbent firm, it pays one single tariff to this firm, P_i.

Once again, we analyze in separate the case in which the gas is cheaper at the domestic market (i.e., $E+I<P_i$) and the case in which the gas is cheaper at the foreign market.

2.2.1 Marketer buys gas in the foreign market $(E+I<P_i)$

In this case the profit functions of the incumbent firm and the marketer are:

$$\pi_i^{EE}=(p-c-c_m)q_i^{EE}+(I-c)q_m^{EE}-F_i \qquad \text{incumbent firm}$$

$$\pi_m^{EE}=(p-E-I-c_m)q_m^{EE} \qquad \text{marketer}$$

Combining the best-reply functions of the two firms, we obtain:

$$\begin{cases} \dfrac{\partial \pi_i^{EE}}{\partial q_i^{EE}} = 0 \\ \dfrac{\partial \pi_m^{EE}}{\partial q_m^{EE}} = 0 \end{cases} \Leftrightarrow \begin{cases} q_i^{EE}\left(E^{EE}, I^{EE}; a, c, c_m\right) = \dfrac{a - 2c - c_m + E^{EE} + I^{EE}}{3} \\ q_m^{EE}\left(E^{EE}, I^{EE}; a, c, c_m\right) = \dfrac{a + c - c_m - 2E^{EE} - 2I^{EE}}{3} \end{cases} \quad \textbf{(13)}$$

The regulator in the foreign market sets the tariff E^{EE} that maximizes the foreign transporter profits:

$$\pi_e^{EE} = \left(E^{EE} - c\right)q_m^{EE} - F_e$$

Replacing here the best-response function of the marketer, given in (13), we can write the profit of the foreign supplier as depending only on the transmission tariffs:

$$\pi_e^{EE} = \frac{\left(E^{EE} - c\right)\left(a + c - c_m - 2E^{EE} - 2I^{EE}\right)}{3} - F_e$$

The first order condition of the maximization of π_e^{EE} is:

$$E^{EE} = \frac{a + 3c - 2I^{EE} - c_m}{4} \quad \textbf{(14)}$$

The national regulator sets I^{EE} that maximizes the social welfare in market *A*. Substituting the best-reply functions obtained in (13) in the demand in the final market, we obtain the price for final consumers:

$$p^{EE} = \frac{a + c + E^{EE} + I^{EE} + 2c_m}{3}$$

Therefore, the consumer surplus in the domestic market is:

$$CS_A^{EE} = \frac{\left(a - p^{EE}\right)\left(q_i^{EE} + q_m^{EE}\right)}{3} = \frac{\left(2a - c - c_m - E^{EE} - I^{EE}\right)^2}{27}$$

Adding the profit of the incumbent π_i^{EE} and the marketer π_m^{EE}, we obtain the expression for social welfare in market *A*, $W_A^{EE} = CS_A^{EE} + \pi_i^{EE} + \pi_m^{EE}$. The first-order condition corresponding to the maximization of W_A^{EE} is:

$$\frac{\partial W_A^{EE}}{\partial I^{EE}} = 0 \Leftrightarrow \frac{-a + 5c + c_m + 14E^{EE} - 4I^{EE}}{27} = 0 \Leftrightarrow I^{EE} = \frac{-a + 5c + 14E^{EE} + c_m}{4}. \quad \textbf{(15)}$$

Combining (14) and (15), we obtain the equilibrium entry and exit tariffs:

$$E^{EE} = \frac{3a + c - 3c_m}{22} \qquad \text{and} \qquad I^{EE} = \frac{5a + 31c - 5c_m}{22}. \tag{16}$$

Substituting these tariffs in the expression for social welfare, we obtain:

$$W_A^{EE} = \frac{81a^2 - 166ac + 97c^2 - 162ac_m + 166cc_m + 81c_m^2}{242} - F_i. \tag{17}$$

In addition, the expression for consumers' surplus is:

$$CS_A^{EE} = \frac{3}{121}\left(2a - 3c - 2c_m\right)^2 \tag{18}$$

2.2.2 Marketer buys gas in the domestic market $\left(E + I > P_i\right)$

In this case, the results are equal to those obtained in section 2.1.2. As in section 2.1.2, we consider that the access price cannot be lower than $c + c_m$. Otherwise, the incumbent firm would have to receive a subsidy in order to remain active in the market.

2.2.3 Welfare comparison

To compare social welfare (with the *entry-exit* system) in the case the marketer buys the gas in the domestic market or abroad, we need to compare expressions (11) and (17):

$$W_A^I > W_A^{EE} \Leftrightarrow$$

$$\Leftrightarrow 5\left(a - c - c_m\right)^2 - 20F_i - \frac{\left(37a^2 - 34ac - 123c^2 - 74ac_m + 37c_m^2 + 242F_i\right)^2}{14641\left(a - c - c_m\right)^2} > 0$$

The left-hand side of the last inequality can be written as a second-order polynomial with negative second order-term, equal to $-\frac{4}{\left(a - c - c_m\right)^2}$. The two roots of the polynomial are:

$$F_i = \frac{-321a^2 + 622ac - 241c^2 + 624ac_m - 622cc_m - 321c_m^2}{121}$$
$$\pm \frac{110}{121}\sqrt{\left(a - c - c_m\right)^2\left(10a^2 - 19ac + 6c^2 - 20ac_m + 19cc_m + 10c_m^2\right)}$$

2.3 Comparison of welfare with the two tariff mechanisms

Suppose that the marketer buys the gas from the foreign supplier. In this section we compare whether social welfare is greater with the *Postage Stamp* tariff, W_A^{Post}, whose expression is given in (4), or with the *Entry-Exit* tariff, W_A^{EE}, whose expression is given in (17).

Proposition 2. Assuming that the marketer buys the gas abroad, the comparison of social welfare with the *Postage Stamp* tariff to the *Entry-Exit* tariff depends on the magnitude of the parameter *a* (compared to the marginal production costs). More precisely:

- $W_A^{Post} > W_A^{EE} \quad \Leftrightarrow \quad c + c_m < a < \dfrac{995 + 264\sqrt{33}}{1283} c + c_m.$
- $W_A^{Post} > W_A^{EE} \quad \Leftrightarrow \quad a > \dfrac{995 + 264\sqrt{33}}{1283} c + c_m.$

Proof. Let us compare social welfare with the two tariff mechanisms (assuming that the marketeer buys all gas from the foreign supplier):

$$W_A^{Post} > W_A^{EE} \Leftrightarrow \frac{107}{288}(a - c - c_m)^2 - F_i > \frac{81a^2 - 166ac + 97c^2 - 162ac_m + 166cc_m + 81c_m^2}{242} - F_i$$
$$\Leftrightarrow 1283a^2 - 1021c^2 + 1990cc_m + 1283c_m{}^2 - 1990ac - 2566ac_m > 0$$

The right-side of the last inequality is a second-order polynomial in a, whose roots are:

$$a_1 = \frac{995 - 264\sqrt{33}}{1283} c + c_m \quad \vee \quad a_2 = \frac{995 + 264\sqrt{33}}{1283} c + c_m.$$

Therefore, the inequality above is satisfied if:

$$a \in \left] -\infty, \frac{995 - 264\sqrt{33}}{1283} c + c_m \right[\cup \left] \frac{995 + 264\sqrt{33}}{1283} c + c_m, +\infty \right[.$$

However, by assumption, another condition must be satisfied: $a > c + c_m$. This is a quite important result for the regulators choice of the transmission tariff regime. If the marketer buys abroad, for large internal markets the preferable regime is the postage stamp.

3. Comparison of the consumer surplus

3.1 Postage Stamp

The following Proposition compares the value of consumer surplus (if the transmission tariff is *Postage stamp*) in the case the marketer buys gas abroad, CS_A^{Post}, with its value in the case the marketer buys gas in the domestic market, CS_A^I.

Proposition 3. If transmission tariff is *Postage Stamp,* consumers are better off if the marketer buys all gas in the foreign market.

Proof. Notice that:

$$\begin{aligned} CS_A^I &= \frac{3}{20}(a-c-c_m)^2 - \frac{1}{20}\left[F_i + (a-c-c_m)\sqrt{5(a-c-c_m)^2 - 20F_i}\right] \\ &< \frac{3}{20}(a-c-c_m)^2 < \frac{49}{288}(a-c-c_m)^2 = CS_A^{Post}. \end{aligned}$$

□

3.2 Postage stamp versus Entry-Exit

Consider that the marketer buys all gas abroad, regardless of the tariff mechanism. Next Proposition compares consumer surplus with each type of tariff.

Proposition 4. If the marketer buys the gas from the foreign supplier, the consumers may be better off with the *Postage Stamp* tariff or with the *Entry-Exit* tariff, depending on the magnitude of $a-c_m$. More precisely,

- $CS_A^{Post} < CS_A^{EE} \Leftrightarrow a-c_m \in \left]c, \frac{745+924\sqrt{6}}{2473}c\right[$
- $CS_A^{Post} > CS_A^{EE} \Leftrightarrow a-c_m \in \left]\frac{745+924\sqrt{6}}{2473}c, +\infty\right[$

Proof. We have that:

$$CS_A^{Post} > CS_A^{EE} \Leftrightarrow \frac{49}{288}(a-c-c_m)^2 > \frac{3}{121}(2a-3c-1c_m)^2$$
$$\Leftrightarrow \frac{2473}{34848}(a-c-c_m)^2 + \frac{12c}{121}(a-c-c_m) - \frac{3c^2}{121} > 0,$$

The left-hand side of this inequality is a polynomial of second-order in $(a-c-c_m)^2$, whose roots are:

$$a-c-c_m = \frac{12(77\sqrt{6}-144)}{2473}c \quad ; \quad a-c-c_m = \frac{-12(77\sqrt{6}+144)}{2473}c$$

As the second root is surely negative and, by assumption, $a-c-c_m > 0$, the inequality above is satisfied if and only if:

$$a-c-c_m > \frac{12(77\sqrt{6}-144)}{2473}c \Leftrightarrow a-c_m > \frac{745+924\sqrt{6}}{2473}c.$$

4. Conclusion

The choice of the method to set transmission tariffs for natural gas is under current discussion and evaluation. This choice has important consequences on international transactions of natural gas. In this paper we compare two models that are among the most used by European countries: the postage stamp and the entry-exit systems. Our aim was to evaluate these methods regarding their effects on welfare.

From a stylized model we conclude that the size of the internal markets and the amount of the fixed costs of the incumbent firms have a crucial role in the method's evaluation.

We found that under the postage regime the consumer's welfare is higher when the marketer buys abroad. The same result is found for social welfare as long as fixed costs are below a certain critical value. This result might be explain due the fact that if the fixed costs are significant their distribution by among a higher quantities traded by the incumbent more than compensate the advantages of the foreign acquisition. Overall, these results draw the attention for the importance of international competition in natural gas market. Additionally, we conclude that if the marketer buys gas abroad, the preferable regime (both from social and consumers welfare perspective) depends on the size of the internal market. For large internal markets postage stamp regime leads to better results. This is a quite important result from the public authorities' perspective when, in a context of liberalized markets, it is necessary choose among different regimes to set the transmission prices.

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The impact of regulation, privatization and competition in gas infrastructure investments

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Abstract

In recent years we have witnessed several reforms in network industries, as privatization, restructuring and deregulation of some vertical segments. In sectors such as electricity and gas, this opening to competition is possible only in certain activities (i.e. generation, storage of natural gas and supply), maintaining as a natural monopoly the activities of distribution and transmission, and therefore still subject to regulation.

The performance of these regulated segments can have important effects on the operation of the competitive segments, because the regulated segments (i.e. the transmission and distribution networks) provide the infrastructure platform upon which the competitive activities rely. The motivation of this paper is to evaluate the effects of privatization, liberalization and regulation, as components of the reform of the natural gas sector, on investments, in doing so, we developed a panel data analysis, which provides separate measures of the level of that variables in firms. The purpose of the analysis is to improve understanding of the determinants that influence investment, thereby contributing to a better understanding design of these components and meet the investments needs established by energy policies.

Keywords: regulation, privatization, competition, gas utilities, price cap

JEL Classification: L14; L43; L50; L95

Introduction

In recent years we have witnessed several reforms in network industries, as privatization, restructuring and deregulation of some vertical segments. Deregulation was typically the separation of potentially competitive segments from, the characteristic segments of natural monopoly, which continue to be subjected to regulatory mechanisms. In sectors such as electricity and gas, this opening to competition is possible only in certain activities (i.e. generation, storage of natural gas and supply), maintaining as a natural monopoly the activities of distribution and transmission, and therefore still subject to regulation.

The performance of these regulated segments can have important effects on the operation of the competitive segments, because the regulated segments (i.e. the transmission and distribution networks) provide the infrastructure platform upon which the competitive activities rely. Accordingly, the welfare consequences of these industry restructuring and deregulation initiatives depends on the performance of both, the competitive and the regulated segments of these industries.

Regulation

The main objectives of regulation are to avoid monopoly inefficiency and to protect customers from exploitation. This "public interest" or "helping hand" theory is based on two assumptions (Shleifer, 2005). First, markets fail because of the problems of monopoly or externalities. Second, governments are benign and capable of correcting these failures through regulation. This public interest theory of regulation has been subjected to a number of criticism by diverse authors (example: Coase, 1960; Stigler, 1971; Posner, 1974). Therefore, by the end of the 1970's there was no doubt that regulation of competitive industries was inappropriate and a major failure. However, the regulation of public utilities was viewed differently. This kind of industries, suffered different modifications. In one hand, the restructuration to promote competition in some potential competitive segments and in other hand the maintenance of regulatory mechanisms to core segments of these industries that continue to have monopoly characteristics (Winston et al, 2000). Although, since the work of Averch and Johnson (Averch et al, 1962) and Stigler and Friedland (Stigler et al, 1962) the way that these monopolies industries were regulate (by rate-of-return regulation) had been criticized.

The information conditions necessary to create a "competitive market" in these segments are rather strong and must also be considered, when designing the regulatory policies. It is widely accepted that regulated firms are better informed about its characteristics and about the industry than the regulator. Thus, an important issue is how the regulator can best induce the regulated firm to employ its privileged information to further the broad interests of society, rather than to pursue its own interest. The critique of traditional regulation monopoly induced economists not only to recommend some deregulation, but also to develop different mechanisms to improve regulation. The regulatory mechanisms may be focus either on the profits of firms or on the prices of services Markets with natural monopoly characteristics are thought to lead to a variety of economic performance problems: excessive prices, production inefficiencies, costly duplication of facilities, poor service quality, and to have potentially undesirable distributional impacts.

When is government regulation justified in an industry with natural monopoly characteristics and how can regulatory mechanisms best be designed to mitigate the performance problems of concern? Answering this set of questions necessarily requires both theoretical and empirical examinations of the strengths and weaknesses of alternative regulatory mechanisms. Regulation is itself imperfect and can lead to costly and unanticipated firm responses to the incentives created by regulatory rules and procedures. The costs of regulation may exceed the costs of unregulated naturally monopoly or significantly reduce the net social benefits of regulation.

In principle, cross-country comparisons can be used in an equivalent fashion, though differences in accounting conventions, data availability, and basic underlying economic and institutional attributes make cross-country studies quite difficult. Nevertheless, there has been increasing use of cross-country data both to evaluate the effects of regulation and to provide data to develop performance benchmarks that can be used by regulators (Jamasb and Pollitt (2003)).

Gas Sector

The natural gas sector, in addition to these reforms, has also assisted to the Third European Directive implementation that has defined a set of requirements for the European Natural Gas Market. However, Europe is characterized as a patchwork of gas markets, each within their state of development. Western European markets are relatively more mature markets than Southwest markets. One question we might ask is whether these markets should have the same type of regulation of the mature markets. One preoccupation that has been considered in the European political agenda is the security of supply, which creates an enormous need for investment in this sector.

According to the world energy investment outlook, the total investment in gas sector required in OCDE Europe, designed for the period 2001-2030, amounts to $465 billion, or nearly $16 billion per year (International Energy Agency 2003:266). The estimate cumulative gas investment in the EU-15 countries between 2011-2030 was: $85-95 billion distribution, $50-75 billion transmission, storage $10-15 billion and %15-20 billion in liquefied natural gas (LNG) regasification. Both opponents and advocates of liberalization of European gas markets are questioning whether the current regulatory regimes in European Energy Markets will be sufficient for these investments needs.

Currently, theories concerning the lack of investment in liberalized markets are very active, and the question as if the competition based approaches are suitable for network based industries, electricity and gas, with high sunk costs. The occurrence or danger of lack of investment in the liberalized market is predominantly seen as a hold-up problem. An insufficient level of regulatory stability can result in the holding return on investment, which means that investments are delayed or even never done.

The academic debate on the study of the impact of regulation and liberalization in investment has been particularly in the area of electricity. The literature shows that the study of economic regulation of the gas market and their effect on investment has been hardly subject to research. We can conclude that the fundamentals of the natural gas market and the market environmental has changed recently, making it necessary to assess whether the regulation of Europe's gas market is still at par with the new energy reality. More specifically, it is legitimate to question whether the economic focus of this new energy policy will meet the desired performance, particularly with regard to the crucial need of investment.

The motivation of this paper is to evaluate the effects of privatization, liberalization and regulation, as components of the reform of the natural gas sector, on investments, in doing so, we developed a panel data analysis, which provides separate measures of the level of that variables in firms. The purpose of the analysis is to improve understanding of the determinants that influence investment, thereby contributing to a better understanding design of these components and meet the investments needs established by energy policies.

Data and Econometric Model

The above question was tested using panel data for 11 TSO's (Transmission System Operator) of different European Countries over the period from 2001 to 2011.

The final date, 2011, represented the last year for which data were available. The choice of the sample TSO's was based on access to data. Even so, not all data exist for all of the years for all 11 TSO's and therefore the sample size differs depending on the year considered. As it has been mentioned earlier, the focus of the study is on gas transmission. The countries considered in the study are reported in table 1.

Table 1

Austria	France	Slovenia
Belgium	Hungary	Spain
Czech Republic	Italy	Uk
Denmark	Slovakia	

All variables used in this study, were calculated using data from annual reports of the TSO's and from publish data and publications from the NRA's (National Regulatory Authority) of each country.

The econometric model used is this study is summarized by the following equation:

$$\log(inv_{it}) = \alpha_0 + \alpha_1 priv_{it} + \alpha_2 tp_{it} + \alpha_3 rt_{it} + \alpha_4 \log(eff_{it}) + \alpha_1 \log(roa_{it}) + \delta_1 year_t + \delta_2 country_i + \varepsilon_{it}$$

Where:

- The dependente variable *inv* used in the study is a proxy of investment associated with the installed capacity. This indicator captures the extent of the transmission capacity;
- *Priv* is a proxy for privatization, measuring the percentage of the shares owned by the state.

In this study, we construct a set of indicators for the regulation variable. The elements are: a dummy tp explaining the type of regulation applied and rt representing the regulatory period. When using a dummy variable approach we are compelled to classify each regulatory regime either into the cluster of zero or into the cluster of one. The assessment simply consists of the choice between cost plus and incentive regulation, broadly defined. For example, incentive regulation would include earning sharing, revenue sharing, rate case moratoria, price cap, rate freeze of any other forms of incentive regulation. In the literature there is some discussion on how to control for the forms of regulation. Most scholars use a dichotomous (0/1) variable to identify the presence (absence) of one characteristic in the regime (Ai and Sappington (2002), Donald and Sappington (1997), Knittel (2002) and Wallsten (2001)).

As argued by Gutierrez (2003), this approach has a great level of simplicity, from which it gets its popularity in literature, but may also be misleading, since it may not explore the real strength of the regulatory environment. Although, the data availability for this variable was not sufficient to create, for example, an index to rank regulatory regimes on a scale. So we consider a dummy variable for the type of regulation variable.

For the performance variable are assigned two proxies, one related to efficiency and the other with profitability. Efficiency (eff) is measured trough operational efficiency, defined as total revenue over total assets. Profitability (roa) is measured by return on assets, defined as net income over total assets.

- *year* represents the set of year dummies, which aim to capture the economic trend.
- *country* gathers the country dummies, which should capture the remaining heterogeneities across the countries
- ε_{it} is the usual regression error, which is assumed to be random with zero mean.

The correlation coefficients shown in table 2 are small and does not suggest likely significant multicollinearity problems,

Table 2

Correlation Matrix for independent variables

	INV	PRIV	TR	RT	EFF	ROA
INV	1.00					
PRIV	-0.20	1.00				
TR	0.14	-0.33	1.00			
RT	0.17	-0.09	0.17	1.00		
EFF	0.54	0.39	-0.08	-0.07	1.00	
ROA	-0.19	0.40	-0.10	-0.06	0.06	1.00

The Results

We estimated our equation with pooled Ordinary Least Squares (OLS), under Random Effects (RE) and under a Fixed Effect (FE) approach, as a matter of completeness. The results are reported in table 3. The standard errors are in parentheses and are asymptotically robust to both heteroskedasticity and serial correlation.

Because regulated firms sometimes lobby intensively to influence the regulatory regime in the country in which they operate, the specific regulatory regime observed in a given country may not necessarily be exogenous, i.e., independent of country and firm characteristics, so it could be consider an FE approach to estimate these impact. Applying the Hausman test to check which of the two approaches (RE and FE) is preferable, the test was inconclusive. This result is not a surprise since it may occur in some applied cases. I reported the results of the three methods. It could be argued that as we have a small number of TSO's, a RE will yield a more efficient estimate for the sample. The results were not so different between the methods.

Table 3

Effect on *inv*

Explanatory variables	OLS	RE	FE
PRIV	0.557 (0.116)***	0.077 (0.028)**	0.079 (0.028)**
TR	0.131 (0.101)	0.024 (0.008)***	0.024 (0.008)***
RT	-0.059 (0.029)	-0.002 (0.002)	-0.003 (0.002)
EFF	25.841 (2.232)***	3.443 (0.679)***	3.357 (0.681)***
ROA	0.317 (0.274)	0.063 (0.033)	0.063 (0.033)
R-squared	0.682	0.486	0.999
Observations	87	87	87

Estimation period 1995e2004, yearly observations.
Year, country dummies were included, but not reported.
*Coefficients ***statistically significant at 1%, ** at 5% and * at 10%.*
Standard errors in parentheses, asymptotically robust to both heteroskedasticity and serial correlation.

In all three methods, the profitability (roa) variable and the rt variable representing the regulatory period are statistically insignificant. It suggests that suggests that regulatory period or profitability, on their own, are not sufficient to increase gas transmission capacities in our sample. Indeed, rt variable has an unexpected negative sign suggesting that increasing the regulatory period on their own may actually reduce transmission output. The positive coefficient for the profitability variable may be explained by the fact that the primary objective of private investors is to make profits. However, in both cases the coefficient values are statistically insignificant and therefore not too much should be read into these results.

Taking the TR estimates, the coefficients 0.131 and 0.024 would mean that TSO's operating under incentive regulation would have on average a bigger investment in transmission pipeline than TSO's operating under cost plus regulation, ceteris paribus. It is statically significant in FE and RE methods.

The coefficient on Efficiency is statistically significant at 1% level in FE and RE and it is positive as predicted by economic theory. The coefficient ~3.4 means that if a TSO's increases the operating efficiency by one point, then investment would increase on average by ~3.4.

When the variable privatization (priv) is considered, it appears to be a negative influence, significant at the 5% level. In other words, although not very significant, private involvement in TSO's is associated with a decrease in transmission pipeline, because the higher the variable the higher the percentage of state in TSO capital. These numbers mean that in my sample the impact of privatization reduces the investment.

I also estimate the model not using the natural logarithm of transmission pipeline (inv) as an alternative, but the results are essentially unaltered.

Conclusion

More and more countries are thinking of, or have already undertaken, reforms in their gas sector with the objectives of increasing private capital, promoting competition and introducing new regulatory structures. This study is based on a data base created from a range of European gas TSO's to measure the effects of privatisation, regulation and competition on performance in gas sector. I sampled 11 TSO's operating in gas sector for the period 2001-2011. To test it, it has been used panel data techniques (OLS, RE and FE). The results obtained have some important concepts.

Different forms of regulation seem to play an important role in transmission investment. The empirical finding of this paper also does not confirm Stern's (2003) idea that 'price cap regulation and ROR are opposite sides of the same coin' (Stern, 2003, p. 21). This idea is not supported by the fact that the investment in transmission pipeline growth trends of TSO's in my sample do differ across different types of regulatory regimes. In other words, the method of regulation appears important to the TSO's business investment.

Efficiency has also an important apart when considering investment in transmission. It seems that TSO's "only" invest if they have good operational efficiency, quotients between revenue and assets. This finding is significant, and it is consistent with economic theory in that it is necessary to give right incentives (good remuneration) for TSO's to invest.

This situation becomes more relevant, because the privatization issue has a factor contrary to the investment objective in our sample, "more privatization means less investment". Nowadays, what we have is an increase in privatization in this kind of firms.

In contrast with these results, regulatory periods and profitability do not have a significant impact on investment. Increasing the number of years of the regulatory period, means that we have a more stable regulation, but it does not incentive more investment, in particular in our sample.

This research has, however a number of limitations, which we acknowledge. Future work should expand this existing sample, including companies operating in other countries. An interesting extension of this work could be to replicate the methodology described here to a broader sample. While we have attempted to produce satisfactory measures of competition, regulation and privatization, more work would be valuable at to obtain superior measures on this indicators. Finally, the paper has not explored the return tax (or WACC) which each TSO's are subject. This indicator could have an impact on the research results.

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Trading a Pumped Storage Hydro in a Liberalized Electricity Market with Increasing Degrees of Market Power

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Abstract-- Most of renewable technologies, such as wind, generate electricity from natural resources, which vary their availability over time. Therefore, the increasing integration of larger amounts of wind energy into the power system raises important operation issues, such as the balance between power generation and power demand, where events of over-generation may occur. The pumped storage hydro (PSH) units are one possible solution to mitigate this problem once they can act as storage for the periods of higher generation and lower demand. However, the behavior of a PSH unit might differ considerably from the expected when it operates in a liberalized market with some degree of market power. This paper computes the optimal weekly scheduling of a PSH unit in the day-ahead electricity market, modeling the degree of market power by a residual inverse demand function with a variable elasticity. The results obtained show that increasing degrees of market power lead to decreasing levels of storage and, therefore, the capacity to integrate wind power is considerably reduced under these circumstances.

Index Terms-- Day-ahead electricity market, market power, MIBEL, price-maker, pumped storage hydro unit, wind integration.

1. INTRODUCTION

Renewable generation has grown considerably in several power systems around the world. However, most of renewable generation, such as wind, derives energy from natural sources that vary their availability over different timescales. Consequently, the integration of larger amounts of renewable energy into the power systems raises important operation issues, such as the balance between demand and generation, which is increasingly important in periods with lower demand and higher wind availability, resulting in the potential occurrence of over-generation.

A potential solution for this problem is to store the excess of generation for the periods in which it can be used with benefit for the system. Considering the high efficiency of the pumping cycle and its important storage capacity, the PSH unit is increasingly seen as a solution to integrate potential over-generations, avoiding the need for wind power curtailment [Faias et al. (2010), Black et al. (2005), Brooks et al. (2005)].

This solution assumes that the PSH units will have the incentive to store the over-generation in the most beneficial way to the power system, condition that is easily achieved in the context of a centralized dispatch. However, when trading its electricity output in a liberalized electricity market, the PSH unit will pursue a profit maximization strategy by purchasing electricity for pumping and selling its generation in the day-ahead electricity market.

Considering the PSH unit a price-taker, periods with low demand and high wind generation will drive market prices down which, in turn, will give the incentive for the PSH unit to pump water, leading to an adequate integration of wind power into the system.

However, when a PSH unit has market power, its profit maximization strategy can lead to a pumping and generation profile that differs from the system objective of maximizing the wind power integration.

Regarding the study of the optimal PSH unit operation strategy in liberalized markets there is some relevant research performed by several authors. This is the case of Lu et al. (2004) that developed an algorithm to determine the optimal bidding strategy for the day-ahead and ancillary services markets.

In addition to the day-ahead and ancillary services markets, bilateral contracts are also taken into account in order to reach the bidding strategies that maximize the profit as in Kanakasabapathy and Swarup (2009). The approach used in Lu et al. (2004) and Kanakasabapathy and Swarup (2009) is deterministic and considers the PSH unit as a price taker, in spite of the impact of the market power in the market clearing price (MCP) being introduced in the later work.

Baslis and Bakirtzis (2011) consider the impact of the market power, through a residual inverse demand function for yearly profit maximization, considering a deterministic first stage of one month and a stochastic approach for the other months.

The present paper studies the behavior of a PSH unit in the day-ahead electricity market, with different degrees of market power, in order to evaluate how its behavior differs from the power system objective of integrating wind power. To achieve this goal, a scheduling of a PSH unit was performed to reach the weekly profit maximization, using a deterministic approach. The different degrees of market power are modeled by a residual inverse demand function with a variable elasticity.

The remainder of this paper is organized as follows. In Section 2 the MCP of day-ahead electricity market is analyzed. The mathematical formulation of a PSH unit included in this market is held in Section 3. Section 4 presents the solution methodology to solve the developed optimization problem. Section 5 presents a case study applied to the Iberian Electricity Market (MIBEL) with a PSH unit that operates with different degrees of market power. Conclusions are drawn in Section 6.

2. MARKET CLEARING PRICE

In most day-ahead electricity markets, such as the MIBEL, market participants submit hourly electricity energy supply offers and demand bids for the entire following day.

For each hour of the day, supply offers are sorted from the lowest price to the highest price, forming the supply curve, and demand bids are sorted from the highest price to the lowest price, forming the demand curve.

Fig. 1 illustrates the supply and demand curves in day-ahead electricity market of the MIBEL, for 20th hour of November 11, 2011.

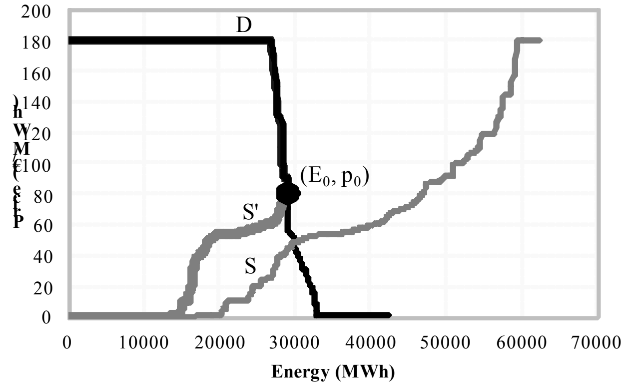


Fig. 1. Supply and demand curves.

The last eligible offer block dispatched by the market operator sets the MCP for that hour, which takes into account the intersection of the supply curve (*S* line) with the demand curve (*D* line). It should be noted that there are complex offers that imposes constraints which implies that some merit offers are disregarded when these conditions are not met, leading the supply curve to shift left, as represented by line *S'*. In this case, the market clearing quantity (MCQ) and MCP are set in E_0 and π_0, respectively, as shown in Fig. 1.

A. Effect of the PSH Unit operation on the MCP

The effect of the PSH unit operation on the MCP is twofold. On one hand, when the PSH unit pumps, it submits purchase bids which shifts the demand curve to the right, which increases the MCP. On the other hand, when the PSH unit generates, it submits sale offers that shifts the supply curve to the right, which decreases the MCP.

To illustrate this effect, consider Fig. 2 a) where the PSH unit makes a purchase bid of ΔE that shifts the demand curve, represented by line *D*, to the right, at the position represented by line *D'*. With this action, the intersection of the demand curve with the supply curve (*S* line) takes place at a higher price point of $\Delta\pi$.

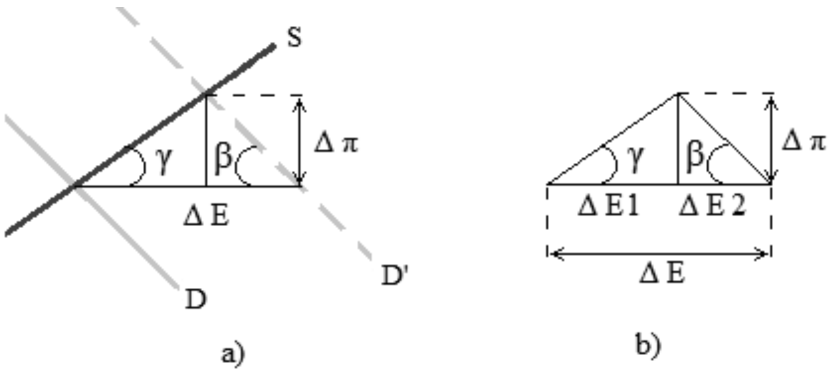


Fig. 2. Effect of the PSH unit operation on the MCP.

This change in price depends on the slope of the supply and the demand curves, given by γ and β respectively.

Taking into account Fig. 2 b) the slopes can be expressed in terms of the changes in quantities and prices given by:

$$\tan\gamma = \frac{\Delta\pi}{\Delta E1} \tag{1}$$

$$\tan\beta = \frac{\Delta\pi}{\Delta E2} \tag{2}$$

$$\Delta E = \Delta E1 + \Delta E2 \tag{3}$$

Considering a generator convention, when the PSH unit pumps, the respective purchase bid will be considered negative, so that $\Delta E<0$. Moreover, when the PSH unit generates, the respective sale offer will be considered positive, so that $\Delta E>0$.

Taking into account (1)-(3), the relationship between the changes in price and the changes in quantity is given by:

$$\delta = \frac{\Delta\pi}{\Delta E} = -\frac{\tan|\gamma|\cdot\tan|\beta|}{\tan|\gamma| + \tan|\beta|} \tag{4}$$

To represent the influence of the PSH unit on the MCP it was considered a residual inverse demand function with a slope given by (4).

B. Residual Inverse Demand Function

A residual inverse demand function expresses the MCP of the day-ahead electricity market on the quantity of electrical energy bided/offered by PSH unit.

The operational states of the PSH unit are: pumping, generation and off-line. In the periods of pumping, the PSH unit will consume electricity and, therefore, the MCP will rise. On the other hand, when PSH unit generates electricity the MCP decreases. When the PSH unit stays off-line, the MCP remains unchanged.

Since market players made their offers/bids in blocks of electricity at a given price, the demand and supply curves behave in stairway. The MCP is limited by a cap and a floor (π_{max} and zero, respectively) and the inverse demand function can be modeled by an approximated sigmoid function Sousa, (2005), given by:

$$\pi(E) = \frac{k_0}{1 + e^{\left(\frac{E+E_0-k_1}{k_2}\right)}} \tag{5}$$

where $\pi(E)$ is the MCP with the influence of the PSH unit operation; E is the electricity consumed or generated by PSH unit; k_0, k_1 and k_2 are parameters of the sigmoid function; E_0 is the MCQ without the intervention of the PSH unit.

The parameters k_0, k_1 and k_2 are calculated in order to meet the following conditions:

$$\pi'(0) = \alpha \cdot \delta \tag{6}$$

$$\pi(0) = \pi_0 \tag{7}$$

$$\lim_{E \to -\infty} \pi(E) = \pi_{\max} \tag{8}$$

From (6), if the PSH unit is off-line, the slope of the residual inverse demand function must be equal to the slope of the day-ahead electricity market given by (4). A multiplier factor (α) was implemented in order to modify the slope of the day-ahead electricity market, thus modifying the influence of the PSH unit operation on the MCP, i.e., changing the degree of market power of the PSH unit.

From (7), if PSH unit is off-line, the MCP of the residual inverse demand function remains equal to the MCP of the day-ahead electricity market without the PSH unit operation (π_0).

Condition (8) assures that the sigmoid function has a maximum value of $\pi_{\max}$.

Thus, the parameters that model the sigmoid function are computed according to the following equations:

$$k_0 = \pi_{\max} \tag{9}$$

$$k_1 = E_0 + \frac{\pi_0^2 \cdot \ln\left(\frac{k_0}{\pi_0} - 1\right) \cdot \left(\frac{k_0}{\pi_0} - 1\right)}{\alpha \cdot \delta \cdot k_0} \tag{10}$$

$$k_2 = -\frac{\pi_0^2 \cdot \left(\frac{k_0}{\pi_0} - 1\right)}{\alpha \cdot \delta \cdot k_0} \tag{11}$$

The degree of market power is changed according to α factor, as represented in Fig. 3.

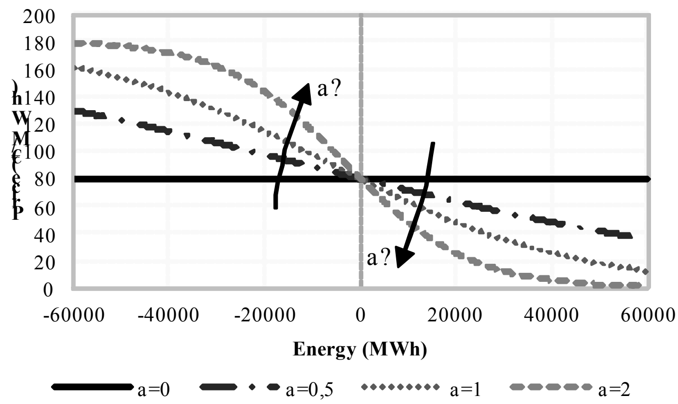


Fig. 3. Residual inverse demand curve for different degrees of market power.

The real slope of the MIBEL residual inverse demand function corresponds to α=1. When α<1, the MCP is less affected by the PSH unit operation. In the limit case of α=0, the bids and offers of the PSH unit will not affect the hourly MCP, which represents that the PSH unit behaves in a perfectly competitive way. On the other hand, if α>1 the operation of the PSH unit will affect more the hourly MCP, which corresponds to increasing degrees of market power.

3. PROBLEM FORMULATION

To formulate the problem, the following assumptions are made:

1. The electricity generated and consumed by the PSH unit is sold and bought, respectively, in the day-ahead electricity market.
2. The operation and maintenance costs of the PSH unit are null.
3. The PSH unit may either generate electricity using stored water in the upper reservoir or consume electricity to pump water to the reservoir.
4. The volume of water stored in the upper reservoir is represented by an equivalent energy level;
5. The initial and final energy levels of the upper reservoir are known *a priori*;
6. The electricity generated by the PSH unit is named E_g, while the electricity consumed for pumping is designated by E_p. The convention considered is the generator, so E_p will have negative values since it represents consumption;

The aim of a PSH unit in a liberalized electricity market is to maximize its profit in a given period of time subjected to operational constraints, as expressed in the following optimization problem:

$$\begin{aligned}&\max \sum_{i=1}^{H} \pi^i(E_g^i, E_p^i)\cdot(E_g^i + E_p^i)\\ &\text{Subject to:}\end{aligned} \tag{12}$$

$$-E_p^{\max} \le E_p^i \le 0 \qquad i = 1 \text{ to } H \tag{13}$$

$$0 \le E_g^i \le E_g^{\max} \qquad i = 1 \text{ to } H \tag{14}$$

$$W^i = W^{i-1} - \eta_p \cdot E_p^i - \frac{E_g^i}{\eta_g} \qquad i = 1 \text{ to } H \tag{15}$$

$$W^i = W^0 \qquad i = 0 \tag{16}$$

$$W^i \ge W^H \qquad i = H \tag{17}$$

$$W^{\min} \le W^i \le W^{\max} \qquad i = 1 \text{ to } H \tag{18}$$

where E_p is the hourly electricity energy pumped by the PSH unit; E_g is the hourly electricity energy generated by PSH unit; W denotes the hourly energy storage level in the reservoir; $\pi(E_g, E_p)$ is the hourly residual inverse demand function, given by (5). Superscript i is the time index.

Parameters η_p and η_g are the efficiencies associated with the pumping and generation of the PSH unit, respectively; W^0 is the initial energy level stored in the upper reservoir and W^H is the minimum energy required in the upper reservoir at the final optimization period; Minimum and maximum energy levels of the upper reservoir are W^{min} and W^{max}, respectively; E_p^{max} and E_g^{max} are the hourly maximum pumped and generated energy by PSH unit, respectively.

The objective function given in (12) is the profit of the PSH unit, which counts the hourly cash flow by trading in the day-ahead electricity market.

The operation limits of the PSH unit are represented in (13) and (14).

The energy stored in the upper reservoir, for a specific hour, depends on the operation of the PSH unit in that hour, and the energy stored in the previous hour. Thus, if the PSH unit pumps water, the stored energy will increase, however due to the pumping efficiency (η_p) the stored energy is less than pumped energy. On the other hand, if the PSH unit generates electricity the stored energy will decrease, but due to generation efficiency (η_g) the energy stored used is higher than the energy generated [Khatod et al., 2009]. Thus, the energy stored in the upper reservoir is given by (15).

Since initial and final energy levels of the upper reservoir are known *a priori*, the conditions in (16) and (17) must be met.

The operation limit of the upper reservoir is represented in (18).

Due to the efficiency of pumping and generation is less than unity, pumping water at the same time generating electricity is a waste of energy without economic gains [Crampes and Moreaux, 2008]. So this behavior will never happen.

Since the problem is nonlinear, it is important to analyze its convexity. In this regard, the objective function is pseudo concave and the constraints, being linear, define a convex set of feasible solutions. Therefore, the optimality conditions are not only necessary but also sufficient.

4. SOLUTION METHODOLOGY

The optimization problem (12)-(18) presented in the previous section is a non linear problem and was modeled and solved using the *MINOS* solver of the *GAMS* programming language [McCarl, 2006].

To determine the slope of the demand and supply curves, a linear approach was carried out in the neighborhood of the MCP for each hour. The algorithm used to solve this problem is as follows:

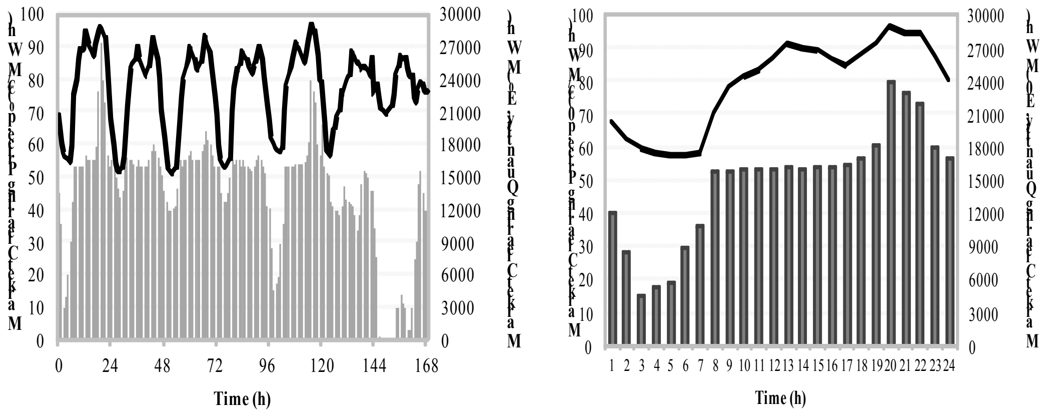
1. Read the following data:
    a. Pumping and generating efficiencies of PSH unit;
    b. Maximum, minimum, initial and final energy levels of the upper reservoir;
    c. Maximum hourly electricity consumption and generation that PSH unit can perform;
    d. Hourly MCP and MCQ without the PSH unit operation;
    e. Hourly demand and supply curves;
2. Compute the hourly slope of the demand and supply curves, with a linear approach;
3. Compute the hourly slope of the residual inverse demand function, given by (4);
4. Choose the multiplier factor (α) that allows modify the degree of market power;
5. Compute the hourly sigmoid function parameters, given by (9)-(11);
6. Solve the optimization problem, given by (12)-(18), using the *MINOS* optimization package available in GAMS, and save the obtained results;
7. To get more results with other degrees of market power go to step 4 and change the value of α; otherwise stop.

5. CASE STUDY

As an illustration, consider a PSH unit with the follow characteristics: $E_p^{max}=E_g^{max}=1000$ MWh, $W^{min}=500$ MWh, $W^{max}=70000$ MWh, $\eta_p=80\%$ and $\eta_g=90\%$. In the day-ahead electricity market, the purchase bids and sale offers are made for each hour of a day, therefore, for a weekly optimization H=168. The weekly operating starts at midnight of Monday with $W^0=50000$ MWh and ends at midnight the following Monday with at least $W^H \geq 50000$ MWh.

The data considered for the day-ahead electricity market are obtained from the market operator of the MIBEL website [OMIE], for the week from 7 to 11 of November of 2011. The maximum price that can be bided or offered (π_{max}) in the day-ahead electricity market of MIBEL is 180.3 €/MWh.

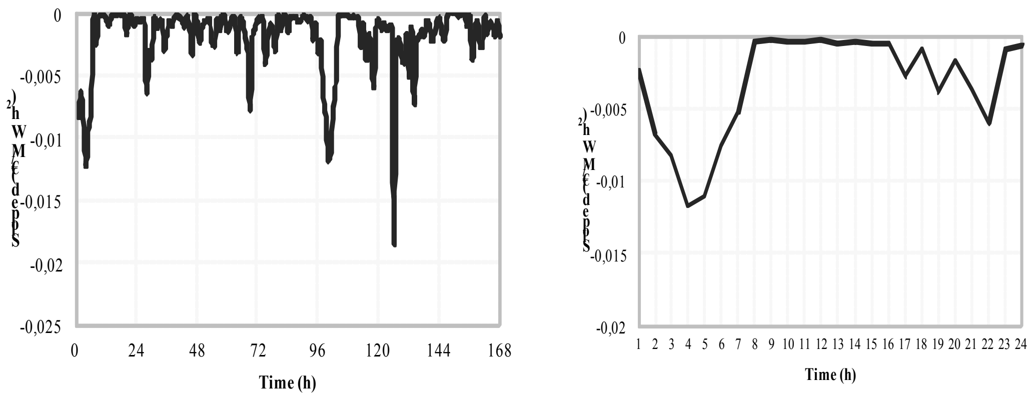
Fig. 4 a) and b) presents the MCP (bars) and MCQ (line) for the entire week and the considered day, respectively, without the PSH unit operation.



a) b)

Fig. 4. MCP and MCQ without PSH unit operation.

Fig. 5 a) and b) illustrates the hourly slope of the residual inverse demand function, for the entire week and the chosen day respectively, calculated by (4). For this calculation it was considered the hourly supply and demand curves, as represented in Fig. 1.



a) b)

Fig. 5. Slope of the residual inverse demand function.

In order to simulate different degrees of market power, the algorithm developed in Section 4 was applied in three different cases of increasing market power: α=0, α=1, and α=2.

The results obtained for the hourly PSH unit pumping and generating profile, for the entire week and the considered day, are presented in Fig. 6 a) and b), respectively.

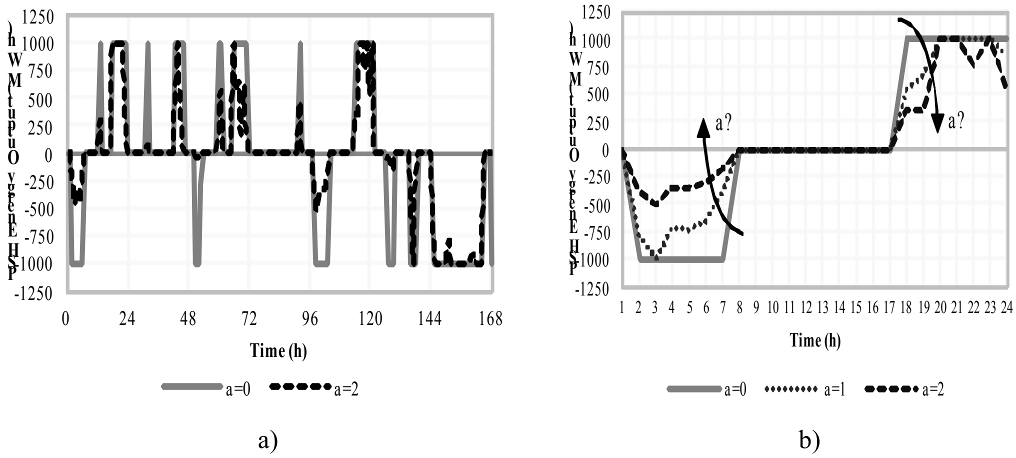


Fig. 6. Pumped and generated electricity by the PSH unit for different degrees of market power.

From Fig. 4 and Fig. 6, we can conclude that, regardless of the degree of market power, when the MCP is lower the PSH unit pumps water into the upper reservoir, when the MCP is higher the PSH unit generates electricity to the power system, and when the MCP has an intermediate value, the PSH unit is off-line.

However, when the PSH unit behaves in a perfectly competitive way (α=0), it pumps and generates at very high levels. With the increase of market power, it is observed a decrease in pumping and in generation of electricity.

The influence of the PSH unit operation on the MCP is also computed and the results, for November 11 of 2011, are shown in Fig. 7.

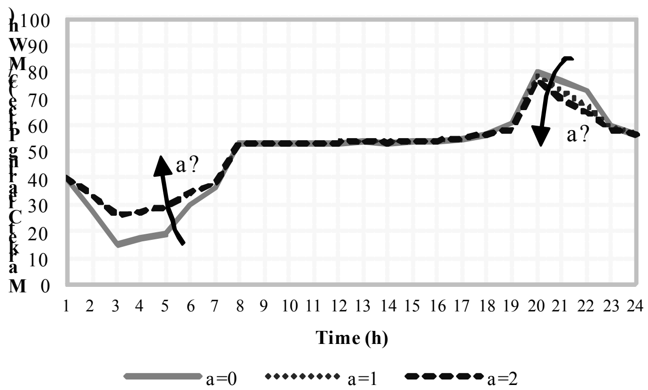


Fig. 7. Influence of the PSH unit operation on the MCP for different degrees of market power, for November 11 of 2011.

When α=0, the PSH unit does not influence the MCP. However, for increasing degrees of market power corresponding to increasing values of α, the influence of the PSH unit in the MCP increases.

In this regard, when the PSH unit pumps water to upper reservoir, the MCP rises and, when PSH unit generates, the MCP decreases, in comparison to the MCP that would result in the absence of the PSH unit operation.

From the results we can conclude that the total energy pumped (and, therefore, generated) by the PSH unit decreases considerably for increasing degrees of market power.

Therefore, when compared to a price taker situation, the energy stored by the PSH unit can be significantly reduced. As this stored energy could result from an excess of wind power in some periods, the ability to integrate wind power could be much lower than usually expected by most of the studies made in this respect.

6. CONCLUSIONS

This paper presents a non linear optimization model for the weekly scheduling of a price-maker PSH unit that participates in the day-ahead electricity market.

This model was used to evaluate the behavior of the PSH unit with different degrees of market power, modeled by a residual inverse demand function with a variable elasticity that depends on the slopes of the demand and supply curves.

The results obtained show that increasing degrees of market power of the PSH unit correspond to decreasing levels of storage and, therefore, the capacity to integrate wind power is considerably reduced when compared to a price-taker situation.

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The "Smart Paradox": Stimulate the deployment of Smart grids with effective regulatory instruments

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Abstract

The concept of Smart grids (SG) encompasses a set of technologies that raise the intelligence of the network, such as smart meters at consumer level or instruments of communication, sensing and actuation at networks. Nevertheless, the cost is still an important obstacle for the transformation of the current grid into a smarter system. Regulation can have an important role to set up a favorable framework that fosters investments in SG. However the novelty with the SG investment, in comparison with other investments in the network in the past, is the disembodied character of the technology. Therefore, it may changes the incentives of a regulated firm to invest, what affects the efficacy of the regulation instruments ("*cost plus*" or "*price cap*"). It is demonstrated that the solution to this "Smart" paradox requires a regulatory scheme different from the one used for the conventional investments, for which a pure incentive regulation would delayed investments. Nevertheless, the regulator cannot jeopardize conventional investment that is unable to be substituted by SG investment in order to promote the investment on such technology. Thus, performance regulation and efficiency obligations may be the key for the creation of a favorable regulatory context for the deployment of SG.

Keywords: Technological change; Economics of regulation; Price-cap; Cost-plus, Smart grids.

JEL codes: O33; L51; L94.

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[1] The results and comments presented in this paper are entirely the authors' responsibility and do not reflect the official opinions of ERSE or other institution.

The "Smart Paradox": Stimulate the deployment of Smart grids with effective regulatory instruments

1. Introduction

The electric system faces many challenges concerning growing demand, environmental constraints, efficiency requirements, connection of more decentralized generation, and security of supply (Clastres, 2011). Smart grids (SG) are particularly well-suited to help addressing those challenges, promoting both decarbonization and competition in the electricity market. This new concept encompasses a set of technologies that raise the intelligence of the networks such as smart meters at consumer level or instruments for capture, transmission and storage data, as well as control devices at the level of electrical networks (European Commission, 2011a). However, costs are still an important barrier for the transformation of the current grid into a smarter system, though they are expected to lower with technology deployment (European Commission, 2011b; Thompson, 2010).

Regulation can have an important role to set up a favorable framework that fosters the investments in SG. The regulator can apply different regulatory instruments (e.g. "cost plus" or "price-cap") to the investment costs and include them in the access tariff of the regulated activities (i.e., networks) (Joskow, 2008). Theoretically a "cost plus" regulation would spur the deployment of innovations in the network by reducing uncertainties on its adoption (Guthrie, 2006). The novelty with the SG investment, in comparison with other investments in the network in the past, is the more disembodied character of the technology, which provides a large spectrum of services with great scope for efficiency gains by relying heavily in software and information and communication technologies. Therefore it changes the incentives of a regulated firm to invest, what may affect the efficacy of each regulation instrument.

This paper assesses the impact of the nature of the SG technologies on the regulation of investments in the networks. Conventional "cost plus" regulation has well-documented effects of overinvestment in physical investments (cf. Averch and Johnson, 1962), but the same may not hold when it comes to more disembodied type of investments. Firstly, the innovative features of SG are presented as well as the main factors that are likely to constraint the rhythm and the direction of diffusion. Secondly, it is presented the theoretical features of a simple regulatory model which deals with the problems of moral hazard and asymmetric information of the investment in innovations in the network. Thirdly, the practical issues with the implementation of this regulation are discussed, and it is assessed against the approach that has been applied in Portugal, before conclusion.

2. Why do we need to support Smart grids?

The diffusion of SG has the potential to address most of the economical and environmental challenges currently faced by the electricity sector, by performing a series of services across different levels of the electric system. The aim of this point is to investigate the effect that the characteristics and benefits of SG have on the investments and on the speed of diffusion of such technology. For that, it is presented a review of the literature on innovation and technological change, followed by the investigation of the effect of economic attributes of SG as well as complexity and infrastructure needs on their diffusion.

The literature identifies a set of key variables that constraint the speed of diffusion. Technological and marketing studies have at least revealed five important determinants of diffusion rate (Rogers, 1995; Grubler, 1998, 2012): relative advantage; adoption effort; complexity; observability; and trailability. Firstly, the perceived "*relative advantage*" depends particularly on the economic attributes of the innovation, namely on performance (e.g., efficiency) and costs. This anticipatory variable relates with the rate of diffusion in the sense that a good "perception" accelerates penetration. Secondly, the *adoption effort* refers to the resources needed (e.g., time, people, financial) to start diffusion. As so, the diffusion should be slower (high diffusion rate) with those innovations that require a comparatively higher investment size. Thirdly, technology *complexity* is related with the perception of the difficulty of use — in a macro level approach this would deal with institutional needs for technological change. More the technology is complex, and less likely it is the adoption. Fourthly, *observability* is a determinant of the speed of diffusion in the sense that a more visible technology has many opportunities to spread the information and create positive externalities. Finally, the possibility of experiment and test of the technology (*triability*) may increase adoption because consumers are more familiar with the innovation, and know how to use it in a more efficient way (Rosenberg, 1982). All these factors are not static but rather evolve with the development of the innovation in the market (Nelson and Winter, 1982).

Economic attributes are crucial for SG diffusion, which rate depends greatly on the relative advantage of the innovation against competitive technologies (Fouquet, 2011). The adoption would be faster with a larger relative advantage in terms of costs, efficiency and performances (Grubler, 2012; Rogers, 1995). SG have multiple functionalities that explain its attractiveness in terms of reducing operational costs, raising efficiency of generation and use of electricity, and improving the quality of service. Table XX shows a more detailed description of the functionalities of SG.

Table 1. Potential benefits of Smart grids implementation [cf. EPRI (2010) and European Commission (2012)]

Main area	**Description**
Economic	Optimized generator operation
	Deferred generation capacity investments
	Reduced ancillary service cost
	Reduced congestion cost
	Deferred network (transmission and distribution) capacity investments
	Reduced equipment failures
	Reduced distribution equipment maintenance and operation cost
	Reduced meter reading cost
	Reduced electricity theft
	Reduced electricity losses
	Detection of anomalies relating to contracted power
	Reduced electricity cost
Reliability	Reduced major, sustained and momentary outages
	Reduced restoration cost
	Reduced sags and swells
	Reduced wide-scale blackouts
Environmental	Reduced CO_2 emissions
	Reduced SO_x, NO_x, and PM-10 emissions
	Reduced fossil fuels usage

The implementation of SG has benefits for different actors intervening in the power system. Moreover, the distribution of those benefits will influence the capacity of each actor to invest and assume a part of the costs (Clastres, 2011; Meeus et al., 2010). Thus: *consumers* benefit from an improved quality of supply, dynamic tariffs and better integration of renewable micro generation, electric vehicles and storage; *electricity providers* could use the enhanced information about consumers' behavior to improve demand response through dynamic pricing, promoting peak load transfer in order to delay the need of investments in new power capacity, as well as reduce costs with meter riding; *producers* benefit from a more predictable demand that facilitates the optimization of production and the satisfaction of instantaneous demand needs; *network operator* gains from a better monitoring and automation of the grid to increase control over the system and more easily (and less costly) balance supply with demand; the *regulator* profits from a better knowledge of demand to anticipate the need of investments in the infrastructure, as well as takes advantage of the development of competition due to a more intense exchange of information between consumers and potential providers; and *society* at large benefit from a high quality service in terms of less frequent and shorter interruptions.

Market surveys showed that distribution system operators (DSOs) have been playing a leading role in early projects (European Commission, 2011b). They are expected to have a great importance in the roll-out together with consumers (Verbong, Beemsterboer and Sengers, 2013). Both actors have important benefits with the deployment of SG, and their participation is needed because of the systemic nature of the innovation, i.e., the benefits with its implementation only come into play once the entire system is in place and actors participate actively in the new grid (European Commission, 2012). For instance, the investment in the grid is a prerequisite for demand to evolve and adopt a more active role in the management of energy through behavioral change or even becoming “prosumers”, i.e., households that produce and commercialize energy (Verbong, Beemsterboer and Sengers, 2013).

Infrastructure needs are another important factor which constraint the rhythm of development of a new technology system. This point was very well documented in previous transitions in transport (Grubler, 1999) or energy technologies (Grubler et al., 1999). SG concerns the deployment of devices in millions of houses and the upgrade of an extensive electrical network, thus the transformation of the entire system will take several years if not decades. For instance the ongoing project to install 40 million Smart meters in Europe has an expected duration of around a decade until 2020 (Faruqui et al., 2010). Even though the challenge is not the same as the construction of the first electrical networks in the past, the need for a minimum of infrastructures is of a paramount importance for the development of services such as telemetering or demand response. Two situations must be separated here. On the one hand, the infrastructure part concerning the update of already installed equipments with new sensors, controllers or communication devices. In this case the implementation may be more rapid because it is a matter of upgrading (not even substitute in most cases) the existing technology with new “Smart” components. On the other hand, the implementation of “Smart grids” will need the creation of an information system that collects, stores and treats (securely) all the new data generated by the system. In this case it is necessary new software and other technologies that in some cases have not been developed yet. Therefore, those technologies are not mature and there are still some technical and market uncertainties surrounding those innovations, what can slow the rhythm of diffusion.

In short, the speed of adoption of SG is likely to slow down by the effect of the size of the technological change, the complexity of the innovation, and the infrastructure needs. Thus, the economic benefits should be high enough to accelerate the implementation, but costs are currently high and technology will only mature with deployment. However its implementation is crucial to make possible the raise of intermittent and distributed generation with the connection of millions of electrical vehicles with very variable loads. There are clearly externalities and public benefits with the investment in SG that may not be possible to grasp without some kind of external support (BNetzA, 2011).

3. Effective support to Smart grids without creating economical rents

The following analysis assumes that the regulator is not in charge of public policy and so it can only support SG in the basis of the expected efficiency gains in the future. Furthermore it is implicit that he searches that its decisions provokes minimal distortions in the economy, particularly by minimizing the creation of rents.

3.1. The “adverse selection” and the “hazard problem”: a review of regulatory approaches and instruments

In order to understand how the regulation of the networks may influence SG investment, one has to understand the main features of the regulatory issue. Natural monopolies, like electricity distribution and transmission activities, are characterized by decreasing long run marginal costs, justifying their need to be regulated. However, the regulation of natural monopolies is a challenging issue for regulatory authorities due to the asymmetric information problem.

In the principal-agent theoretical framework, this challenge can be divided into two main concerns: the “adverse selection” and the “hazard problem”. If we focused on the cost issue, the first concern would be related to the lack of information about the firm cost function and to the economical rent, whereas the second concern would be related to the manager effort to decrease firms’ cost level (Joskow, 2007). To overtake the “adverse selection” situation, the regulator applies a “cost plus” regulation based on the regular ex-post firms costs analyses and on their profits limitation. However, this can limit the effort of firms’ manager for controlling costs, leading to economical inefficiencies. This is a moral hazard problem that can be overtaken by the regulators through an incentive based regulation approach (Laffont and Tirole (1993), Armstrong and Sappington (2006), Joskow (2008a)). Under “pure” incentive regulation, the price level is fixed by the regulator and it is not reviewed (Baron and Myerson (1982)). The firm has an incentive to reduce its costs, but all the welfare gains due to the cost reductions are kept by the firm. As the regulator doesn’t know the true cost level of the firm, he may define a price level much higher than the true cost level. This is the main drawback of this regulatory methodology, since it can produce monopolistic rents (Schmalensee, 1989). Thus, both pure incentive regulation and cost plus regulation are partial approaches that cannot by themselves solve the lack of information issue. Therefore hybrid methodologies have been adopted trying to consider both the adverse selection and the hazard problem concerns (Armstrong and Sappington (2006), Joskow (2007)). For example, variants of the pure incentive regulation methodology with temporary price review and productivity targets have been applied since 1984 (Beesley and Littlechild (1983)), namely for regulating the electricity distribution network (see e.g. Jamasb and Pollit (2005), Farsi et al (2007)).

Since the eighties, variants of pure incentive regulation have widespread in parallel with the liberalization of Utilities in most western countries. Most of the time, those methodologies are labeled as price cap or revenue cap methodologies. Actually, the main differences between a price cap regulatory scheme and a cost plus regulation scheme are related to (see Joskow (2000) and Guthrie (2006)) the maximum lag between the price review and the minimum range of cost that determines the price review. The impact of this price review on the choice of suboptimal strategies by the regulated firm has been broadly analyzed (see Weitzman (1980) about the ratchet effect in general terms or Vogelsang and Finsinger (1979) and Sappington and Sibley (1988) for price review in the regulatory context). Once those conditions are relaxed, it's quite difficult to define the boundaries between these two types of regulatory methodologies (see Marques, 2003). As it will be argued in the next section, these factors play a main influence in the investment strategies that are followed by regulated firms.

Equation (1) illustrates how the different regulated methodologies are related.

$$P_{t+i} = E_t\left[\frac{\hat{R}_{t+i}}{\hat{Q}_{t+i}}\right] = \frac{E_t^{[\hat{A}_{t+i}\times r+\hat{D}_{t+i}+\hat{O}_{t+i}]} - X + \left(\left(C_{t-i}-C_{t-2i}^{t-1}\right)\times(1+rA)^{2i}\right)}{E_t^{[\hat{Q}_{t+i}]}} = \frac{E_t^{[Capex+Opex]} - X + Ad\ t-i}{E_t^{[\hat{Q}_{t+i}]}} \qquad (1)$$

Where:

- i is the number of periods between each regulatory review.
- $\hat{R}_{t+i}$,, the expected regulatory revenue in period $t+i$.
- $\hat{A}_{t+i}$, the expected regulatory asset base (RAB) in period $t+i$, which includes the actual net asset value plus the expected investments in period $t+i$ of the regulated activities. The actual net asset value can be based on the historical costs (account value) or based on the substitution costs (market value).
- $\hat{D}_{t+i}$, the expected firm capital depreciation in period $t+i$.
- $\hat{O}_{t+i}$, the expected operating cost in period $t+i$.
- r, is the rate of return of the regulatory asset base, which has to be equal to the regulated activity cost of capital, since the cost of capital is the minimum rate of return necessary to attract capital to an investment (Kolbe et al, 1984).
- P_{t+i} is the price level settled for period $t+i$.
- $\hat{Q}_{t+i}$ are the expected quantities sold in period $t+i$.

- X is the incentive[2] factor.
- C_{t-i} are the costs allowed to be recovered that occurred in *t-i*.
- C_{t-2i}^{t-1} are the costs allowed to be recovered that were foreseen in *t-2i* and were related to *t-i*.
- rA is the interest rate considered by the regulator to adjust the allowed revenues.[3]
- Ad_{t-i} is the allowed amount of costs occurred in period *t-i* that can be recovered.

Prices are settled in period *t* for period *t+i* based on the expected regulated revenue and quantities sold in period *t+i*. Beyond the expected Opex and Capex, the regulated revenue includes an incentive factor and an adjustment factor. This latter factor corresponds to the allowed recovery of the difference between the firm's costs that occurred in period *t-i* and the costs foreseen in period *t-2i* that have been recovered through the regulated incomes of the period *t-i*. X and Ad_{t-i} factors explain the difference between the incentive regulation and the cost plus regulation.

The magnitude of the difference between the pure incentive regulation and the pure cost regulation can be defined by the variable β, as follows:

$$\beta = \frac{Ad_{t-i}}{\left(C_{t-i} - E_{t-2i}^{[\hat{R}_{t-i}]}\right) \times (1+r)^{2i}} \text{ and } \beta \in [0;1] \quad (2)$$

Where:

- C_{t-i} is the firm's costs occurred in the *t-i* period.
- $E_{t-2i}^{[\hat{R}_{t-i}]}$ the expected firm's regulated revenues foreseen in the *t-2i* period for the *t-i* period, without any adjustment for costs recovery related to the period before *t-i*.
- *r* is the firm's cost of capital.

There is a continuous relation between the pure incentive regulation and the cost plus regulation. If β equals to 1 all costs variation are transferred to the consumers through the regulated prices. That is a typical cost plus regulation. If β equals 0, costs variation are not transferred to the consumers through prices. The gain and the lost due to the cost evolution are borne by firms. Therefore, the regulatory methodology is not risk neutral for the regulated firms and consequently the firms' investment choice will be influenced by the regulatory framework.

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[2] Which can be related to technical efficiency targets as for a typical price cap regulation or to include other targets namely related to quality of supply (Giannakis, et al 2004) what is close to the performance base regulation (Ajodhia et al., 2006; Joskow, 2008a)).

[3] Theoretically this interest rate should be equal to the firm's cost of capital. However, when most of costs are adjusted, this adjustment is similar to a pay-off with no systematic risk associated.

3.2. The impact of the regulatory approach on investment decisions

The regulatory framework can influence investment decisions in completely different directions: not only for the level of investment, but also for the type of investment. Since the paper published by Harvey Averch and Leland Johnson in 1962 (Averch and Johnson (1962)), it is known that the typical cost plus regulation leads regulated firm to overinvest, in the sense that the firm's investment decision is not motivated by its long run marginal cost, but rather by the allowed return on investment. However, it also has been demonstrated that pure incentive regulation promotes investments leading to cost reduction (Carrington et al 2002, Guthrie, 2006). The SG investment can be framed in this category of investments.

Guthrie (2006) analyzed the impact of regulatory schemes on the firm's decision to make irreversible investments that can decrease operating costs. The relation between pure cost plus and pure incentive regulation is related to the proportion γ of the investment expenditure that is accrued on the firm's RAB after the next price review, *T*, and to the proportion α of the cost savings that is transferred to consumers after *T*. Moreover, Guthrie also related those variables and the type of regulatory scheme. Thus, whether γ= α = 0 the regulatory scheme is a pure incentive regulation approach and whether γ= α = 1 the regulatory scheme is a pure cost of service regulation. This kind of investment is quite similar to a SG investment type. Guthrie concluded that a firm will not invest in a "socially optimal cost reducing project" if $\alpha > \gamma$. It has to be highlighted that when the investment allows some cost reduction, the decision to invest is neutral for the firm, when the regulatory schemes are pure cost plus or pure incentive regulation. In the present case, a regulatory scheme that mix an inventive type regulation on the OPEX and a cost plus type regulation on the CAPEX would promote this type of investments.

However, reformulating Guthrie approach, SG investment may have a wider impact on costs, allowing to avoid some substitution investments or to extend the assets' economical life. The present value of an investment of this kind, when the first price review has occurred in period *T* is:

$$-I_{SG} + \sum_{t=1}^{T} \frac{\Delta C}{(1+r)^t} + \sum_{t=1}^{T} \frac{\Delta I_C}{(1+r)^t} + \sum_{t=T+1}^{\infty} \frac{r\gamma(I_{SG}-\Delta I_C)(1-\alpha)\Delta C}{(1+r)^t} =$$

$$-I_{SG} + \frac{\Delta C}{r}\left(1 - \frac{\alpha}{(1+r)^T}\right) + \frac{\Delta I_C}{r}\left(1 - \frac{1}{(1+r)^T}\right) - \frac{\gamma}{(1+r)^T}(I_{SG} - \Delta I_C) \qquad (3)$$

Where:

- *T* is the next time review period.
- α is the proportion of the cost savings that is transferred to consumers after *T.*
- γ is the proportion of the investment expenditure that is accrued on the firm's RAB after *T.*
- ΔC is the cost decrease.
- I is the cost expenditure.
- *r* is the firm's cost of capital.
- I_{SG} is the amount invested in SG technology.

- ΔI_C is the reduction of conventional investment due to the SG investment.

In the present case, a firm will invest whether:

$$\Delta C + \Delta I_C + \left(\frac{\gamma(I_{SG} - \Delta I_C) - (\alpha\Delta C + \Delta I_C)}{(1+r)^T}\right) \geq rI_{SG} \qquad (4)$$

The firm motivation to invest is directly proportional to i) the next price review period, *T*; ii) the reduction of operating costs, ΔC. On the contrary, firm motivation to invest is inversely proportional to: i) the proportion of costs saving that are transferred to the consumers, α ; ii) the cost of capital, *r*. The impact of ΔI_C on the investment decision is not straightforward, depending whether the reduction on investment cost is greater or not than the SG investment. Considering $\Delta I_C \leq I_{SG}$, the firm motivation to invest increases with γ and the firm investment decision will follow the relation presented by Guthrie: $\alpha > \gamma$. On the contrary, if $\Delta I_C > I_{SG}$, the firm motivation to invest increases with ΔI_C and decreases with γ. This situation is likely to happen since the investment avoided in "copper and iron" may be larger than the expenditure in getting the grid more "intelligent". In that case, a pure incentive regulation, where $\alpha = \gamma = 0$, is the best regulatory scheme to promote SG investments.

3.3. The "smart grid incentive paradox"

It is generally agreed that cost plus regulation promotes investments in the network as the investor is sure to recover all its investments and the gains are directly proportional to the amount invested. However, the nature of investments may be such that it breaks the relation between gains and scale, namely when it can avoid the need to invest more, as it can be the case of SG. The implementation of sensors and controls in the grid may solve most of the foreseen problem without the needs for more physical investments in the near future. In that sense the system operator may prefer to invest in conventional investments which can raise his regulated revenues in the future.

The nature of investment effect on decisions has to be considered whenever the regulatory scheme is designed. Focusing in SG, as equation (4) shows, the impact of regulatory instruments on these investments depends on the technology characteristics: less need of capital investment and improved operational efficiency. Therefore, the regulatory scheme has to be adapted to the SG effects on firm's CAPEX and OPEX. The more SG decrease costs, the more incentive regulation is effective on promoting "smart" technologies and the less cost plus regulation is effective. In this situation, we are in front of what can be called the "smart grid incentive paradox".

4. The new regulatory model in practice

In this section it is discussed the solution to practical issues that may rise with the implementation of an incentive regulation to promote smart grids. Then, the theoretical model is compared to the regulatory model that was applied in Portugal.

4.1. Dealing with the paradox: uncertainties on technology and on investor response may lead regulators to prefer a mixture of approaches

As suggested above, the type of investments on SG requires a regulatory scheme different from the conventional approaches (see: Dobbs, 2004, Guthrie, 2006[4]; and de Broer, 2012). However whether SG promotion will only be based on a highly incentive regulation, two main problems may appear. Firstly, the "adverse selection" issue becomes crucial as the firm may retain most of the rent. Secondly, this regulatory option can jeopardize conventional investment that is unable to be substituted by SG investment (Joskow, 2008a). Additional measures may have to be taken by the regulator to ensure that investments are made in a timely and efficient manner, and the quality of service is not affected by the incentive regulation.[5]

In a context marked by several uncertainties on technology and on investor response, the regulator may prefer a hybrid approach composed of a mixture of approaches instead of to stick to a more unpredictable incentive regulation, alone. In particular, it is suggested three possible measures that can help the regulator to implement a favorable framework for the deployment of SG:

- by enhancing quality standards of electricity supplies - performance-based regulation (see: Armstrong and Sappington, 2006; Sappington, 2005) - through greater incentives and penalties, in a process of gradual increase of the quality targets in order to create a more challenging benchmark for network operators;[6]

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[4] In that case for CAPEX

[5] It was shown above that an incentive regulation can raise the efficiency of the regulated firm, but it can also push the company to further cut costs and investments which undermining the quality of the service. In a study for utilities in the US in the years 1990s, it was shown that a move towards price-cap regulation resulted in a significantly longer duration of service outages (Ter-Martirosyan and Kwoka, 2010).

[6] The reliability of electric networks has become crucial due to the increase of systems and devices that are strongly dependent on electricity, raising customer's requirements for quality of the service. Several studies have evaluated the costs of customer outages, mainly based on customer surveys and simulation procedures (ALLAN & KARIUKI, 1999)(Lehtonen & Lemstrom, 1995)(Billinton, Cui, & Pan, 2002).

Typical values of the cost of not delivered energy in some countries can be found in Zemīte & Gerhards (2009) and Henry, Lagland & Kauhaniemi (2007), where the following range of values are presented: Residential – 0,98-16,4 €/kWh; Agricultural – 1,83-15 €/kWh; Commercial – 2-124 €/kWh; Industrial – 0,3-56 €/kWh; Public – 1,59-80 €/kWh. Despite the significant variation in the costs, they are significantly higher than the lost revenue faced by network operators with the non-delivered energy. Therefore, the regulation of electrical systems often measures the performance of the regulated firms and encloses incentive mechanisms intended to improve the quality of service, namely concerning the continuity of supply, seeking a reduction of the costs for consumers that result from outage situations (Ajodhia et al., 2006; Joskow, 2008a; Joskow, 2008b).

- by taking advantage of declared SG efficiency gains to revise the price cap and limit the perception of rents by the regulated firm later on;
- and by differentiating remuneration applied to SG and conventional assets, or the implementation of a cost plus regulation differentiated by type of technologies. In this case, the SG investment may receive a risk premium to mitigate unwished effects of this kind of methodology on SG, as well as accounting for technology uncertainties.

The last two measures, especially the last one, are practical alternatives to the incentive regulation in case it reveals problems to deal with the formation of rents or to induce timely investments on the physical parts of the network. The first measure can complement all type of regulatory instruments.

In particular the premium/penalty mechanism should be appropriately set, namely concerning the targets to be achieved, in order to be effective in promoting the innovation diffusion. This is essential to preserve the quality of the service in a context of increasing demand and connection of more variable and decentralized generation. In the past, those investments have been mainly concentrated in increasing the amount of “copper and iron”. However, the design of more “intelligent” networks is an interesting approach to be followed by system operators (namely distribution system operator) to improve its reliability performance, while minimizing capital and operational costs in comparison with a more physical “copper and iron" type of investments (EPRI, 2010). Therefore the incentives for the implementation of new “Smart” technologies in the network will depend greatly on the performance criteria adopted by the regulation.

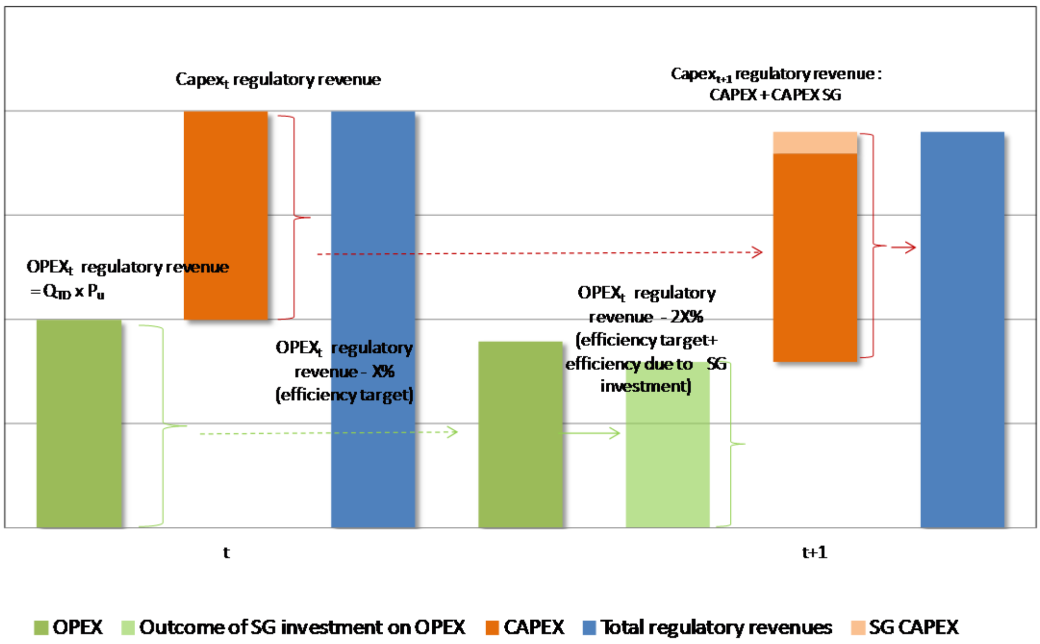
4.2. The incentive scheme adopted in Portugal

The regulatory framework presented in the later sections is now assessed by comparing with the approach adopted in Portugal, to stimulate the deployment of SG, which has been applied since 2012.

The Portuguese regulation brings together two main features (ERSE, 2011a), 211b)): i) a cost plus regulation applied on CAPEX, with investments on SG benefiting of higher remuneration than conventional investments; and ii) an incentive regulation applied on OPEX, where the efficiency target rises with the penetration of SG. The “premium” of 1.5% was estimated to correspond to the externality of the investment in SG (i.e., benefits for society at large), in order to improve efficiency in the allocation of resources while avoiding any distributional distortions. In particular, it considers the efficiency gains in terms of physical investment avoided by the implementation of SG (Fig. 1).

The expected benefits resulting from the implementation of these innovations in the networks is compared to the greater risk that the investor has to hold with the adoption of an immature technology, which is in the early years of diffusion. In that sense, the additional risk is compensated by differentiating the capital expenditure in such investments in relation to the capital costs in conventional investments in the distribution network. However, this discrimination is not likely to remain beyond the period of maturity of the newly deployed technology, also in order to stimulate early deployments of the “smart” technologies.

Figure 1. Considering the investments in innovation in the networks (ERSE, 2011a)



The initial increase in the value of CAPEX, as a result of the implementation of SG, is coupled with an expected decrease in the value of OPEX, which raises the fear of rationed investments in the physical network that may lead to a lower quality of the service in the future. Hence, on the one hand, the return on assets associated with innovative investments is higher compared to other investments, but on the other hand, the target efficiency required to OPEX in SG is also more important. In this way the regulator searches to ensure that conventional investments, which are unable to be substituted by SG, are made without being affected by the promotion of those entities.

Considering the uncertainties that still characterize SG implementation and benefits, the regulatory approach followed in Portugal features some advantage in terms of sharing the risk of the investment between the actors (namely the distribution system operator and final consumers). However, the efficacy of this approach remains uncertain. Firstly, SG innovations and concepts are still immature. Even though progresses has been made in the diffusion of smart meters in several countries, the investments in the distribution network (a key component for SG) are much far from the start (European Commission, 2012; European Commission, 2011b). Secondly, the adverse conjunctural context, which started with a huge public deficit crisis that became an important economic crisis, has lead to the reduction of investments in the economy. Hence the more difficult financing conditions may lead to a slow progresses in SG penetration, though it is not discarded that in a context of a more rationed capital availability SG would not be enough attractive in relation to other more profitable investments. Thirdly, the disembodied nature of the SG technologies may not be suitable for a cost plus type of regulation because of the risk of strategic behavior of the regulated firm, who may prefer to invest in conventional assets in order to ensure a higher level of regulated revenues for the future ("Smart grids paradox", see subsection 3.3.). If that is the case, there is an interesting challenge to the regulation community in the coming years to improve the regulatory instruments in order make them more effective in the promotion of innovations such as SG.

5. Conclusions

The cost-plus regulation is generally used to stimulate investments in new networks and technologies because it transfers a part of the risk from the investor to the society. In the past such regulation showed very effective results in the early phase of electrification. The implementation of SG promises to supply new services to the users of the system; however in the medium term it will substitute the need for more heavy, though lower risk, investments in the network, which would increase the revenues of the regulated firm. This explains why a cost plus framework may not spur investment in technology that is less capital intensive and able to save operational costs, like SG. Conversely, an incentive regulation allowing the investor to keep a part of cost reduction gains may prove more effective to prompt the investments in SG. Nonetheless, this approach has generally two main drawbacks: economic rents and a deterioration of the service. On the one hand, the choice of efficiency requirements to the regulated firm and a predicable schedule for tariffs revision can balance the will to support SG, with the minimization of any redistribution distortion. On the other hand, the quality of the service can be ensured by a better redefinition of the performance standards in order to lead the regulated firm to make additional efforts without deteriorating the service. These two elements (efficiency obligations and performance regulation) may be the key for the creation of a favorable regulatory context for the deployment of SG, and their role in the adoption of innovations in networks should be more studied in future researches.

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DAY 9 - 16:30		
Room 639 - Wealth Accounting and Valuation of Eco Systems		
Non-market valuation of environmental resources in Portugal	Paula Simões[1]; Luís Cruz[2]; Eduardo Barata[2]	[1]Polytechnic Institute of Leiria; [2]GEMF, Faculty of Economics, University of Coimbra
Transport infrastructure project evaluation using cost-benefit analysis: how are environmental impacts assessed?	Heather Jones[1]; Filipe Moura[1]; Tiago Domingo[1]	[1]Insituto Superior Técnico
The carbon responsibility of capital and labour	Alexandra Marques[1]; João Rodrigues[1]; Tiago Domingos[1]	[1]Instituto Superior Técnico, Universidade Técnica de Lisboa, Lisbon, Portugal
Public opinion on renewable energy technologies. The portuguese case.	Fernando Ribeiro; Paula Ferreira; Madalena Araújo; Ana Cristina Braga	Universidade do Minho

Non-market valuation of environmental resources in Portugal

Paula Simões [a)], Luís Cruz [b)] and Eduardo Barata [c)]

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Abstract

There are three dominant methodological approaches in non-market environmental valuation: contingent valuation, choice modelling and travel cost. This paper presents a comprehensive survey of their empirical application in Portugal. Three main research questions are addressed: “What has been done in the domain of non-market environmental valuation in Portugal?”; “What common features can be observed across different studies?” and “What do we know about the validity/reliability of the monetary values estimated?”. The survey lead us to conclude that environmental valuation in Portugal began in the early 1990s and has been devoted mainly to the evaluation of natural parks and traditional landscapes. Contingent valuation has proved to be the leading method. Price, income and the use of the resource for recreational purposes are among the most important explanatory variables. The results confirm the theoretical validity of the methods.

Keywords: non-market valuation, travel cost method, contingent valuation, choice modelling.

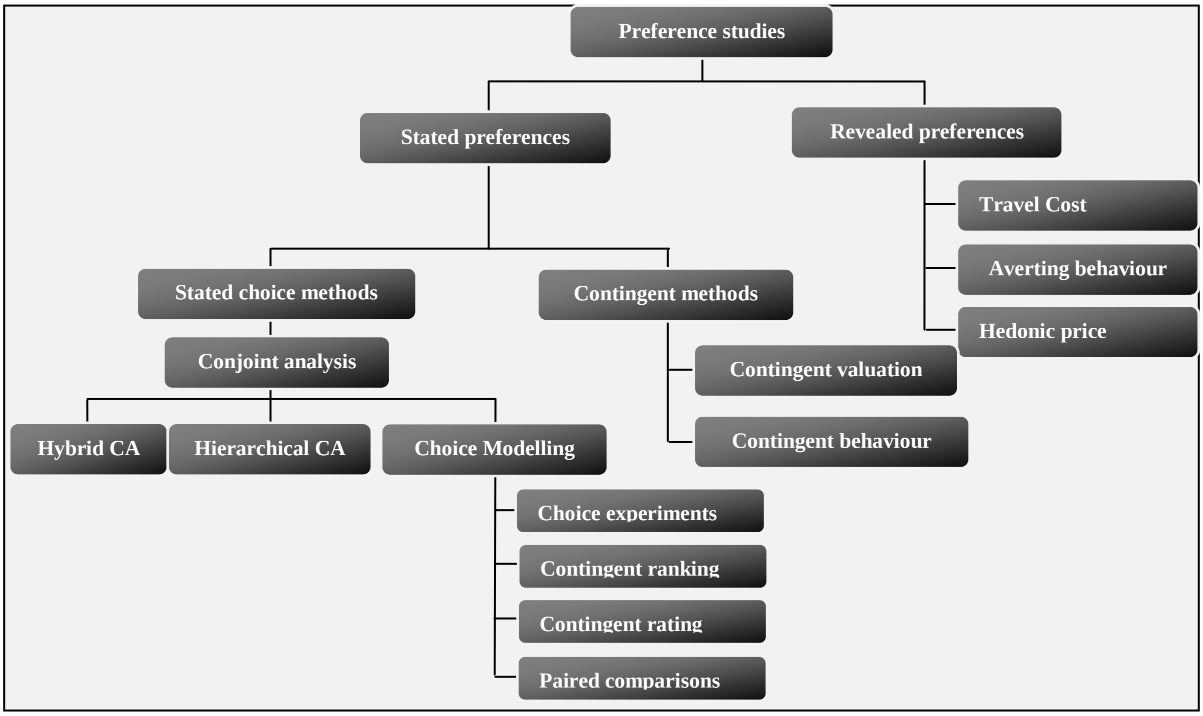
JEL code: Q26, Q51

1. Introduction

One of the basic premises of economic analysis is that people live in a world of scarcity where resources tend to be insufficient to produce the goods and services that would be necessary to satisfy all the human needs. Among the scarce resources there are the environmental ones which provide a wide diversity of goods and services that are valuable for society. The set of needs and wants satisfied by these resources is extensive, going from the most basic such as breathing pure air, to much more complex ones such as recreation and short breaks. Moreover, as societies become richer and more urbanized, demand for environmental services tends to increase, as illustrated by the U-shaped environmental Kuznets curve (Culas, 2007: 430). This means that as the time goes by, demand for environmental services tends to increase, putting great pressure on natural resources. Hence, the efficient allocation of the resources involved is increasingly urgent. Moreover, a wide range of different environmental values is likely to be involved. The total economic value of natural resources includes marketable and non-marketable values, their present and future values, and goods provided can be either material or non-material.

The values of environmental services are not usually directly revealed in market transactions because many of them are non-tradable. Accordingly, non-market valuation techniques must be used to assess their economic value and promote efficiency. These techniques are usually categorized into two major groups of methods, states preferences (SP) and revealed preferences (RP). Figure 1 summarizes diagrammatically the main methods in each group.

Figure 1: Non-market valuation techniques



Adapted from Alriksson and Öberg (2008: 246)

RP and SP methods differ concerning the information required and values measured. RP methods recover people's preferences from actual behaviour and this information is used to work out monetary measures of welfare. Studies applying SP methods use data derived from what people state when directly asked to reveal their choices or to express their judgements regarding monetary values. Any of the methods can be used to estimate actual use values as these values relate to some use, activity or traceable economic behavioural trail. Conversely, only SP methods are able to capture passive use values (non-use values plus option value) as they are independent of any actual use by the people making the evaluation and they leave no clear behavioural footprint. Among the RP methods, the travel cost method (TCM) is the most widely used, while the contingent valuation method (CVM) is the most well-known among the SP techniques. On the other hand, the application of the choice modelling (CM) technique in environmental valuation has been growing rapidly.

In Section 2 we briefly present these methods. Section 3 focuses on their use in the context of the non-market valuation of Portuguese environmental goods. Section 4 concludes.

2. The leading non-market valuation methods

The CVM was originally suggested by Ciriacy-Wantrup in 1947, but its first empirical application was made by Davis in the 1960's to estimate the economic value of big game hunting in Maine backwoods (Mitchell and Carson, 1989: 9). The CVM is a survey-based methodology which involves the construction of a hypothetical market where a proposed environmental program would be transacted. After the description of the hypothetical scenario, people are asked directly or indirectly how much they would be willing to pay/accept (WTP/A) to guarantee/avoid the proposed action. The method is based on the assumption that persons are able to identify the amount they would be WTP/A and that they will report the true value if the questionnaire is correctly designed (Hanley, 1989; Mitchell and Carson, 1989; Arrow et al., 1993; Carson et al., 2001).

Several years of research and empirical application on CVM created the necessary space so that many methodological issues could be raised and discussed. Among the main topics of discussion and research, there are: the ways to minimize or avoid the biases in responses; the choice of the most suitable elicitation format; and the treatment of uncertainty (Li and Mattsson, 1995; Shaikh et al., 2007; Hanley et al., 2009).

CM is a family of survey-based methodologies which has its roots in conjoint analysis (Adamowicz et al., 1999: 461). It models preferences for goods described as sets of attributes, which can be quantitative or qualitative in nature and have different levels. Each combination of attributes is an alternative in the consumer's choice set. The inclusion of price as one of the attributes and the *status quo* situation as one of the alternatives enables the indirect estimation of the WTP/A and the relative values of different attributes. The CM method is consistent with Lancaster's characteristics theory of value which assumes that the utility consumers receive from the consumption of a good can be decomposed into the utilities from the component characteristics (Hanley et al., 2001: 436). In a CM valuation exercise respondents are presented with various alternative descriptions of a good, distinguished by variations in the levels of the underlying attributes, and must choose one of the alternatives, rank or rate them. These different ways of measuring preferences correspond to the different variants of the CM method (choice experiment (CE), contingent ranking (CRk), contingent rating (CRt) and paired comparisons (PC)). CM techniques provide a natural way of analysing environment multidimensionality, but unlike the TCM and the CVM, these techniques were not developed in the context of environmental economics. The earlier applications were made in the fields of psychometrics, marketing and transport (Mackenzie, 1990).

The foundation of the TCM is ascribed to Hotelling, who in 1947 suggested the use of the zonal version of the travel cost model (ZTCM) in a letter to the director of the United States National Park Service. Earlier studies were devoted mainly to the estimation of the monetary value of actual users' benefits derived from water based recreational activities (see, e.g., McConnell and Strand, 1981; Vaughan and Russell, 1982; Desvousges et al., 1983). The TCM has been used in the evaluation of an extensive spectrum of recreational sites, such as forests, parks, lakes, rivers, beaches, heritage sites and related activities (e.g., fishing, kayaking, rock and ice climbing). These sites and activities have two main common features: users must travel to the site to enjoy it and access is free or only a nominal entrance/licence fee is charged.

The TCM establishes a site demand curve by associating the number of trips, or visit rates, to a recreational site with the implicit trip price. Economic benefits are derived by the area under this demand curve between the current price and the choke price. The method is based on the premises that visit frequency to a recreational site declines with increasing travel distances (due to higher costs) and that people consider travel costs similarly to entrance fees. The idea is that the observation of the travel cost that people bear to gain access to recreational sites makes it possible to infer how much people value each site. The implicit price (or travel cost) is given by travel expenditures.

Travel costs may include several components, such as travel expenditures, entrance fees, the opportunity cost of time, equipment costs and on-site expenditures. A number of factors, such as substitution possibilities and socio-demographic characteristics act as demand shifters and help in explaining visitors' recreation behaviour. These factors are believed to explain the demand for trips as visitors with particular characteristics travel to specific sites with preferred attributes to attain the desired recreation experience (Shrestha et al., 2007).

Recreation demand analysed in the TCM framework may refer to a single site or to several sites. In the first case, a single site model is used. A multiple site model is usually used to estimate recreation demand for various substitute sites. There are several versions of the multiple site model which have evolved from the earlier demand system of Burt and Brewer (1971) into other sophisticated models based on a discrete choice framework. Regarding time, choices were originally modelled following one of two possible perspectives: the number of trips made within a period of time, like a year or a season, was analysed; or the decision made at a particular moment regarding what recreational site to visit from a set of sites was examined. When opting for the latter framework, a random utility model or the hedonic travel cost model are usually used (Pendleton, 1999). The development of hybrid approaches is fairly recent. Some of them combine features of the zonal version with features of the individual travel cost model (ITCM). Others combine the choice of the site with the number of visits (Morey et al., 1993).

The CVM and CM are both SP methods and as such, theoretically, are both able to deal with any component of the total economic value. However, these methods have been approached differently in literature. Much research on the CVM has been devoted to the analysis of its main biases and ways of overcoming them. The discussion regarding the application of CM in environmental non-market valuation has been more focused on its advantages relative to the CVM and on the comparison of results across techniques. The most widely emphasized advantages of CM regard the fact that respondents are made aware that different amounts of each attribute might be available, and that price is treated simply as one of the attributes, without being the focus of the survey (Mackenzie, 1990). However, the flipside to each of these advantages is a disadvantage. The most obvious is the higher degree of complexity in comparison with the CVM. For example, Madureira et al. (2011: 402) report the excessive cognitive burden noticed in the pilot survey using CE as the reason for applying the CVM in the main survey instead.

In comparison with the SP methods, the TCM suffers from some limitations. First, like any RP method it cannot be used to estimate any component of passive use value. Second, the welfare measure directly obtained is the Marshallian consumer surplus (the exception is for models based on the random utility theory) while with CM and the CVM one of the Hicksian welfare measures can be recovered directly. Finally, it is based on historical data and thus does not enable the estimation of values for quantity/quality levels that have not been experienced. The TCM is based on observed behaviour and not on the answers to hypothetical questions, thus avoiding all the biases associated with the hypothetical scenario, which is an important advantage. Furthermore, Hicksian welfare measures can be indirectly derived (Bockstael and McConnell, 1980). Hence, we argue that the TCM should be preferred when the research aims to compute actual use values.

3. Empirical research focusing on Portuguese resources

The survey of empirical research which focuses on Portuguese resources presented in this section aims to answer three main questions. We begin by asking: "*What has been done in the domain of non-market environmental valuation in Portugal?*". The following logical question is "*What common features can be observed across different studies?*". The last question is "*What do we know about the validity/reliability of the monetary values obtained?"*

3.1 What has been done in the domain of non-market environmental valuation in Portugal?

Table 1 provides a partial answer to this question as it lists the main studies and for each one identifies: i) the type of publication; ii) the resource involved and the year the survey was administered; iii) the policy measure (when applicable); iv) the method, the question format and the sample size; v) the population surveyed; vi) the component(s) of TEV under evaluation; and vii) the payment vehicle (when applicable). Research results have been made available through different channels, namely, academic theses, books, technical reports, working-papers, conference papers or/and journals articles. When one main piece of research gave rise to different publications, only the main work is included in Table 1[1].

[1] We leave out of the survey the following studies: i) the CVM results of Perna's Master's thesis because the same method was later used in more depth by the author for the same resource. ii) A report by Cruz and Royuela (2009) concerning the estimation of the socio-economic benefits of the Special Protected Area of Pico da Vara/Ribeiro do Guilherme in the S. Miguel Island (Azores). Though estimations based on the TCM and the CVM are referred to, methodological details are not provided. iii) Figueira (1994) who tried to apply the CVM to estimate the WTP for water quality improvement in the public supply system. The research was conducted in an unfavourable social context: the population was elderly, had a low level of education and participation was low. The WTP could not be asked directly and only 41 persons took part. iv) Pereira (2004) as we have some reservations about the valuation scenario.

Table 1: Studies applying non-market valuation methods to Portuguese resources

Study	Type of publication	Resource and year of the survey	Policy measure	Method, format and sample size	Population surveyed	Values	Payment vehicle
Perna (1994)	Master's thesis	*Culatra* Island beaches, Ria Formosa Natural Park (1992)	---	Single site ZTCM, n=406 CVM – DC, n=406	Visitors	Recreational use	---
Machado and Mourato (1998)	Conference paper	Estoril Coast beaches (1997)	Water quality improvement	CVM – MBDC, n=401	Region visitors	Health benefits	Fee
			---	CM – CRk, n=195		Use value	Access cost
Santos (1998)	Book [a)]	Agricultural landscape of the PGNP (1996)	Landscape conservation	CVM – DC, n=704	Visitors	Recreational use + Passive use	Household income tax increase
Perna (2001)	Doctoral thesis	*Culatra* Island beaches, Ria Formosa Natural Park (1997)	Conservation	CVM – OE, n=604 CVM – DBDC, n=577	Visitors	Recreational use	Environmental fee
Santos et al. (2001)	Report	Sportive Fishing (2000-2001)	---	Multiple site ZTCM, n=905	Users	Recreational use	---
Madureira (2001)	Doctoral thesis	Traditional landscape of almond trees (1998-1999)	Landscape conservation	CVM – DC, n=1 027 CM – CE, n=796	Visitors and region residents	Recreational use + Passive use	Increase in the annual income tax
Ribeiro (2002)	Master's thesis	Sportive fishing in Lagoons in the Alentejo region (2000)	Access restriction	CVM –DBDC, n=223	Users	Recreational use	Entrance fee
			---	Multiple site ZTCM, n=497 and ITCM, n=325			---
Nunes (2002a, b)	Journal article	*Sudoeste Alentejano* and *Costa Vicentina* Natural Park (1997)	Protection programs	CVM – DBDC, n=1 678	General population	Recreational use + Passive use	One-time donation
Marta-Pedroso et al. (2007)	Journal article	Cereal Steppe of *Castro Verde* (2001)	Landscape preservation	CVM – OE, n=422	General population	Passive use	Annual tax increase or One-time donation
Madureira et al. (2011)	Journal article	Forestry perimeter of *Cantão das Hortas* (2003)	Management strategies	CVM – DC, n=900	Region residents	Recreational use + Passive use	Household annual income tax Increase
Mendes and Proença (2011)	Journal article	PGNP (1994)	---	Single site ITCM, n=243	Visitors	Recreational use	---

Cunha-e-Sá et al. (2012)	Journal article	Traditional landscape in the Douro Region (2006)	Landscape conservation	CVM – DC, n=706	Visitors	Recreational use + Passive use	Household annual income tax increase
Simões (2012)	Doctoral thesis	Bussaco National Forest (2010-2011)	---	Single site ITCM, n=264 TCM – CB, n = 234	Visitors	Recreational use	---

[a)] *Results of the parallel study for the Pennine Dales (United Kingdom) are not reported here. Dichotomous choice (DC); Multiple bounded dichotomous choice (MBDC); Double bounded dichotomous choice (DBDC); Open Ended (OE); Contingent behaviour (CB).*

Research in the field began about twenty years ago. The earliest studies we could find date from the 1990s. The earliest is Perna's (1994) Master's thesis, where the CVM and TCM were used in evaluating the recreational use value of the Culatra Island beaches. Given the number of studies and articles published in journals, interest in environmental non-market valuation seems to have been increasing since the late 1990s, following the general trend of research in the economic field in Portugal (Guimarães, 2002: 8).

As a general overview, we emphasize five main features. First, the CVM is the prevailing method, probably because of its ability to estimate any component of economic value and its lower degree of complexity in comparison with CM. Second, in SP studies visitors have been the population most often surveyed; accordingly, assessing recreational use value seems to be of particular interest. Third, the Peneda-Gerês National Park (PGNP) has received special attention, most likely because of its features, which make it the only national park in the country. Fourth, the loss of positive externalities as a result of the abandonment of traditional agricultural activities with impacts on fauna and/or on landscape conservation seems to concern the researchers in this area. Finally, interest in the subject seems to be shared equally by economists and agronomists/biologists.

3.2 What common features can be observed across different studies?

Concerning the CVM, three elicitation formats have been used in the WTP questions. The report of the National Oceanic and Atmospheric Administration, known as NOAA panel (Arrow et al., 1993), recommended the use of DC because it better mimics the market *take it or leave it* situation, characteristic of private goods' markets. Instead of DC, its variants are frequently preferred because the additional question(s) improves the efficiency of estimates. In the studies surveyed, the DC variants are indeed dominant but only Machado and Mourato (1998) assessed the degree of certainty in responses. The OE format has been used as well. The preference for this format is usually justified by its more conservative estimates. This result is corroborated by Perna (2001), whose estimates using the DBDC are 1.57 higher than using the OE format.

There are a few variables which seem to be globally important to explaining the WTP, as they are statistically significant across studies. In SP models, the past and current use of the site being studied is associated with higher WTP levels. WTP is also positively related to income and formal education, while age seems to exert a negative influence. Furthermore, Nunes (2002b) and Santos (1998) concluded that the WTP of urban populations is significantly higher than that of rural ones.

Madureira (2001) used the CE in addition to the CVM to assess the value of different landscape attributes. Two important conclusions are that the order of preference concerning different combinations of landscape attributes does not differ among methods and that the CVM produced the most conservative estimates. The author attributes the difference to a flawed focus of the respondents on the price in the CM exercise, which counters the idea that treating price as one among many attributes is an advantage.

The internet is the most recent channel used in questionnaire administration and was used by Marta-Pedroso et al. (2007) in parallel with in-person interviews. This seems to be a promising option in Portugal as well because in spite of the very low response rate, no major differences were found between the sub-samples. This channel is advantageous in what concerns time and budget constraints, which are always important obstacles to obtaining larger samples.

The TCM was used in the estimation of the recreational values of four quite different resources/activities: a beach, used mainly for bathing; a set of lagoons, used for fishing activities; the PGNP and the Bussaco national Forest. The majority of the studies used the zonal version and regressions were always performed using administrative zones as origins due to the difficulties in obtaining data to deal with concentric rings. Mendes and Proença (2011) opted for the individual version of the model which currently dominates the literature. In both versions, besides travel cost, some measure of income (household income, income available for recreational activities and purchasing power) proved to be significant in explaining the demand level. The effect of the travel cost is always negative (as expected), while the influence of income on demand differs across studies. All of the authors considered the opportunity cost of time as a component of the total travel cost. The percentage of the wage rate used as a proxy for the opportunity cost was not uniform across studies, which is evidence of the lack of consensus among researchers.

3.3 What do we know about the validity/reliability of the monetary values estimated?

In preference studies, researchers are unable to observe true economic values. Hence, one of the main areas of concern regards the ability of valuation methods to produce reliable and valid estimates. Reliability concerns the replicability of the measurements and validity is about the correspondence between what one wishes to measure and what is actually measured (Carson et al., 2001: 193).

Three main types of validity can be assessed: content, criterion-related and construct (Mitchell and Carson, 1989: 190). Content validity "refers to the extent to which design and implementation of the survey conform to the generally recognized best practice or state of the art" (Freeman, 2003: 178). Criterion validity is confirmed when the welfare measure estimated is not statistically different from a value known to be the truth or close to the theoretical construct under investigation (Carson et al., 1996: 80). Construct validity includes convergent and theoretical validity (Bishop, 2003: 543). Theoretical validity is verified when results conform to the economic theory. Convergent validity is confirmed when different methods yield measures that are not statistically different, without any presumption about which method is the most correct one. In the words of Bishop (2003: 543), "the measures have roughly equal status", otherwise it would be a criterion test.

The research conditions underlying the studies surveyed are conducive to content validity as these studies were produced in the context of supervised academic research or evaluated by peers before publication. There is also evidence of theoretical validity since price and income are significant explanatory variables of demand and sensitivity to scope is verified. Convergent validity can only be assessed when more than one method is used in a similar evaluation exercise. That is, when the resource and components of value involved coincide. Convergent validity was not confirmed by Ribeiro (2002) who compared the results derived from the CVM and the TCM. In Madureira (2001), after correcting for the *yea saying* bias in the CVM, welfare measures were not statistically different from the ones obtained through the application of CE.

Reliability involves the extent to which a survey will yield statistically equivalent estimates in repeated trials. Test-retest procedures and temporal stability tests have been used to assess reliability. Temporal stability is tested by comparing monetary values obtained interviewing two different samples using the same survey instrument, at two different points in time (Carson et al., 2001: 195). Test-retest procedures are even more demanding as they require the same sample to be re-interviewed using an identical survey instrument (Loomis, 1993: 184). These tests are rare, mainly due to the high costs involved, and this is probably the reason why none of the studies listed above has conducted such tests.

4. Conclusions

This paper has provided an overview of the three most widely used on non-market valuation methods. CM is the newcomer, whereas the CVM and the TCM have a long tradition in the field. From a global perspective, we can say that research relying on these methods has been intense. In Portugal, the decade of the 1990s can be identified as the turning point.

Our survey shows that past and current use of natural areas and similar sites for recreation purposes positively influences the WTP. In general, income has been shown to have a significant and positive effect on the value of resources. Furthermore, evidence that higher levels of formal education are associated with higher demand for outdoor recreation sites and with a higher WTP for conservation (Madureira, 2001; Nunes, 2002b), lead us to expect that, as the level of formal education improves in Portugal, values assigned to natural resources will tend to increase. The accelerated urbanization of the country is likely to act in the same direction.

Assessing the preferences, perceptions and concerns of Portuguese citizens regarding natural areas is particularly relevant for policy-makers. Abroad, public agencies recognize the usefulness of the estimates obtained by the application of these techniques for deciding among alternative policies (List, 2005; Sugden, 2005) and studies have been conducted in order to meet the needs of public agencies (Cameron et al., 1996). However, it seems that in Portugal, in ten years, the state of affairs has not changed significantly. As observed by Perna (2001: 254), in Portugal “out of the academic circle, there is not yet enough knowledge and/or trust to use results of non-market valuation as data sources for public decisions”.

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Transport infrastructure project evaluation using cost-benefit analysis: how are environmental impacts assessed?

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Abstract

This paper addresses cost-benefit analysis (CBA) as an evaluation tool and its major weaknesses. We make a comprehensive review of critiques of CBA. These include its decision making process, it monetizes non-market goods, it does not account for equity, the openness of the interpretation of its results, its scrutiny by the public, its ethics, its discounting of long-term environmental consequences and it is only as good as its critical assumption factors. We conclude that the treatment of environmental impacts is inadequate and needs further research.

Keywords: Cost benefit analysis, transport infrastructure, environmental impacts, lifecycle analysis,

1. Introduction

Infrastructure projects should be evaluated before investment. There are several frameworks used to evaluate projects. Cost-Benefit Analysis (CBA) is the most popular framework (Munger 2000, Nickel et al 2009, Valentin et al 2009, Grimaldi et al 2010). It is widely used because it is a comprehensive evaluation tool (Munger 2000, OECD 2006. ITF 2011), it allocates resources efficiently (World Bank 2004, Ackerman 2008, Ninan 2008), it accounts for costs and benefits (Nash 1991, Archibugi and Nijkamp 1989, Guhnemann 1999, Beder 2000, World Bank 2004, Vining and Boardman 2005, OECD 2006, Ninan 2008) and it is required by regulation in many circumstances. Regulation includes requirement for funding from the Instrument for Pre-Accession countries, Cohesion Fund or Structural Funds for European Union (EU) countries, infrastructure projects in countries such as the U.S., Canada and Netherlands, and for funding from agencies such as the OECD (1969), UN (1972), and World Bank (1975) (Mishan and Quah 2007).

In order to accurately evaluate projects all costs and benefits need to be carefully assessed (Nash 1991). Some impacts are adequately covered by CBA while others leave areas for improvement. Environmental impacts are a factor that has some coverage but also has a lot of room for improvement.

1.2 Cost-Benefit Analysis

CBA is a formal process for evaluating projects. It is based on the concepts of utility (Dupuit 1844, Breton and Klotz 2006, Morrison 2008), consumer surplus (Svoboda 2008), Pareto efficiency (Pareto 1896, Ninan 2008), externalities (Pigou 1932, Demsetz 1996) and welfare economics (Harrod 1938, Hotelling 1938, Hicks 1939, Kaldor 1939, Persky 2001). It allocates resources efficiently (World Bank 2004, Ackerman 2008, Ninan 2008) and equity can be attained if compensation can occur as in applied welfare economics (Persky 2001, Ninan 2008).

CBA is the "single most important problem-solving tool in policy work (Munger 2000)". It is used in decision making for projects and programs (ITF 2011) and is the most commonly used form of decision analysis (Munger 2000). It is an indispensable tool for policy design and decision-making (OECD 2006) and is the most widely accepted and applied method for project appraisal for infrastructure investments in the public sector (Nickel et al 2009, Valentin et al 2009, Grimaldi et al 2010).

CBA is "an essential tool for estimating the economic benefits of projects" (EC 2006) It forces decision makers to take a wider view and assess gainers and losers across space and time (OECD 2006, Ninan 2008), provides guidance on the criteria to use in decision making (Nickel et al 2009), and monetizes inputs and outputs that are not priced in the market place. Monetization transforms inputs into a monetary value that expresses social welfare. The ultimate objective is to provide a structured and common approach to maximize this welfare (Guhnemann 1999). CBA includes explicit individuals' preferences through contingent valuation methods for monetization of effects (Ninan 2008), besides explicitly stating economic assumptions so these are not overlooked or remain implicit (World Bank 2004).

CBA requires valuation of all impacts using actual or shadow prices (Vining and Boardman 2005) that should be the same for projects nationally so as not to be manipulated by decision makers (Archibugi and Nijkamp 1989). It is a way of integrating economic and environmental considerations into decision-making (Beder 2000). Essentially, it seeks to enumerate all costs and benefits to society of a particular project over its service time, assign monetary values, discount them to a Net Present Value (NPV) - thus accounting for time effects - and add them into a single number to evaluate the project (Nickel et al 2009, Ninan 2008, Munger 2000).

CBA inherently requires the creation and evaluation of at least two options, "do it or not". Both alternatives must be evaluated and others may be added. CBA is unique in that it not only requires the alternative of doing nothing at all, it also requires an evaluation at several different scales (nothing, minimum and all as the least requirements) (OECD 2006, European Commission 2008, Ninan 2008).

2. Major Weaknesses of Cost Benefit Analysis

The CBA process is a valuable tool for assessing the desirability of a public investment project. However, it has some weaknesses that should be considered. It has been criticized on many fronts such as its decision making process (Mouter et al 2011), its process (Beukers et al 2012), it monetizes non-market goods (Mackie and Preston 1998, Layard and Glaister 2003, Annema et al 2007, Heinzerling and Ackerman 2002 and Niemeyer and Spash 2011), it does not account for equity (Heinzerling and Ackerman 2002, Annema et al 2007, Banister and Berechman 2000 and Beder 2000), the openness of the interpretation of its results (World Bank 2004), its scrutiny by the public (Persky 2001), its need for completeness and correctness (Annema et al 2007), its lack of being understood (Heinzerling and Ackerman 2002), its ethics (van Wee 2012 and Annema et al 2007) and its discounting of long-term environmental consequences (Ludwig et al 2005). A CBA is highly technical and due to its popular use in promoting (or preventing) public projects, it comes under public scrutiny and it is only as good as its assumptions. CBA mainly focuses on aggregate costs and benefits and not on distribution or equity.

CBA is technical which requires not only a monetary investment but also a staff capable of performing the analysis. Also, some of the data is not known and must be calculated based on assumptions which increases the risk of lower accuracy (as mentioned above). The results are open to interpretation especially in cases that include data assumptions or are difficult to quantify (World Bank 2004).

Because CBA is used as a way to communicate the desirability of a public investment project to many others (government representatives, general population, etc.) it has pushed its way into public debates which in turn has brought about scrutiny of the CBA process (Persky 2001). Because decision makers rely on information from CBAs in order to make investment decisions, the completeness and correctness of the analysis is vitally important (Annema et al 2007). Impacts that are hard to monetize can be left out or be given less attention to, resulting in a biased recommendation (Mackie and Preston 1998). Double counting is also a potential issue and should be considered. A CBA is not only difficult to perform but due to its highly technical nature, it is also difficult to understand and interpret. The general public will have a hard time understanding and participating in the process. Sometimes this is also difficult for those directly involved in the process and decision making (Heinzerling and Ackerman 2002).

CBA considers aggregated costs and benefits and is usually not concerned with the distribution of these costs and benefits and therefore does not always promote equity (Annema 2007, Heinzerling and Ackerman 2002 and Beder 2000). Beder (2000) gives the following example, "a chemical plant may provide many benefits, such as profits to shareholders, taxes to governments and wages to workers whilst causing a deterioration of air quality in the neighborhood. As long as the sum of benefits outweighs the sum of the costs, even if a small group of people get the benefits and many people suffer the costs, the society as a whole is assumed to be better off". One of the principals of CBA is that the economic gainers could compensate the economic losers; the problem is that this seldom occurs.

CBA has also been criticized from an ethics perspective (van Wee 2012) by those that claim it is based on utilitarianism which some experts believe is an "unsatisfactory moral system." One of the tenets of CBA is that "all impacts of a project on individuals are valued on the basis of the impact issue, i.e. does it satisfy or dissatisfy individual preferences?" (Annema et al 2007). This implies that individual preferences may be met but that the greater good might be worse off and therefore might need to be safeguarded. Examples include preserving land or the environment.

The analysis is only as good as the assumptions or estimates. "The right decision only results if prices used by decision makers correctly reflect the social values of inputs and outputs at the social optimum or "shadow prices"; market prices seldom do this so it is important to" arrive at adequate and consistent valuations where market prices fail in some way" (Layard and Glaister 2003). CBA is extremely sensitive to the values used for the different assumptions. A major error in any of these can cause a bias in the results or even change the outcome from negative to positive or vice versa. For example, an extreme error in one of the assumptions for the demand estimation can cause the benefits to exceed the costs for a new road. It has been repeatedly pointed out that placing a value on non-priced impacts is difficult and can probably not result in an accurate price (Annema et al 2007, Heinzerling and Ackerman 2002 and Niemeyer and Spash 2001).

Critical assumptions in CBA include **traffic forecasts and cost estimates** (Skamris and Flyvbjerg 1997, Flyvbjerg et al 2003, Flyvbjerg et al 2004, Flyvbjerg 2005, World Bank 2005a, Mayer and McGoey-Smith 2006, van Wee 2007, Salling and Banister 2009, Rasouli and Timmermans 2012) the **discount rate** (Hemmersbaugh 1993, Weitzman 1994, Weitzman 1998, Weitzman 2001, Florio and Vignetti 2003, RAILPAG 2005, Florio 2006a, Florio 2006b, European Commission 2006), **value of a**

statistical life (VSL) (Farber and Hemmersbaugh 1993, Hanley and Spash 1993, Gerrod and Willis 1999, Miller 2000, Dubgaard et al. 2002, Mrozek and Taylor 2002, Quinet and Vickerman 2004, de Blaeij et al 2007, Bellavance et al 2007, Trottenberg, P. and Rivkin, R. 2011), **value of time (VOT)** (Hanley and Spash 1993, Rainey 1997, Gwilliam 1997, Mackie and Preston 1998, Gerrod and Willis 1999, Banister and Berechman 2000, Dubgaard et al. 2002, Mackie et al 2003, World Bank 2005c, van Wee 2007, Trottenberg, P. and Rivkin, R. 2011, U.S. DOT 2011), **value of accident reduction** (Bristow and Nellthorp 2000, Grant-Muller et al 2001, World Bank 2005b), **regional and local impacts** (Chintz 1961, Rietveld 1989, European Commission 1997, Banister and Berechman 2000, Sieber 2001, Vickerman 2007, Flyvbjerg et al 2003, Mairate and Angelini 2006, Banister 2007, Coto-Millan et al 2007, van Wee 2007, Martinez 2010, ITF 2011) **disregarding equity** (Mera 1967, Hewings 1978, Richardson 1979, Bateman et al 1993, Masser et al 1993, de Silva and Tatam 1996, Banister and Berechman 2000, Beder 2000, Bristow and Nellthorp 2000, Feitelson 2002, Persky 2001, Heinzerling and Ackerman 2002, Annema et al 2007, Ninan 2008, Thomopoulos et al 2009, Shi and Wu 2010, Martens 2011), **treatment of environmental impacts** (Culhane 1987, Buckley 1991, Button 1994, European Commission 1995, Wood et al 2000, Banister and Berechman 2000, Niemeyer and Spash 2001, Heinzerling and Ackerman 2002, Gijsen and van der Brink 2002, van der Brink et al 2003, Flyvbjerg et al 2003, van Wee et al 2003, Laird et al 2005, Chester and Horvath 2007, van Wee 2007) and **lack of residual value** (Lee Jr. 2002, Florio and Vignetti 2003, RAILPAG 2005, European Commission 2006, IASB 2006, Edgerton 2009, Matria 2012).

CBA has been criticized on several aspects from the political process of choosing alternatives (Mackie and Preston 1998) to an ethical perspective (van Wee 2012, Annema et al 2007) and about several critical assumptions. For the purpose of this paper we will focus on the treatment of environmental impacts in CBA.

2.1 Environmental Valuation

Environmental impacts are rarely audited *ex post* meaning that little learning takes place and knowledge is lacking about the environmental risks involved in infrastructure development (Wood et al 2000, Flyvbjerg et al 2003). Environmental assessments are "*inadequately quantified, only guardedly accurate and generally unimpressive as rational-scientific exercises (*Culhane 1987*)*." The lack of data indicates that agencies possess inadequate information about consequences of projects, which implies they can neither refine their predictive decision making models nor mitigate adverse project consequences. Most forecasts made are not accurate. Those that are found accurate are deemed so by their vagueness or because they are qualitative (Culhane 1987, Buckley 1991, Wood et al 2000).

Critics argue whether these elements should be monetized, and if so, how it should be done (van Wee et al 2003, Banister and Berechman 2000). Some argue that environmental elements are priceless goods that should not be monetized (Heinzerling and Ackerman 2002). Others argue that common methods used for monetization are inherently flawed (Niemeyer and Spash 2001, Feng and Wang 2005, Ackerman 2008) or subjective (Button 1994). Others argue that as many impacts as possible should be monetized and included (Bateman et al 1993, Bristow and Nellthorp, 2000). While agreement may be a long ways off, the discussion is important and will have a large impact on future CBA.

In order to account for energy consumption and environmental impacts most CBAs use only the period when the infrastructure is operating and ignore the energy consumed and impacts produced during construction, maintenance or dismantling. Most energy use and emissions are calculated 'tank-to-wheel' (van Wee et al 2003, Gijsen and van der Brink 2002, Chester and Horvath 2009) and assume values for technical characteristics (e.g., for trains-weight, rolling resistance and air resistance) and operational characteristics (e.g., for trains-number of stops, maximum speed and acceleration and deceleration levels). Energy use and emissions from the production of electricity are often included (van Wee et al 2003).

Studies have been performed on indirect energy use and emissions but not inside CBA. Indirect energy use and emissions from the production of trains is marginal compared to the construction of rail infrastructure partly due to the use of cleaner lorries and fuels with less sulphur content (Van der Brink et al 2003). Examples include energy used in the production of vehicles, administrative/office energy use and emissions related to the maintenance of vehicles. Van Wee (2007) believes this issue is complicated and new insights are unlikely. However, Chester and Horvath (2007) estimated that road construction, maintenance, lighting and herbicides and salting accounted for 14% of the lifecycle energy consumption of cars and 16% of CO_2 emissions, proving significant. We argue that energy consumption and environmental impacts from construction, maintenance and dismantling can and should be included in CBA, for finer inspection of the magnitude of their impact on the total lifecycle costs and benefits, or to enable the differentiation between alternative projects (for example, different construction approaches have different lifecycle energy and environmental costs).

CBA monetizes some environmental elements such as energy use and emissions such as PM, SO_2, NO_X and CO_2 (Ulgiati and Basosi 2010, Van Wee et al 2003, Hayashi and Morisugi 2000, Spash 2000, Guhnemann 1999, Mandell 2011). However, other elements are disregarded and the costs of doing something versus nothing are not included such as the value of the aesthetics of land if nothing were to be built. Elements that could be accounted for are aesthetics, cultural heritage, health and safety, peace and quiet, water and air quality, ecosystems functions and biodiversity (Spash 2000). Habitat disruption (Ackerman 2008) and biodiversity loss are ignored but could be monetized and included through Hedonic methods or by connecting ecosystems to their role in the global carbon cycle and climate system (Murray et al 2011). Impacts related to resource withdrawal from the environment such as mining for construction materials, threat to biodiversity, and eco-toxicological potential from particulate matter could be included (Ulgiati and Basosi 2010). Irreversible environmental damages and the interests of future generations are clearly issues but are hard to monetize (Guhnemann 1999, Hanley and Spash 1993). CBA does not promote sustainable development and does not ensure intergenerational justice. The time horizon chosen is important for environmental impacts as some (such as irreversible deforestation costs or benefits from the Kyoto Protocol) take decades to appear (Hansen and Gilberg 2003).

Finally, local emissions are important regarding noxious pollutants such as PM, NOX and CO and noise. Accordingly, the exposure level of population should be distinguished. For example, the distance between a power plant and people is usually much greater than the distance between roads and people. They can have the same emissions but the road is more harmful because it is closer to people. The only CBA that addresses this was the Schipol Airport CBA (van Wee 2007). This indicates an additional weakness of current practice. Environmental impacts outside the geographical scope (such as in other countries) of the CBA are excluded (Hansen and Gilberg 2003).

Table 1. Monetized Impacts Included and Excluded in CBA and LCA

	Included in CBA	Excluded in CBA	Included in LCA	Excluded in LCA
Noise	GM, BN	EU		
Local Air Pollution	BN	EU, VW		HG
Regional Air Pollution	EU, GM		HG	
Global Air Pollution	EU, GM, BN		HG	
Landscape		EU, GM, BN		
Land Take	EU			
Land Amenity		EU		
Special Sites		EU, GM, BN		
Severance	(limited) GM, (very limited) BN	EU		
Water Pollution		EU, GM, BN		
Vibration		GM, BN		
Visual Intrusion		GM, BN		
Resource Consumption		GM, BN		

BN=Bristown and Nellthorp 2000, EU=EUNET 1998, GM=Grant-Muller et al 2001, HG=Hansen and Gilberg 2003, VW=Van Wee 2007

Life-cycle Assessment (LCA) accounts for some impacts that CBA does not and it accounts for impacts over the entire life cycle (refer to Table 1). One important difference between methodologies is the unit used for weighing different factors included in each methodology. In LCA, every environmental impact is converted into some non-dimensional eco-unit, ultimately (e.g., eco-points in the Eco-Indicator 99 (EI99) (Goedkoop and Spriensma 99)), whereas all socioeconomic costs and benefits are estimated in monetary terms in CBA (Hansen and Gilberg 2003). Interestingly, environmental damage costs included in many CBA are based on Impact Pathway Analysis methodology defined by the EU funded ExternE Project on External Costs of Energy (EC, 1995). This methodology follows the approach of WTP for improved environmental quality or WTA for environmental damage.

Instead of potential impacts in LCA, actual impacts that are site specific should be presented as they can be monetized based upon impact pathway analysis and existing values expressing individuals´ preferences toward the impacts. Monetization has advantages over weighting schemes as weighting is based on e.g. air quality standards or expert judgment making it based on measured preferences. Monetization is more illustrative and easier to interpret than utility points or other measures. However there is more uncertainty around impact assessment and valuation than an LCA inventory and additional concerns such as the existence of thresholds, discounting of future impacts and valuation of mortality can arise (Krewitt et al 1998).

Bringing CBA and LCA together requires unit harmonization, as referred previously. Monetary valuation of environmental impacts is the more adequate approach, despite implementation issues (e.g., data intensity of impact pathway analysis, uncertainty related to monetary valuation, feasibility of the approach to all impacts analyzed within the LCA methodology). One option is to extend the existing and accepted monetary valuation of environmental damage costs (e.g., monetary costs of atmospheric emissions and noise exposure) to other environmental impact categories (refer to Table 2) based on the weighting system of current LCA aggregation methods. Impacts expressed in terms of Disability Adjusted Life Years (DALY) have been used to value Human Health damages from EI99 and presents a way to monetize impacts (Fiurza et al 2006).

Table 2 presents the existing intersection of CBA and LCA methodologies starting with the damage-oriented methodology used in SimaPro software from PRé Consultants for LCA according to EI99. For each of damage category and corresponding environmental impacts, we identify those that are partially covered in CBA practice, but also if there are existing or potential ways of monetary valuation of the remaining impacts that are not covered at all in existing CBA practice.

Clearly as many environmental impacts as possible should be included in CBA. These impacts include landscape and habitat preservation, habitat disruption and biodiversity loss, exposure level of the population and environmental impacts over the project lifetime Further research into monetizing these impacts is needed. Monetizing the damage categories in Table 2 would bring completeness to CBA.

Table 2. Intersection of CBA and LCA with respect to environmental impacts based on the Eco-Indicator 99 approach

LCA Damage Categories [a)]	LCA Environmental Impacts [a)]	Covered in CBA	Existing methodology for monetary valuation?
Human health	Carcinogenic	Partially, through air emissions estimation for use stage, only	Potentially through Impact Pathway Analysis (IPA) approach
	Respiratory organics	Partially, through air emissions estimation for use stage, only	Partially, for some air emissions, based on IPA
	Respiratory inorganics	Partially, through air emissions estimation for use stage, only	Partially, for some air emissions, based on IPA
	Climate Change	Partially, through air emissions estimation for use stage, only [b)]	Yes, based on IPA or through emissions' trading schemes
	Radiation	No	No
Ecosystems	Ozone Layer	Partially, through air emissions estimation for use stage, only	Partially, for some air emissions, based on IPA
	Ecotoxicity	Partially, through air emissions estimation for use stage, only [b)]	Partially, for some air emissions, based on IPA
	Acidification/ Eutrophication	Partially, through air emissions estimation for use stage, only	Partially, for some air emissions, based on IPA
	Land Use	No	No
Resources	Minerals	No	No
	Fossil fuels	No	Yes, by accounting lifecycle costs of final energy use.

[a)] List based on the damage-oriented methodology used in SimaPro software from PRé Consultants for the LCA according to the Eco-Indicator 99.
[b)] Except when "well-to-wheel" emission factors are used to estimate the complete air emissions related with the lifecycle of the energy used.
Source:

3. Conclusion and research agenda

CBA is widely accepted as a decision making tool. However its weaknesses have been loudly criticized which has driven research into improving the methodologies for its critical factors. Some critical factors have received more attention and research but none of the factors are yet solved and further investigation is crucial until solutions are universally accepted. The treatment of environmental impacts is inadequate and requires further research.

Environmental costs are difficult to monetize with large uncertainty ranges and LCA is not performed, thus not accounting for impacts from construction and maintenance of infrastructure (Culhane 1987, Buckley 1991, Button 1994, Bos 1998, Wood et al 2000, Banister and Berechman 2000, Niemeyer and Spash 2001, Heinzerling and Ackerman 2002, Gijsen and van der Brink 2002, van der Brink et al 2003, Flyvbjerg et al 2003, van Wee et al 2003, Chester and Horvath 2007, van Wee 2007).

CBA monetizes some environmental elements such as energy use and emissions such as PM, SO_2, NO_X and CO_2. Elements that should be accounted for include: costs of doing something versus nothing, aesthetics, cultural heritage, health and safety, peace and quiet, water and air quality, ecosystems functions and biodiversity, habitat disruption, biodiversity loss, resource withdrawal (mining for construction materials, threat to biodiversity, and eco-toxicological potential from particulate matter), irreversible environmental damages, interests of future generations, exposure level of population and environmental impacts outside the geographical scope.

Clearly as many environmental impacts as possible should be included in CBA. Further research into the monetization and inclusion into CBA of the environmental elements mentioned above is needed. Monetizing the damage categories in Table 2 would bring completeness to CBA and would help to account for the life cycle impacts.

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The carbon responsibility of capital and labour

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Abstract

Since the Industrial Revolution developed economies' economic growth has been powered by the combustion of fossil fuels. This is believed to be the main cause of one of the most debated environmental problems: climate change (IPCC, 2007). Climate policy's objective is to minimize the effects of climate alterations in a just and fair manner. A new point of view on responsibility for carbon emissions is emerging (Clark, 2012; Petherick, 2012), bringing into discussion the role of those who enable emissions. In this comment we follow the rationale that carbon emissions from a production process were enabled by and provide economic benefit to those who supplied inputs to that process (Rodrigues *et al.*, 2006; Lenzen *et al.*, 2007). If we follow every production chain upstream to the source we find that primary suppliers are income categories (capital, labour, land and natural resources). Here, we present the carbon emissions enabled by each income category and show that capital is the category that enables more emissions worldwide (47%), and where each dollar received enables more emissions. We also present a multi-country analysis showing that major fossil fuel exporters are those who enable more emissions worldwide. These results may help understanding the position of such nations in climate negotiations (Clark, 2012; Petherick, 2012), and may be useful for climate policy, especially with regard to the issue of climate finance.

Keywords: income-based responsibility, primary suppliers, carbon responsibility, multi-regional input-output

JEL Codes: *C67, Q56, Q57*

1. INTRODUCTION

Progress in climate policy has been slow, and one of its last major achievements occurred in the 2009 Copenhagen Climate Summit, with the creation of a climate fund “to support projects, programmes, policies and other activities in developing countries related to mitigation" (UNFCCC, 2009). Consequently developed countries agreed to mobilize US$100 billion a year by 2020, and pledged US$30 billion to a fast-start financing over the period 2010-2012 (UNFCCC, 2009). However, these intentions remain somewhat vague since no binding contributions or time periods were established. Despite the creation of new mechanisms to tackle climate change, climate negotiations are in a deadlock.

Recently, a new approach to carbon responsibility has emerged. For example, a report released by Banktrack (Schüking *et al.*, 2011), a network that measures the effect of financial activities on people and the planet, highlights the importance of banks in enabling emissions through investment decisions. They assessed banks’ performance regarding investments and concluded that self-proclaimed greener banks are those who enable more emissions through investments in the coal industry (Petherick, 2012; Schüking *et al.*, 2011). Also, they found that in 2010 total investments in coal was almost the double of what they were, before the financial crisis, in 2005, when the Kyoto Protocol came into effect (Petherick, 2012; Schüking *et al.*, 2011). Another example is the analysis of the relation between positive and negative influence of countries in climate negotiations and their fossil fuels reserves, reported in (Clark, 2012). Interestingly, the countries with higher fossil fuels reserves are also those who more actively push back climate policy advances (Clark, 2012). These examples, suggest a new approach to carbon responsibility focused on those who enable emissions to occur, through the supply of inputs to production processes.

To deal with climate change a lot of effort has been put into finding ways of reducing fossil fuels’ consumption; through more efficient production processes, but also by developing alternative energy technologies and sources. However, if these measures are not accompanied by measures dealing with resource extraction they might not be effective (Sinn, 2008). If extraction paths are maintained, with a decreased demand the world price of carbon and fossil fuels would decrease inducing countries that have not ratified the Kyoto Protocol to consume what Kyoto countries have economized8. Moreover, if suppliers feel threatened by climate policies they will feel encouraged to extract their stocks more rapidly thus accelerating global warming (Sinn, 2008).

Here, we show how primary suppliers, or in other words income categories (capital, labour, land and natural resources) enable carbon emissions, receiving an economic benefit from it; we also present an analysis at the country and region level.

2. MATERIALS AND METHODS

<u>Multi-Regional Input-Output Model</u>

In this work, we measured how primary inputs (the same as primary factors of production, value added or income categories) enable emissions to occur downstream along the supply chain, using a multi-regional input-output (MRIO) model (Rodrigues *et al.*, 2006; Lenzen *et al.*, 2007). This is an approach symmetrical to the more frequently used *consumer responsibility* which measures how final demand (the same as consumption) stimulates emissions to occur upstream along the supply chain (Wiedmann *et al.*, 2011). These two approaches provide different and complementary results. The former results are supply-driven results, whereas the later demand-driven.

In recent years, multi-regional input-output (MRIO) models have been extensively applied in order to analyse global environmental problems, namely the impacts of consumption (Wiedmann *et al.*, 2011); however, few have been the studies analysing how primary inputs enable carbon emissions in order to guarantee their income (Rodrigues *et al.*, 2006; Lenzen *et al.*, 2007).

An input-output (IO) model (Miller and Blair, 2009) is a description of the direct monetary flows between economic sectors (industries and categories of final demand and of primary inputs) also allowing the quantification of indirect effects, through IO multipliers. One basic assumption of this model is that everything that enters the economy must come out; therefore total input must equal total output. The first applications of the classical Leontief input-output model analysed how an economy would react to a shock in final demand; this is the so-called demand driven model.

An alternative IO model was suggested by Ghosh (Ghosh, 1958), this model analysed how an economy would react to a shock in primary inputs. The plausibility of the Ghosh model has been discussed in the literature (Oosterhaven, 1996; Suh *et al.*, 2010), one of its major criticisms being the full substitutability of inputs, since it would be very difficult to accept that "factories may be run without essential input or even worse without labour" (Oosterhaven, 1996). However if causal interpretations are avoided the model can be used in a descriptive analysis of the economy (Oosterhaven, 1996).

In the consequential analysis described above the objective is to study the effect that a stimulus in an exogenous parameter (e.g., final demand) causes in some endogenous parameter (e.g., added value), by considering the economic structure to remain fixed. In the study of environmental problems the aim is to provide a description of the environmental pressures generated due to economic activity and not to establish causal relationships. This can be done through the use of the well-known Leontief inverse, if we want to measure the direct and indirect environmental pressures generated upstream the supply chains and embodied in an agent's final demand; or through the use of the Ghosh inverse if we want to measure the direct and indirect environmental pressures generated downstream the supply chains and that have been primarily enabled by primary factors of production. This interpretation, which is in consonance with process-oriented life cycle analysis, requires the specification of allocation rules but no technological assumption (Suh *et al.*, 2010).

In this work we use the Ghosh inverse to measure direct and indirect CO_2 emissions enabled by primary factors of production. We start by considering a set of monetary balance equations:

$$\mathbf{Z}'\mathbf{1} + \mathbf{v} = \mathbf{x} \tag{1}$$

$$\mathbf{Z1} + \mathbf{y} = \mathbf{x} \tag{2}$$

where **Z** is the matrix of inter-sectoral transactions, **v** is the vector of added value, **y** is the vector of final demand, **x** is the vector of total input, **1** denotes a vector of ones of appropriate length, ‘denotes transpose and vectors are in column format by default. Eq. 1 indicates the monetary inputs of each industry while Eq. 2 indicates the monetary outputs.

We now consider that there is a quantity of enabled downstream emissions associated with each economic transaction, subject to the following balance equations:

$$\mathbf{Z}^{\mathbf{e}\prime}\mathbf{1} + \mathbf{v}^{\mathbf{e}} = \mathbf{x}^{\mathbf{e}} \tag{3}$$

$$\mathbf{Z}^{\mathbf{e}}\mathbf{1} + \mathbf{d}^{\mathbf{e}} = \mathbf{x}^{\mathbf{e}} \tag{4}$$

where superscript **e** denotes carbon emissions and $\mathbf{d^e}$ is the vector of direct emissions. Since we are interested in downstream emissions, now Eq. 3 represents the outputs of enabled emissions, while Eq. 4 represents the inputs. Notice that there is no input of enabled emissions from final demand. We make the conventional homogeneity assumption and consider that every monetary input into a given industry has the same downstream intensit, $\mathbf{m_j} = \mathbf{x^e}_\mathbf{j}/\mathbf{x_j} = \mathbf{z^e}_\mathbf{ij}/\mathbf{z_{ij}}$. By dividing Eq.4 by $\mathbf{x_j}$ and rearranging terms we find that:

$$\mathbf{m} = (\mathbf{I} - \mathbf{B})^{-1}\mathbf{d} \tag{5}$$

where **I** is the identity matrix, **B** = **xZ** and d is defined by $\mathbf{d_j} = \mathbf{d^e}_\mathbf{j}/\mathbf{x_j}$. The term

(I - B) $^{-1}$ in Eq. 5 is known as the Ghosh inverse[S3] and an entry $\mathbf{b_{ij}}$ express the share that $\mathbf{z_{ij}}$ represents in the total sales $\mathbf{x_i}$. The total carbon emissions enabled by the income of class i from industry j is obtained by multiplying each entry of the vector of downstream intensity **m** by the corresponding entry of the value added vector **v**.

GTAP Database

To perform the calculations of the emissions enabled by each income category, we developed a full environmentally extended multi-regional input-output (MRIO) model based on version 7.1 of the Global Trade Analysis Project (GTAP) database.

The GTAP database consists of a set of interconnected tables displaying transactions between several economic agents, with the objective of facilitating the operation of economic simulation models, namely Computable General Equilibrium (CGE) models (Narayanan and Walmsley, 2008). Its primary objective is not to be a repository of input-output tables but the data it provides is very useful for multi-regional input-output studies (Peters *et al.*, 2011).

With GTAP data we built a full MRIO model that combines domestic technical coefficient matrices with bilateral trade matrices thus capturing global trade supply chains between all trading partners (Peters *et al.*, 2011). The GTAP database provides information for 57 sectors and 112 regions, it provides 3 final demand sectors (households, governments and investment), and 5 primary inputs sectors plus information on taxes and subsidies. Data used is valued at GTAP's *market prices*, which is the valuation system more similar to the *basic prices* usually used in input-output analysis (Peters *et al.*, 2011). GTAP market prices refer to what the purchaser pays minus commodity taxes (Peters *et al.*, 2011).

Next we describe the categories of primary inputs and taxes that comprise the value added vector. The GTAP Database provides information for 5 types of primary inputs (the GTAP endowment categories): land, unskilled labour, skilled labour, capital and natural resources. Land concerns only rents from agricultural land (Narayanan and Walmsley, 2008). Labour categories are based on the International Labour Organization classifications, unskilled labour concerns production workers (trades-persons, clerks, salespersons and personal service workers, plant and machine operators and drivers, labourers and related workers, and farm workers), skilled labour concerns professional workers (managers and administrators, professionals, and para-professionals) (Narayanan and Walmsley, 2008). Capital concerns Gross Operating Surplus (Horridge *et al.*, 2008) which is equivalent to economic rent or value of capital services flows or benefit from the asset (Peters *et al.*, 2011). Finally, in the natural resources category are included rents from forestry, fisheries and fossil fuels and mining (Narayanan and Walmsley, 2008).

The last category in our vector or primary inputs includes the information provided by GTAP Database on several types of taxes and subsidies; for the purpose or our analysis we lump these together in a category of net taxes, which we denote simply by Taxes.

The information on CO_2 emissions was taken from version 7.1 of the GTAP Database, and refers to CO_2 emission from fossil fuel combustion only.

Data Aggregations

The 57 sectors of the GTAP 7.1 database were aggregated after calculations into nine sectors, as follows (nec – not elsewhere considered):

Agriculture: Paddy rice, wheat, cereal grains nec, vegetables, fruit and nuts, oil seeds, sugar cane, sugar beet, plant-based fibers, crops nec, bovine cattle, sheep and goats, horses, animal products nec, raw milk, fishing, bovine meat products, meat products nec, vegetable oils and fats, dairy products, processed rice, sugar, food products nec, beverages and tobacco products, water, wool, silk-worm cocoons, textiles, wearing apparel, leather products, wood products, forestry, paper products, publishing.

Chemicals: Chemical, rubber and plastic products.

Construction: Construction, dwellings.

Electricity: Electricity.

Fossil Fuels: Coal, oil, gas, petroleum and coal products, gas manufacture and distribution.

Machinery: Motor vehicles and parts, transport equipment nec, electronic equipment, machinery and equipment nec, manufactures nec.
Minerals: Minerals nec, mineral products nec, ferrous metals, metals nec, metal products.
Services: Trade, communication, financial services nec, insurance, business services nec, recreational and other services, public administration, defence, education and health.
Transport: Transport nec, water transport, air transport.

3. RESULTS AND DISCUSSION

Our results (Fig.1) show that, in 2004, the income category which enabled most emissions was capital (47%), followed by unskilled labour (23%) and taxes (14%). The categories that enabled fewer emissions were skilled labour (10%), natural resources (6%) and land (1%). The capital and natural resources categories are the only categories where a dollar of added value enables more than one ton of CO_2, indicating that these are the most carbon intensive categories.

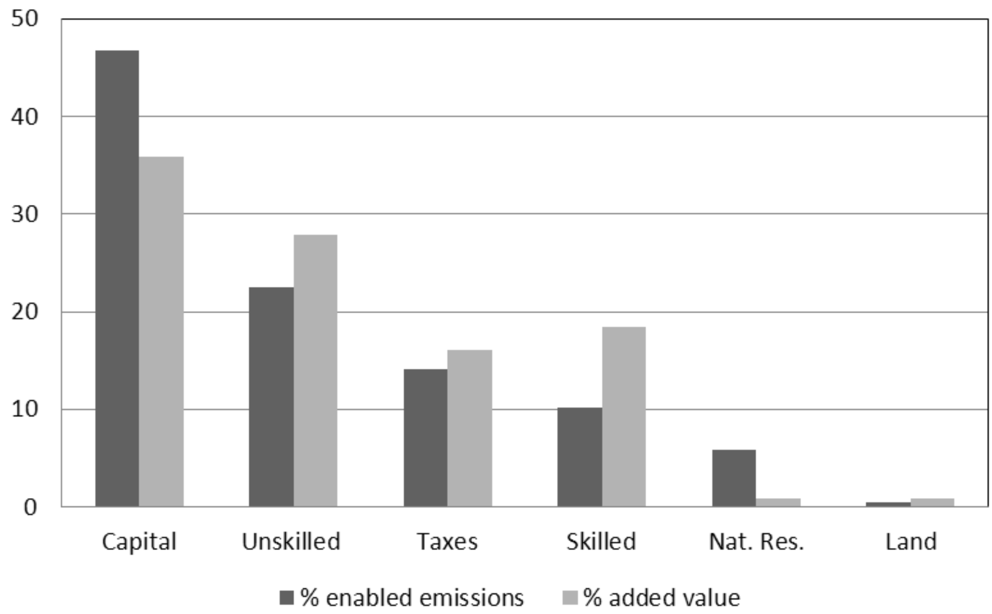

Figure I - Share of world enabled emissions and revenues, by income category, in 2004 (in %).

The capital income category refers to payments made to capital owners (Horridge *et al.*, 2008; UN, 2009). From a policy point of view these are potential useful results since capital is the most mobile income category, and therefore the one with more options to reduce its enabled emissions. An investor has a wider range of alternatives to alter his/her enabled emissions (i.e., change his investment portfolio) than a worker does (i.e., find a new job). These findings illustrate how the involvement of the private sector is "essential for the transition to a low-carbon, climate-resilient future" (UN, 2010), and how investment decisions can play a major role in mitigation of climate change. But which sectors, within each income category, have enabled more emissions?

Investment in the electricity (31%), fossil fuels (20%) and services (19%) sectors were the ones that enabled most carbon emissions (Fig.2). It is not surprising that the income received by capital from energy related sectors enables a large share of emissions, since combustion of fossil fuels takes place in these sectors. The high share of emissions enabled by the services sector is more surprising and is a consequence of the large share of income earned by investment in this sector (Figure 2), which corresponds to 48% of capital's total income. Our results show that a dollar invested in the electricity or fossil fuels sectors will enable more emissions than a dollar invested in the services sector (Figure 2). A recent work (Lenzen and Murray, 2010) analyzed the emissions enabled by the provision of primary inputs to a number of Australian industries. This analysis, at the supply chain level, shows, for example, that someone supplying \$1.000 worth of capital (or another primary input) to the technical services sector would enable the generation of 60kg of CO_2 in the electricity supply sector, whereas someone supplying \$1.000 worth of capital to the natural gas sector would enable the generation of 1130kg of CO_2 in the electricity supply sector. This provides an excellent insight on how this approach can be useful to promote climate informed investment decisions.

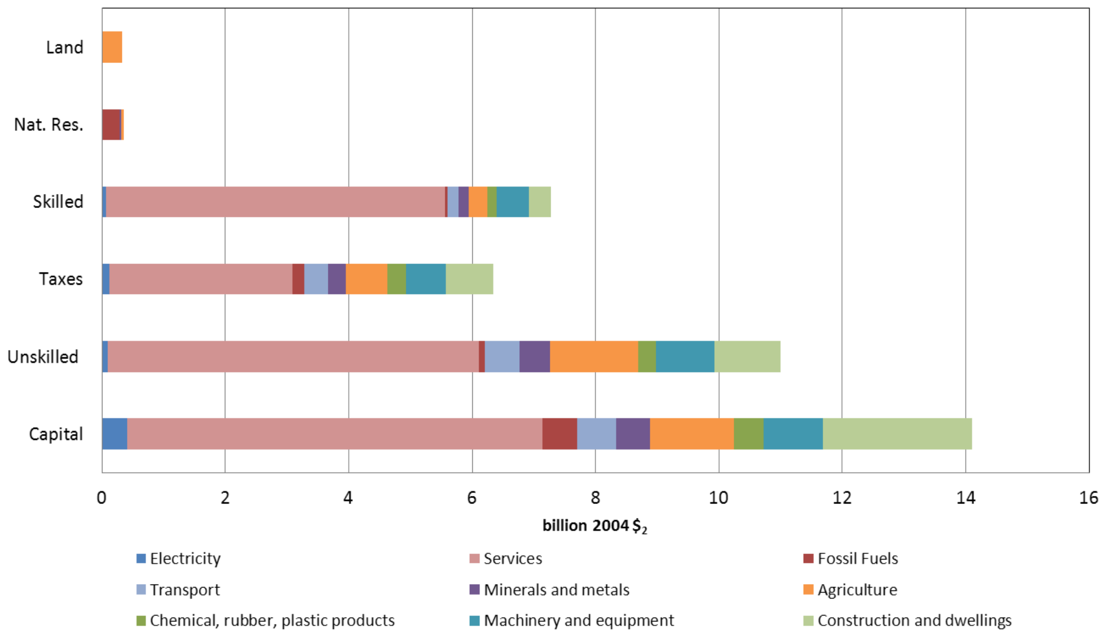

Figure II - Share of world revenues, by income category and by sector, in 2004 (in billion 2004$).

The categories of skilled and unskilled labour account for the income received (salaries) by workers in return for the labour input they provide to production processes. Unskilled labour includes the so-called production workers (e.g., plant and machine operators, drivers, farm workers and salespersons), whereas skilled labour includes the professional workers (e.g., managers and administrators) (Narayanan and Walmsley, 2008). Within the labour income category, it is the services sector that accounts for the highest share of the carbon emissions enabled by both skilled and unskilled workers, with 40% and 22%, respectively. Again this is related with the fact that the services sector accounts for the largest share of world income.

After the services sector, unskilled workers of the transport (20%), electricity (16%), fossil fuels and agriculture sectors (10%) are those who enable most emissions, whereas skilled workers of the electricity (20%) and transport (13%) sectors are the ones enabling most emissions. The emissions enabled by workers through their salaries reflect current production chains and would be indirectly altered by investment decisions to support low-carbon development and the promotion of green employment. The climate debate often neglects the social dimension of climate change; these results show how jobs and salaries are connected to carbon emissions, and how salaries depend on the existence of industries that enable emissions. This highlights the importance of including workers into climate policy discussions, since any measure adopted to mitigate emissions will have a social consequence. The International Trade Union Confederation has been actively engaged in bringing employment and development issues into the climate debate, as part of its commitment to "supporting ambitious actions aimed at combating climate change while shifting growth towards a truly sustainable development (..) providing hope for the capacity of a "green economy" to sustain decent jobs and livelihoods for all." (ITUC, 2009).

The category of taxes concerns the income received by governments. By requiring the payment of taxes governments enable emissions to occur, in order to pay taxes, the company will have to produce, and therefore generate emissions. The sectors where payment of taxes enabled more emissions were: electricity (24%), transport (18%), fossil fuels (17%) and services (15%). In a recent report, Romani and Lord Stern argued that developed economies could raise a substantial amount of money, to tackle climate change, if carbon taxes were created (Romani and Stern, 2011). Our results show which sectors would be more affected by the creation of carbon taxes by governments, this new type of information could aid governments in the implementation of an effective carbon tax mechanism.

Finally, natural resources and land income categories include the income received by owners of natural resources' exploitation rights and agricultural land (Narayanan and Walmsley, 2008, UN, 2009). Owners of exploitation rights of fossil fuels deposits are those who enable almost all (95%) of the emissions associated with natural resources exploitation, and are also those who receive the largest share of income (82%). These results highlight the impacts, in terms of CO_2, emissions associated with natural resources exploitation, and the importance of including actors from the supply side in the climate debate.

In this comment we show that capital is the income category enabling more emissions worldwide, and where each dollar received enables more emissions. We also show that capital intensive sectors (like electricity or fossil fuel sector) enable more emissions, per dollar received, than labour intensive sectors (like services). These results highlight the importance of the increasingly carried out analysis of ascertaining the environmental responsibility of investments (Schüking *et al.*, 2011; Petherick, 2012); moreover our approach provides a comprehensive way of performing it.

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Public opinion on renewable energy technologies: the Portuguese case

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Abstract:

Renewable energy technologies are part of the solution to meet future increasing demand of electricity and decommissioning of power plants in the European Union. Public opinion surveys indicate general support of these technologies, but particular projects face local opposition, a phenomenon known in the literature as the NIMBY (Not In My BackYard) hypothesis. In this study, the public opinion on renewable energy technologies was analyzed by means of a survey implemented in Portugal. The survey addresses four technologies: hydro, wind, biomass and solar power. The study has three main purposes: firstly, to recognize if the people acknowledges the existence of these technologies, secondly, to study the validity of the NIMBY hypothesis in Portugal while realizing in which technology it is more pronounced, and thirdly to perceive the levels of acceptance of each technology, under Sustainable Development aspects (Economy, Ecology and Society). The results suggest that acknowledgement of technology decreases with age, increases with educational degree and is greater in males. There is a generally positive attitude towards new projects of all technologies, and this tendency is more pronounced for solar power. Solar power plants are regarded by the Portuguese public as the most desirable technology in terms of economic and environmental aspects, while hydro power is perceived as the RES technology that can contribute the most to local residents' welfare.

Keywords: Survey, questionnaire, public opinion, social acceptance, renewable energy technology, NIMBY

JEL Classification: P28; Q42; C83

1. INTRODUCTION

Electricity demand projections for 2030 in the European Union (EU) impose the construction of new power plants, due to the required replacement of obsolete ones and increase of the electricity demand (European Commission, 2009). Many uncertainties exist in this process, and their nature lie both on the costs associated to the technologies to implement and on the prices for primary energy, often imported from geographically unstable areas and subject to even higher increasing demand in the developing world. Planning on the long run becomes essential, as power plants require the commitment of large initial capital sums and operate for long periods.

Planning assumes a variety of time scales and purposes. While the practical guide called roadmap2050 (http://www.roadmap2050.eu/) is directed to a very long-term frame, the policies EU20-20-20, targeted to 2020, involve concrete goals: (i) to cut in greenhouse gases (GHG) emissions to at least 20% below the 1990 levels, (ii) to reach 20% of renewables' share in the energy mix and (iii) to increase energy efficiency in 20%. Therefore, Renewable Energy Sources (RES) are expected to play a significant role in the electricity generation mix, and policies have been successfully designed in order to do so (Marques and Fuinhas, 2012). The present study addresses RES in Portugal, so the remainder of this section outlines the country past and present electricity generation situation.

1.1 Portuguese electricity system

As can be seen in Figure1, Portugal's non-renewable production is provided by power plants using coal, natural gas and non-renewable cogeneration (representing roughly half of "Other"). The consumption of electricity from renewable sources represented approximately 46% in 2011 (REN, 2011). This share was achieved with 18% of wind, 20% of hydro, and nearly half of the 18% of "Other", comprising renewable and non-renewable cogeneration, biomass and photovoltaic.

Figure 2 presents data concerning renewable energy in more detail and demonstrate the importance of both large hydro and wind power technologies. Having produced, in 2010, electricity from a mix of energy sources, where renewable ones accounted for 39%, Portugal achieved its EU target. The other successful countries achieving these goals were Denmark, Germany, Hungary, Ireland, Lithuania and Poland (European Commission, 2011).

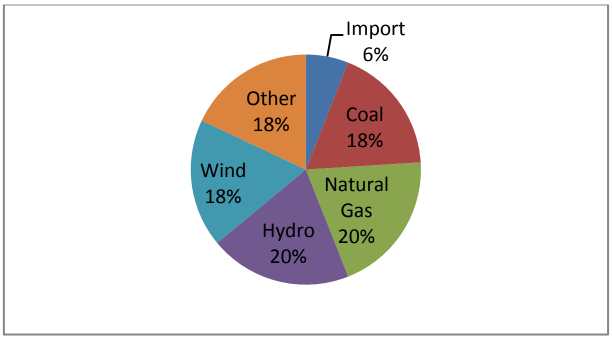


Figure 1: Electricity production shares, by technology, in 2011. Own elaboration from REN (2011) data.

The evolution of energy produced from RES has been increasing but not steadily. As the most significant part of it is based on hydro power it is, therefore, subject to the profile of the rainfall (the so-called hydroelectric productivity index) in a given year.

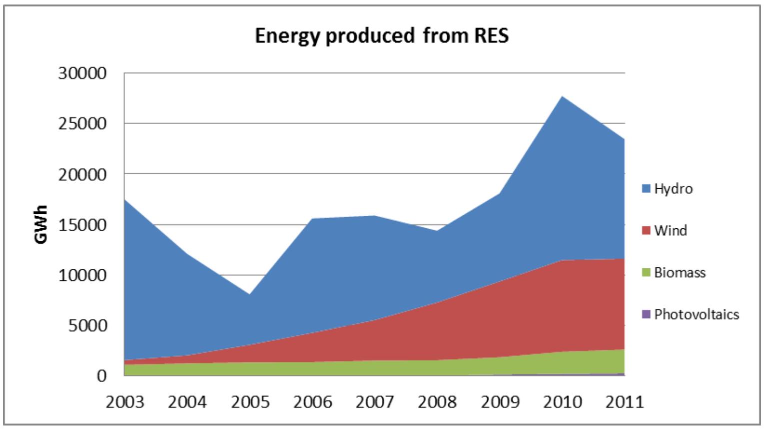


Figure 2: Energy production in Portugal, 2011, using the renewable energy sources addressed in the present study: hydro, wind, biomass and photovoltaics. Own elaboration from DGEG (2011).

Among the policies used to promote RES, feed-in tariffs are a solution used by Portugal and many other countries. The justification for this support mechanism is that free market would constrain RES use as they are still economically less attractive than the traditional technologies. Among renewable energy technologies, the exception to this rule is hydro power, which has been playing a major role in Portugal since the 50's and is mostly operating outside the feed-in tariff schemes. These hydro power plants are now privately owned, and by the end of 2011, the total installed hydro power in Portugal was 5390 MW. From these, 92.4% of the installed power were power plants with more than 10 MWand were not included in feed-in tariff schemes (Ordinary Regime Production); only 7.6% were small units, subject to feed-in tariffs and included in the Special Regime Production (REN, 2011).

Among the remainder renewable energy sources, the most prominent is wind power. The first wind farm was built in 1992 and the growth of installed power was exponential until the end of 2011, when it totaled 4081 MW (REN, 2011b). According to the Portuguese Renewable Action Plan, this number will increase to 5300 MW in 2020 (DGEG, 2012).

There exist various types of biomass production, and they can be divided in two types: a first one where the origin of biomass is the forest or agriculture (dedicated production), or a second type where biomass results from the processing of primary biomass, including residues, waste and subproducts (Carneiro and Ferreira, 2012). In some cases, the power plant may generate, besides the electricity, an amount of heat that is useful for industrial purposes. Currently Portugal has 462 MW of biomass installed power, among which 348 MW exist in cogeneration mode (e2p, 2012).

Installed solar power in Portugal, in 2011, was 149.3 MW (DGEG, 2011). Among these, the units that can be considered "solar power plants" or "solar farms" are 17 (besides two in the island of Madeira, not addressed in the present study) and represent 90.5 MW. The biggest of these units has 45.8 MW installed. These large-scale units are the object being addressed in our study (E2p, 2012).

The remainder of the paper is as follows: in section 2 we address the paper design and implementation, in section 3 we present results, in section 4 we discuss the results and in section 5 conclusions are made, along with future work proposals.

2. Survey design and implementation

The survey aims at studying the differences of public opinion towards the four technologies (hydro, wind, biomass and solar) between regions where they are and are not present. Therefore, four different surveys exist, each to be applied in two samples consisting of distinct regions, totaling eight cases. A hydro power questionnaire delivered in municipalities where hydro power is present is further represented as “H”; the same questionnaire applied to respondents who live in municipalities where hydro power is not present is represented as “NH”, the equivalent for wind is “W” and “NW”, for biomass “B” and “NB” and finally for solar “S” and “NS”.

Given that the study addresses the NIMBY hypothesis, perhaps the best case would be studying the opinion of the respondent and relate it to the distance to a given infrastructure; however this approach would be difficult to implement, given the survey was intended to be handled by telephone. As a result, it was needed to define the delimitations of the “region” size, and in the present study, the geographical unit is the municipality (*“concelho”* in Portuguese). There are 308 of these in Portugal, with population ranging from 451 to 529.485, and areas between 7.9 to 1720.6 km^2.

Information on the Portuguese renewable energy generation infrastructures can be found online, in the http://e2p.inegi.up.pt/ website. This website was used to retrieve a list of municipalities which contain wind, biomass and solar power plants. For the large hydro power plants, the website www.edp.pt was used for the same purpose.

In our study, some municipalities were not consulted for some technologies. In the case of hydro power, the municipalities affected by the 10 power plants expected to be built in PNBEPH (2011) were left outside. In the “non-hydro”, “non-wind” and “non-biomass” cases, only municipalities with less than 20.000 permanent residencies according to the National Institute of Statistics, www.ine.pt, were consulted. This option was taken to avoid inquiring urban districts where these technologies are unlikely to be implemented due to their own urban nature.

The surveys were taken during May and June of 2012, and were delivered using CATI (computer assisted telephone interviewing), by a specialist company. The number of surveys to be collected was 381 in each case, which would ensure at least a confidence degree of 95% with a margin of error of 5%.

2.1 The surveys

Each survey addresses only one technology. The surveys cases N and NH only ask the respondent about hydro power, the N and NW only wind power, and so on.

Each survey was divided in six sections. The first section acted as a filter, and the questionnaire would count as valid for the respondents that passed on this filter question. When the interviewer read the scales of possible answers, scales were reversed randomly, to avoid biases.

Section I (Filter question)

Have you ever heard of electricity produced in HYDRO DAMS / produced from the WIND, or on WIND FARMS / from BIOMASS, or in FOREST RESIDUE FIRED POWER PLANTS / produced in SOLAR POWER FARMS or SOLAR POWER PLANTS?

<u>Note: Respondents who do not pass the filter question do not proceed to complete the questionnaire.</u>

Section II (NIMBYism)

1: More HYDRO/WIND/BIOMASS/SOLAR power plants should be built in our country.

2: More HYDRO/WIND/BIOMASS/SOLAR power plants should be built in our concelho. (Note: municipality).

3: More HYDRO/WIND/BIOMASS/SOLAR power plants should be built in our freguesia. (Note: subdivision of municipality)

Scale of possible answers: 1 – totally disagree, 2 – tend to disagree, 3 – tend to agree, 4 – totally agree, 5 – doesn't know/doesn't answer. (Note: the order of the scale has been randomized to avoid biases.)

Section III (Perception of costs)

What impact do the dams/wind/biomass/solar power plants have upon the electricity bill, in your opinion?

Scale of possible answers: 1 – lowers extremely the bill, 2 – lowers slightly the bill, 3 – has no impact in the bill, 4 – raises slightly the bill, 5 – raises extremely the bill, 6 – doesn't know/doesn't answer. (Note: the order of the scale has been randomized to avoid biases.)

Section IV (Perception of environmental impact)

What impact do the dams/wind/biomass/solar power plants have upon the environment, in your opinion?

Scale of possible answers: 1 – degrade the environment considerably, 2 – degrade the environment slightly, 3 – have no environmental impact, 4 – protect the environment slightly, 5 – protect the environment considerably, 6 – doesn't know/doesn't answer. (Note: the order of the scale has been randomized to avoid biases.)

Section V (Perception of social impact in local populations)

What impact do the dams/wind/biomass/solar power plants have upon the populations near which they are built?
Scale of possible answers: 1 – develop considerably the populations, 2 – develop slightly the environment, 3 – don't develop nor harm the populations, 4 – slightly develops the populations, 5 – greatly develops the populations, 6 – doesn't know/doesn't answer. (Note: the order of the scale has been randomized to avoid biases.)

Section VI (Socio-demographics)
Education degree: *scale of possible answers: 1 – no studies; 2 – 4 year level, 3 – 9 year level, 4 – 12 year level, 5 – university degree*
Sex:
Age:

3. Results

In this section we begin by characterizing the respondents of the questionnaire, and their responses in the questionnaires. From the 3646 respondents that agreed to take the survey, 16% did not acknowledge the technology mentioned in the survey (and therefore did not proceed to complete it to the end).

3.1 Respondent's characterization and technology acknowledgement

In table 1 the results are distributed by gender, and the two conclusions to be taken are (i) the majority (64%) of respondents is female, and (ii) the lack of knowledge is more pronounced in their case, 19% against 12% in the case of males.

Table 1: Results of the filter question, according to gender.

	Gender (beforefilter)	Gender (afterfilter)	% did not pass the filter
Female	2346	1905	19%
Male	1300	1145	12%
N	3646	3050	16%

The values related to age are presented in Table 2. It can be concluded that the group of respondents that passed the filter have a slightly lower average age than the original group.

Table 2: Results of the filter question according to age.

	Age (beforefilter)	Age (afterfilter)	% did not pass the filter
N	3619	3027	16%
Missinganswers	27	23	15%
Minimum	16	16	
Maximum	95	95	
Mean	54,3	53,9	
Std. Deviation	16,8	16,6	

The educational level of respondents is not evenly distributed by the five categories predefined: 46% of respondents either have no schooling or only completed the 4 degree educational level, and only 17% have a high degree. It is noteworthy that the more advanced is the educational level attained by the respondents the more acknowledged is the technology.

Table 3: Results of the filter question according to educational level.

	Education (beforefilter)	Education (afterfilter)	% did not pass the filter
N	3529	3002	15%
Missinganswers	117	48	59%
1 - No schoolingcompleted	219	160	27%
2 - 4th grade	1390	1150	17%
3 - 9th grade	665	580	13%
4 - 12th grade	645	564	13%
5 - Highereducation	610	548	10%
Minimum	1	1	
Maximum	5	5	
Mean	3,01	3,06	
Std. Deviation	1,23	1,23	

For each of the eight cases of questionnaires, acknowledgement of technologies is as follows:

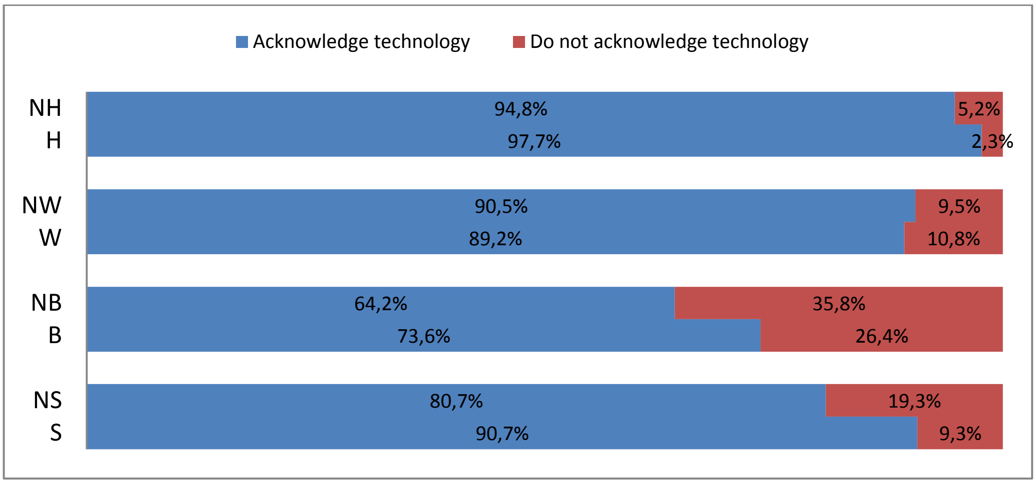


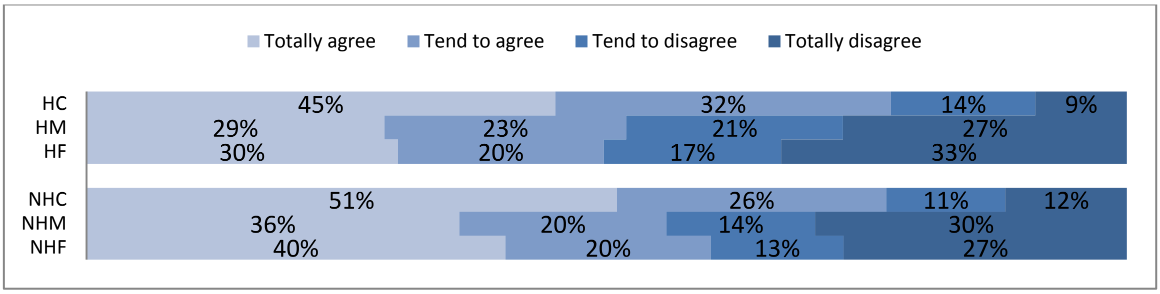
Figure 3:Acknowledgement of technology according to technology.
(Note that there are four different questionnaires applied to respondents who live in a municipality where the technology focused by the questionnaire is present (H, W, B, S) and where it is not present (NH, NW, NB, NS)).

Hydro power is the most acknowledged technology, which is quite expected, due to the importance that this technology has had during the last decades. Biomass remains the least known. Solar power, however the least contributor to the energy mix as shown in the previous section, remains better known than wind power in the cases where the questionnaire was implemented in municipalities in which these technologies were already implemented. Wind power is the only case in which a technology is more recognized in municipalities where it is not present than in municipalities where it exists, although with a small difference.

3.2 Willingness to accept new projects

The following plots are the results of the second section in the questionnaires, where the respondent is asked what is his opinion about the implementation of new projects of the technology (H=municipality with hydro, NH=municipality without hydro, W= wind, B=biomass, S=solar) taking into account an increasing proximity from country (C) level, to municipality (M) level and to "*freguesia*" (F) level, representing this last a sub-division of the municipality and as such showing the highest proximity situation enquired.

Respondents retain a better opinion towards new wind and solar power projects, whereas hydro power remains the least supported RES technology.



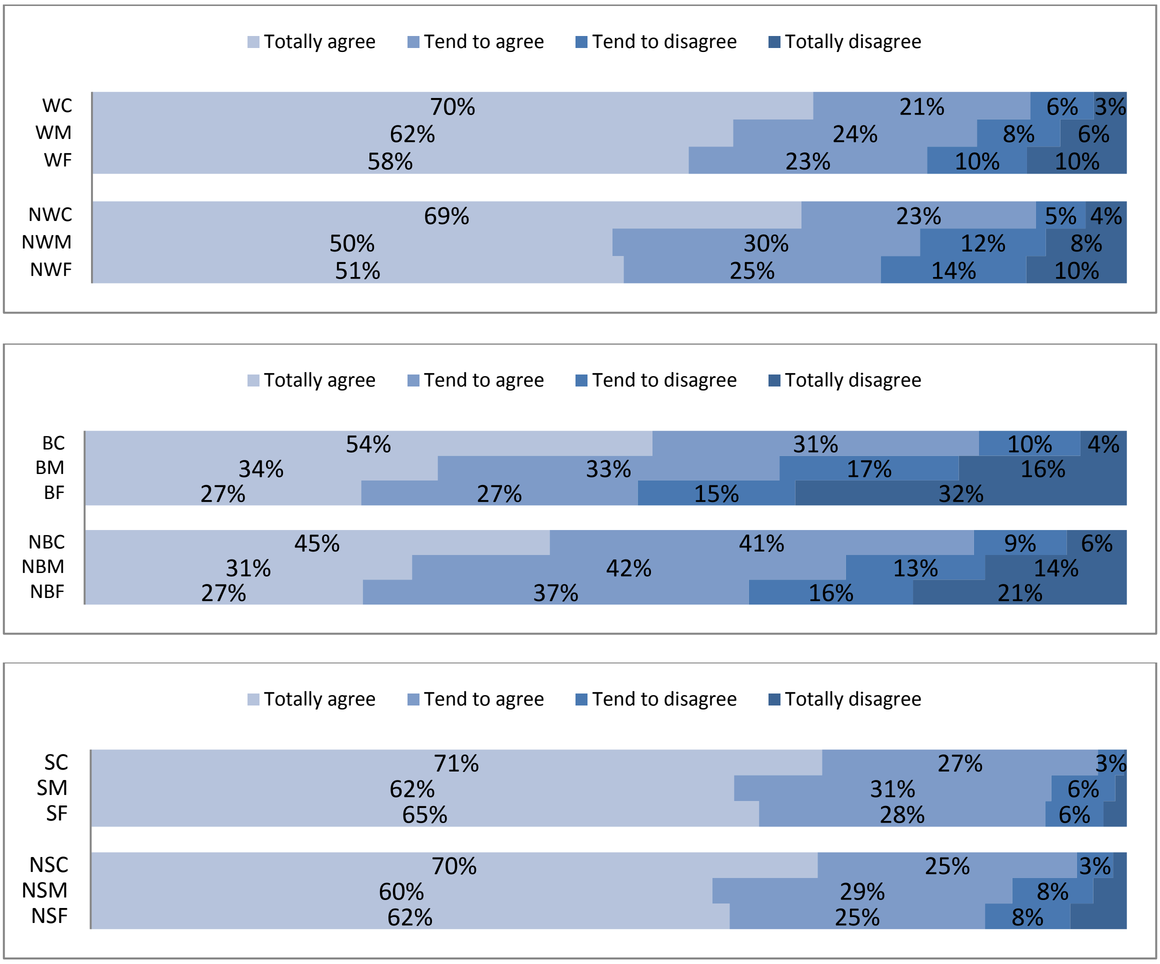


Figure 4:Willingness to accept new technology implementation projects in country (C), municipality (M) or freguesia (F).

Three major conclusions can be drawn from these results. Firstly, the attitude of respondents is generally positive towards all energy generation forms: the case with least support is that of respondents HF, who live in municipalities with hydro power projects and who are asked whether they would support new hydro power plants in their *freguesia*; if we sum the results of “totally agree” and “tend to agree”, this result is 49.7%.So, always more than a half of the respondents are favorable to a new power plant, whether it is in their *freguesia*, municipality or country. Solar power, followed closely by wind power, are the technologies which have the higher acceptance, both if projects would be implemented in the country, in the municipality or in the *freguesia*”. The result facing higher acceptance is that of respondents who live in municipalities with solar power, when asked their opinion on new solar power plants in the country, with 98% of “totally agree” and “tend to agree” responses.

Secondly, the residents in municipalities where wind and solar power already exist are more supportive (adding the “totally agree” and “tend to agree” results) than residents where this technology does not exist.

Finally, the respondents which did not express their opinion amounted to 2.5% when asked about new project implementation in the country, 3.1% in the municipality and 3.6% in the *freguesia*. The respondents showing more reluctance to give an opinion were the S case (6.1% did not respond what their opinion was about new projects in country, 6.3% in the municipality and 6.6% in the *freguesia*), followed by NH respondents (5.5% for country, 6.1% for municipality and 5.3% for *freguesia*). The respondents more willing to respond were invariably the B case (99.7% for country, 99.2% for municipality and 99% for *freguesia*).

3.3 NIMBYism

Similarly to Jones (2009), in our work we will use the term“NIMBYism” as an attitude of generally supporting a technology but rejecting it in the particular case of seeing it implemented near one's “backyard”.A new variable “nimby_aggregate” was created.

For each respondent, the computation of this variable is:

$$NIMBY_{aggregate} = NIMBY_{country} - NIMBY_{freguesia}$$

The scale of $NIMBY_{country}$ and $NIMBY_{freguesia}$ ranges from 4 (totally agree with new projects) to 1 (totally rejects new projects), so that high values for $NIMBY_{aggregate}$ indicate a high NIMBY attitude, i.e., that the respondent totally supports new projects in the country but rejects them near his backyard. Negative numbers will indicate a PIMBY attitude (please in my backyard, as in Swofford and Slattery (2010)).

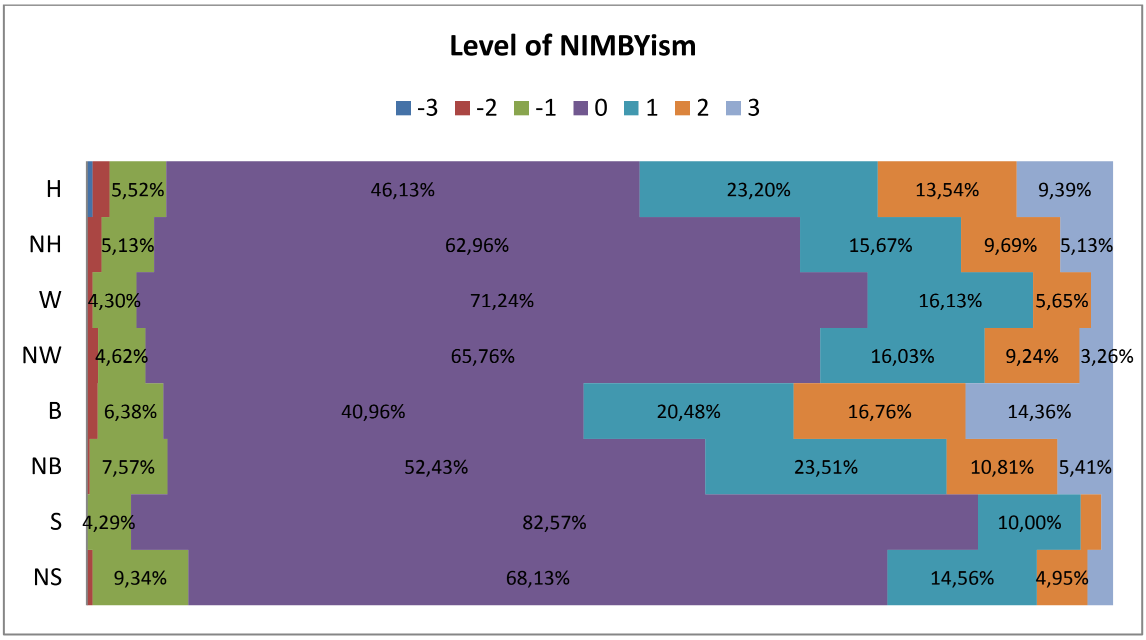


Figure 5:Levels of NIMBYism. The more positive the value, the greater is the difference between acceptance of the technology in the country and the acceptance of technology in the freguesia.

From figure 5 some conclusions can be drawn:

- Respondents whose opinion remains the same for new projects in the country or in the *freguesia* (i.e. $NIMBY_{aggregate}$ = 0) vary from 83% in the case of residents in municipalities with solar power plants, to 41% in the case of respondents who live in municipalities with biomass. This suggests that NIMBYism is not, in any case, affecting the vast majority of respondents.

- If we count the cases of positive $NIMBY_{aggregate}$occurrences, NIMBY attitude is leaded by residents in municipalities with biomass (51%), followed by residents in municipalities with hydro power (46%) and municipalities without biomass power plants (40%). As seen in Figure 5, attitude towards solar power is in every case very positive, and it is the less susceptible technology of generating negative reactions, to residents in municipalities where it exists or not.

- Between residents that have a NIMBY attitude, those who live in municipalities with biomass tend to be more extreme (14.4% cases of $NIMBY_{aggregate}$= 3).

- PIMBYattitude, i.e. NIMBYaggregate< 0, is not greater than 10% in any case (9.34% for residents in municipalities with solar power plants), and is not greater than NIMBY attitude in any case.

3.4 Perception on economy, environment and social impacts of different technologies

The perception of economic impact in the respondent's bill showed that more pessimistic attitudes (i.e. perception of higher costs) are the ones of hydro and wind power. Among these, the more extreme positions ("greatly raises bill") are the cases of respondents that live in municipalities where the technology is implemented. Biomass is the one that causes a more positive perception of reducing the bill, but solar power is the one that receives the more extreme attitude of greatly reducing it.

Aggregating the results in three categories ("reduces bill", "does not changebill" and "raises bill"), only three cases exist where respondents perceive the costs as more "raising bill" than "reducing bill": H, NH and W.

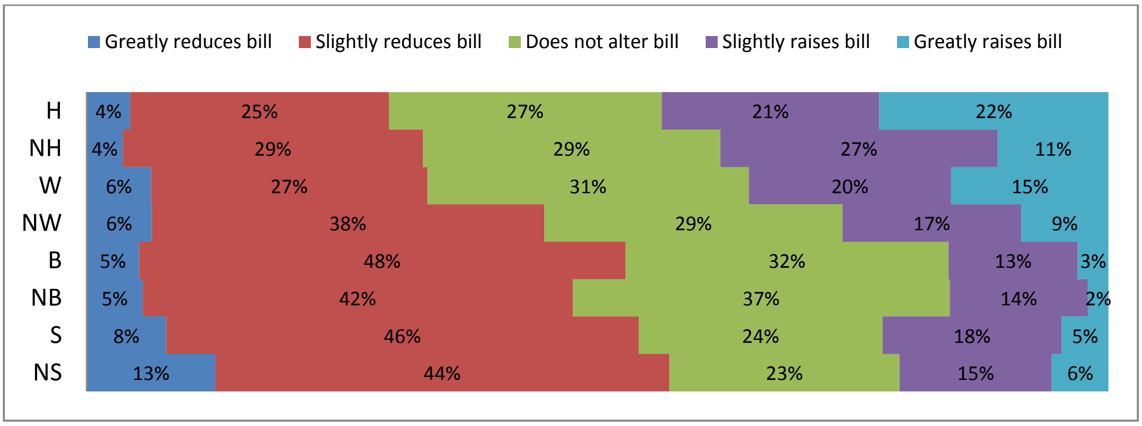


Figure 6:Respondents' perception on technology's contribution to the electricity bill.

A major finding of our study is that the perception that the majority of the Portuguese population hold on the full costs of electricity produced by different sources does not necessarily reflect real market costs or the existence of support mechanisms. Portuguese are negative about the costs of hydro power, which in fact is the only one of the analyzed RES technologies that operates outside the subsidized feed-in tariff system. They also perceive wind power as being more expensive than biomass and solar power. Judging from the feed-in tariffs, which are calculated in a way that gives the investor the payback of the investment, plus some rent, solar power is the most expensive (45 c€/kWh), followed by biomass (10.7 c€/kWh) and in last place wind power (7.45c€/kWh) (EREF, 2012). There is, therefore, a total inversion of the perceived costs and the actual costs, if we accept that the feed-in tariff reflects true costs of technologies.

In the question of environmental impacts, hydro power and biomass are perceived as the most threatening technologies. Solar power is the technology perceived as more protective of environment, but that perception is more pronounced in municipalities where it is not implemented.

Aggregating the results in three categories (“protects environment”, “no impact” and “endangers environment”), there is no single case of respondents’ perceiving any case as being more protective than endangering towards the environment, although it comes close in the case of residents of solar power municipalities.

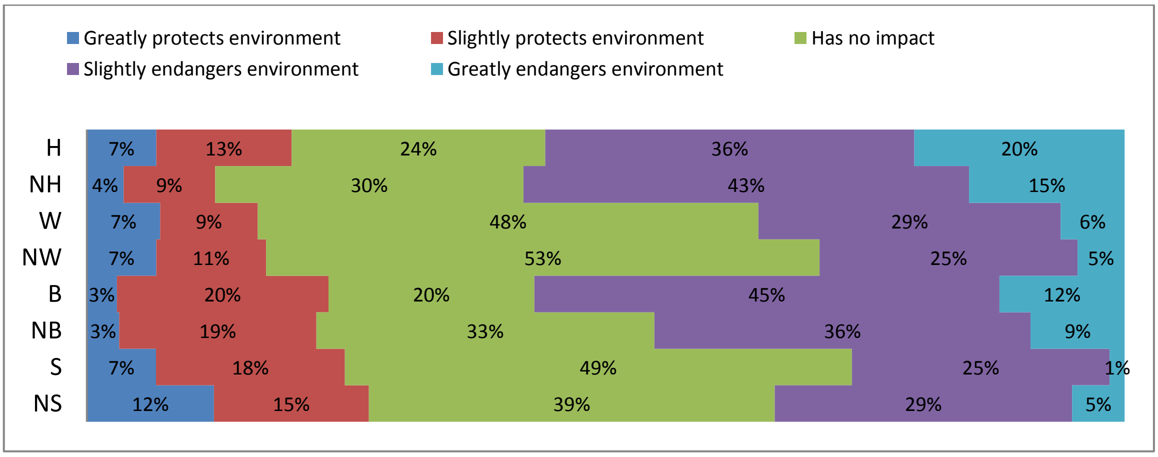


Figure 7:Respondent’s perception on technology’s environmental impact.

To what concerns the social impacts of the technologies, answers are globally more positive than economic or environmental impacts. More negative opinions (“greatly harms local population”) represent, at most, 7% of H respondents. However, it is also 20% H respondents who support the vision that hydro power “greatly develops local population”.

Among the optimistic opinions (“greatly develops local population”), the less emphatic are obtained in the case of NB, with only 3% of respondents.

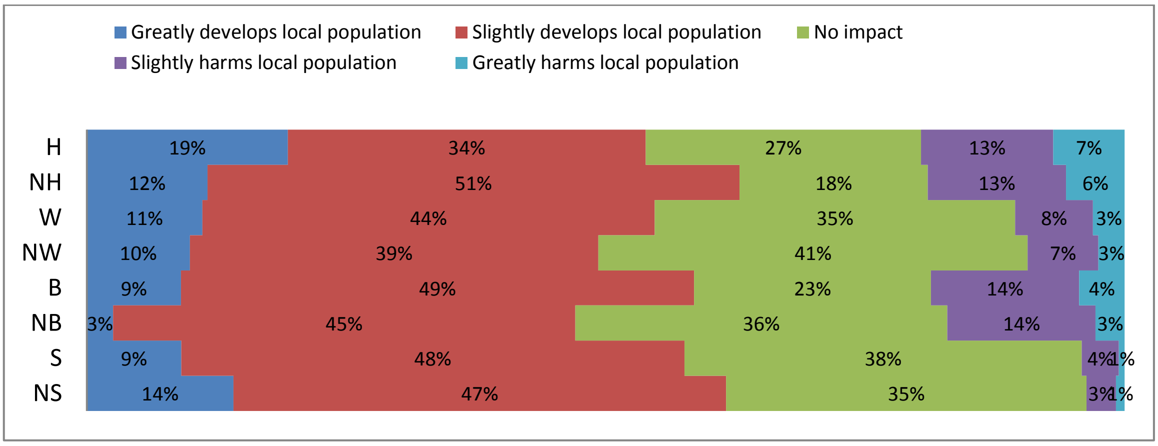


Figure 8: Respondent's perception on technology's social impact.

Regarding no responses in the last section of the questionnaire: respondents that live in municipalities where the technology is not implemented were always more inclined to give a "no answer" than respondents that live in municipalities where the technology is implemented, the only exception being the case of perception of costs of biomass. The biggest difference between no response rates was in the hydro power technology: "H" respondents were always more willing to respond, and their rates of no response were always lower than half of "NH" respondents. The highest no response rate was 18% in the cost perception of hydro power.

4. Discussion

We start the discussion pointing to potential weaknesses of our survey. The results obtained do not seem to differ much in cases where technology is already present and where it is not present, with the exception of biomass. It is possible that distance to the power plant becomes more influent in a smaller distance. In our case we based our geographical area roughly in literature results, (50 miles in (Greenberg, 2009) and (Ansolabehere, 2007)), which in Portugal can be roughly the size of municipality *concelho*. Other intrinsic problem in our survey could be the size of some power plants: some of them are small enough that the population might not be aware of their existence. For example, the biggest solar power plant is 45.8 MW with an area of 250 ha, and the smaller has only 0.4 MW installed power, 625 times smaller than the former; in biomass the bigger is 95 MW and the smaller 0.3 MW. Other difficulty in our survey was the task of formulating a question that addresses each of the three pillars of Sustainable Development. In order to avoid a long questionnaire that would imply a larger absence of responses, only three questions were addressed in this section. It would have certainly been needed more than one question for each pillar to obtain a better perception of the respondents' opinion, since the pillar "economy" is more than the cost of the electricity bill, and the pillar "social", besides not being still fully understood, certainly means more than local issues (Ribeiro et al., 2011).

Some studies present in the literature address the question “willingness-to-pay” (WTP). Since the renewables are generally more expensive than the traditional sources, schemes such as feed-in tariffs are created to compensate them, and it would be required that the consumers would pay a higher price for the electricity bill. For example, the Eurobarometer (European Commission, 2006) clearly asks whether respondents would be willing to pay 5%, 10%, 25% more than the present electricity bill; the majority of respondents (59%) would not be willing to pay more. In our study, while we didn’t directly asked the respondents their willingness to pay, it is possible to articulate two questions (section 2 “opinion about new power plants in the country” and section 3 “perception of costs”) and deduct the willingness to pay, although not on concrete values like the Eurobarometer. Crossing the tables of the respondents that agree with new projects in the country (“totally agree” + “tend to agree”), with the respondents that perceive the technologies increasing the prices (“greatly increases bill” + “slightly increases bill”) we have the results shown on Table 4.

Table 4: Willingness to pay.

	A: Perceives technology as contributing to higher prices	**B: Agrees with new projects**	**Responded both A and B**	**C: Disagrees with new projects**	**Responded A and C**
H	43%	77%	30%	23%	13%
NH	37%	76%	26%	24%	12%
W	35%	90%	29%	10%	6%
NW	25%	91%	19%	9%	6%
B	16%	86%	12%	14%	4%
NB	15%	87%	12%	13%	4%
S	21%	97%	19%	3%	2%
NS	20%	95%	18%	5%	2%

Results suggest that, in line with the Eurobarometer (European Commission, 2006), it is a minority of the respondents that agree with new projects when they are aware that they will increase the electricity bill. This minority ranges from 30% in hydro power to 18% in solar power. Of course, like said in the previous section, it is also only a minority of the respondents that appear to be aware that wind, biomass and solar power plants are subsidized (i.e. their real costs are above the average of the electricity bill); but it is still interesting to note that most of the respondents who perceive the technology as more expensive still agree with its implementation: this fact is observed in the similarity of the first and third columns of Table 4. On the other hand, the last column of Table 4 shows the percentage of respondents who disagree with the implementation of the technologies and at the same time perceive that costs contribute to raise the bill: we can conclude that it is a small minority inclined to disagree with new projects because of the higher costs, and this minority is even smaller than the respondents inclined to agree with them even knowing they represent higher costs.

The Eurobarometer (European Commission, 2012) emphasizes that the Portuguese believe that the goal of achieving 20% of renewable energy in the EU is reasonable, more than the EU average citizen (59% vs. 57% of respondents). Our results are in line with the Eurobarometer 2012, since the Portuguese showed a generally supportive attitude towards more renewable energy projects: as shown in Table 4, the case showing least acceptance for "building new projects in country" is NH, which still shows 77% of positive attitudes.

Greenberg (2009) surveyed in the USA different samples that differed in the fact that one of them was within 50 miles to a nuclear power plant while the other didn't. The author also included natural gas and coal in the options to be studied. Similar conclusions to our work were that the majority of population agreed with more hydro, solar and wind power plants, and that this tendency was stronger for younger and male respondents. The opinion of the sample of the population that lived in the area of the nuclear power plant did not differ much from the other sample. That also applies to our case: results don't vary much within the same technology samples, not nearly as much as they differ from technology to technology.

5. Conclusions and future work

Surveys addressing the public opinion on four renewable energy technologies (hydro, wind, biomass and solar) were implemented in Portugal. Major conclusions can be resumed in eight topics. (i) Portuguese residents are fairly aware of renewable energy technologies. Always more than half of the respondents were aware of technologies: hydro power remains the most known source, whereas biomass is the least known. (ii) Females, less educated and older respondents tend to be less acquainted with the technologies. (iii) There is a generally positive attitude towards new projects of all technologies, being solar the one that receives the most favorable opinions. (iv) NIMBYism is more pronounced in biomass. (v) Respondents do not generally tend to perceive the technologies as contributing to raise the costs of electricity; biomass and solar are seen as the least cost ones; this suggests that the Portuguese are unaware that most of the technologies under study benefit from feed-in tariffs precisely because they are not competitive in the market. (vi) Solar power is positively seen in environmental terms. (vii) Respondents tend to believe that the technologies under study, when implemented, bring more development than harm to local populations.(viii)Among those who perceive the technologies as contributors to raise the electricity bill, there is a tendency to still be favorable to the projects implementation; as a result, willingness to pay is high among these individuals.

Future work will involve the construction of logistic regression models using data from this survey. As a result, predictors of attitudes will be modeled.

Acknowledgements

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DAY 10 - 9:30		
Room 642 - Energy Technology 1		
The usage of BiogasWebPlanner® system for analysis of biogas market tendencies in Poland	Pablo Cesar Rodriguez Carmona, Krzysztof Pilarski, Tomasz Kluza, Jacek Dach, Piotr Boniecki, Wojciech Czekała, Andrzej Lewicki, Damian Janczak, Kamil Witaszek	Institute of Biosystems Engineering, Poznan University of Life Sciences, POLAND
Prospects on employing microalgae into the production of biofuels: outcomes from a Delphi study	Lauro André Ribeiro[1]; Patrícia Pereira da Silva[2]; Teresa Margarida Mata[3]; António Areosa Martins[4]	[1]Energy for Sustainability Initiative - Univ. Coimbra and INESCCoimbra; [2]Faculty of Economics - Univ. Coimbra, INESCCoimbra and Energy for Sustainability Initiative; [3]Faculty of Engineering - University of Porto; [4]Faculty of Natural Sciences, Engineering and Technology - Oporto Lusophone University
Low intensity pretreatment before anaerobic waste activated sludge anaerobic digestion	Klaudiusz Grubel[1]; Jan Suschka[1]; Bozena Mrowiec[1]	[1]University of Bielsko-Biala
Influence of sewage sludge content in the mixture with sawdust and maize straw on composting process dynamics	Wojciech Czekała[1*], Jacek Dach[1], Jacek Przybył[1], Krzysztof Pilarski[1], Damian Janczak[1], Andrzej Lewicki[1], Kamil Witaszek[1], Pablo César Rodríguez Carmona[1], Robert Mazur[2], Krystyna Malińska[3], Magdalena Myszura[2]	Institute of Biosystems Engineering, Poznan University of Life Sciences, POLAND
Analytical and Computational Studies of Utilising LSCs Luminescent Solar Concentrators Incorporated With Multi-Junction Photovoltaic Cells in the UAE	Hisham Mashmoushy	Beirut Arab University, Beirut, Lebanon

The usage of BiogasWebPlanner® system for analysis of biogas market tendencies in Poland

Pablo Cesar Rodriguez Carmona, Krzysztof Pilarski, Tomasz Kluza, Jacek Dach, Piotr Boniecki, Wojciech Czekała, Andrzej Lewicki, Damian Janczak, Kamil Witaszek,

Institute of Biosystems Engineering, Poznan University of Life Sciences, Poland

Abstract

The paper presents the internet tool for decision support and data acquisition for Polish biogas market. This system helps investors to plan the size and potential power of biogas plant with usage of selected, own substrates. Because of open access via internet, the BiogasWebPlanner® allows to create one of the biggest databases about future Polish biogas market.

Keywords: biogas, Polish market, data acquisition, Internet, modelling.

1. Introduction

Energy security and constant growth in greenhouse gases i.e. methane, CO_2 emission and their accumulation in our atmosphere has strengthened the interest in development and use of an alternative, non-petroleum based renewable sources of energy [Chandra et al. 2012]. Biogas produced from anaerobic digestion of organic feedstock can potentially be an important contributor to a future, more environmentally benign, energy system. Biogas is a highly versatile fuel which can be utilized as transport fuel as well as for heat and electricity generation [Börjesson and Ahlgren 2012]. This technology has been available for many decades, but it has not been widely used because of the availability of cheap fossil fuel [Bin Basrawi et al. 2012].Therefore, the biogas technology can help reduce poverty and support a sustainable development [Teune 2007]. It is also particularly suitable for remote areas where there is no energy infrastructure [Thien Thu et al. 2012].

In Central Europe, biomass will be the main source of renewable energy in the horizon of 2020 [Pilarski et al. 2009]. The biogas production (and further electricity and heat production) will be one of the most important aims of biomass usage [Igliński et al. 2011]. What is also very important, the biogas plants are very efficient in deodorization of slurry and other malodorous wastes. However, in Poland the new anti-odor regulations will be implemented soon, the European Commission works also with the anti-odor directive project. Looking on this fact as well as the Polish target for electricity production from renewable source of energy (15% in 2020), the perspectives for development of biogas market in Poland are huge [Krzak 2009]. That is why in 2010 the Polish government established the national program for biogas plant development (2500 installations with the power of 1-3 MW_e built before 2020). With additionally 15-30 thousands of small installations (below 0.4 MW_e) planned to build before 2030 by farmers, Poland seems to be actually the biggest future biogas market in Europe [Popczyk 2011].

The Polish energy sector has noticed a possibility of biogas production, especially of agricultural biogas [Igliński et al 2011]. Currently there are 28 agricultural biogas plants working in Poland and several hundred localization for future installations. Looking on the targets mentioned above, the Polish biogas market is still almost empty [Pilarski et al. 2010]. But thousands of investors (big international companies, Polish businessmen, farmers etc.) are interested in planning of biogas plants and they need some support. Poznan University of Life Sciences has got a unique in Poland Laboratory of Ecotechnologies, where the research on biogas production are largely developed. Within last 4 years, the amount of questions and inquiries concerning substrates usage and biogas plant planning from private sector increased significantly. That is why we decided to create the BiogasWebPlanner® (BWP) as a tool for decision support for private investors.

The BWP project came to life as an idea to create a web based application that can help farmers and investors interested in entering the biogas market to simulate and calculate potential Return On Investment and provide answers for the entry-level questions that they were asking during conferences and via e-mail or phone calls. On the other hand, from the scientific perspective we wanted to gather the data about the potential biogas industry in

Poland and to be able to point out the key regions of Poland actively interested in such development.

The aim of this study is to check the potential of data collecting from Polish biogas market with usage of BWP as a free internet tool. Moreover we want to analyze the structure of planned market, including size of the planned installations, their geographic distribution in Poland and the substrates taking into account for future biogas plants. This study is also the part of two scientific projects: "Technologies of reduction of methane emission from animal production and manure management in the context of GHG taxation" and "Technologies of management the wastes from biofuels production" (research projects financed by the Polish Ministry of Science and Higher Education, Contract numbers: N N313 271338 and N N313 050036).

2. Material and methods

At the beginning of the project we have decided how the overall architecture of the solution should look like. We wanted to keep the link between the Excel Spreadsheet (which contained the model and the basis for the calculations) and the new Web Application. This let us to do frequent updates of the BWP whenever the underlying model changes or develops. The BWP was also designed to be placed on the website of The Laboratory of Eco-Technologies (http://www.ekolab.up.poznan.pl). Furthermore, we decided, that we will maintain a database of substrates that we have been experiment with or read about in publications along with the ability for the users to provide their own substrates or mix those two categories in a single simulation. With all that in mind, we also thought about the usability and the user-friendly interface during the design of the interaction.

As a part of the solution we used the Spreadsheet Converter® (http://exceleverywhere.com) which made the conversion between the Excel native file format and html/javascript which is the standard set of languages of the Internet. With the use of more advanced features of the Spreadsheet Converter® extended by Google Analytics® platform we were able to gather the data about the use of our application. It is important that users are aware of that background process of gathering the data for scientific purposes.

Some of new features that we are currently working on for the future releases of the BWP: to extend the capabilities of the application by adding new calculation models (cost of the bank loan and how it affects the overall ROI, cost of transport and utilization of the pulp as the natural fertilizers) and more advanced analytical module (including Software as a Service architecture for gathering the data and custom build module for processing).

3. Results

Before we introduce the BiogasWebPlanner® on the laboratory website there were around 250 visits per month on average. Our visitors were looking for contact information and other general info about The Laboratory of Ecotechnologies (Fig. 1.).

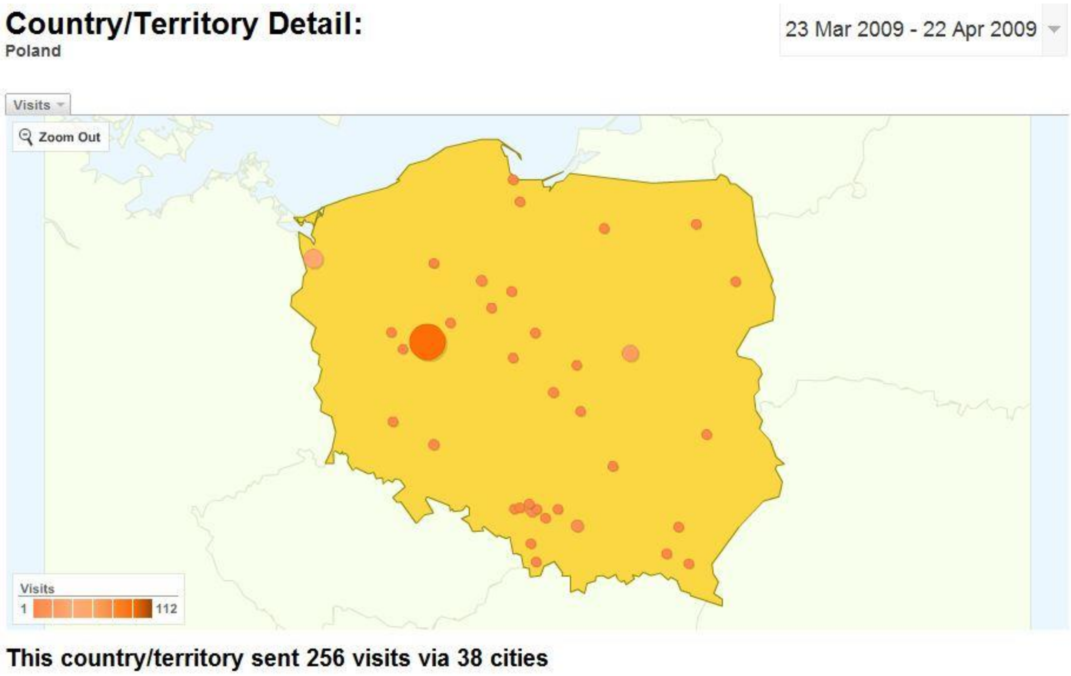


Fig. 1. Details of visits on laboratory website before BWP run

After the full year from the start of the Biogas Web Planner the traffic on our website increased over 10 times and we have reached almost the whole country (but also from other counties like Western Europe, USA, Brazil, and China). From the data we were able to define what are the key regions interested in the Biogas industry (Fig. 2.). A lot of traffic came from the largest cities of Poland, probably because they are the places where the consulting companies and/or investors have their offices.

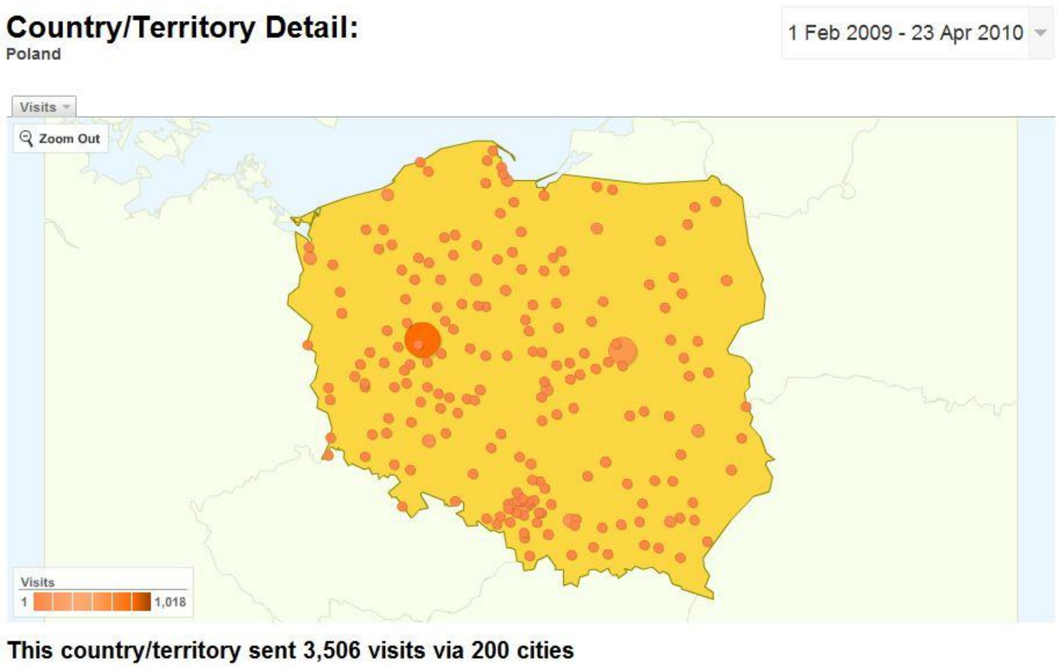
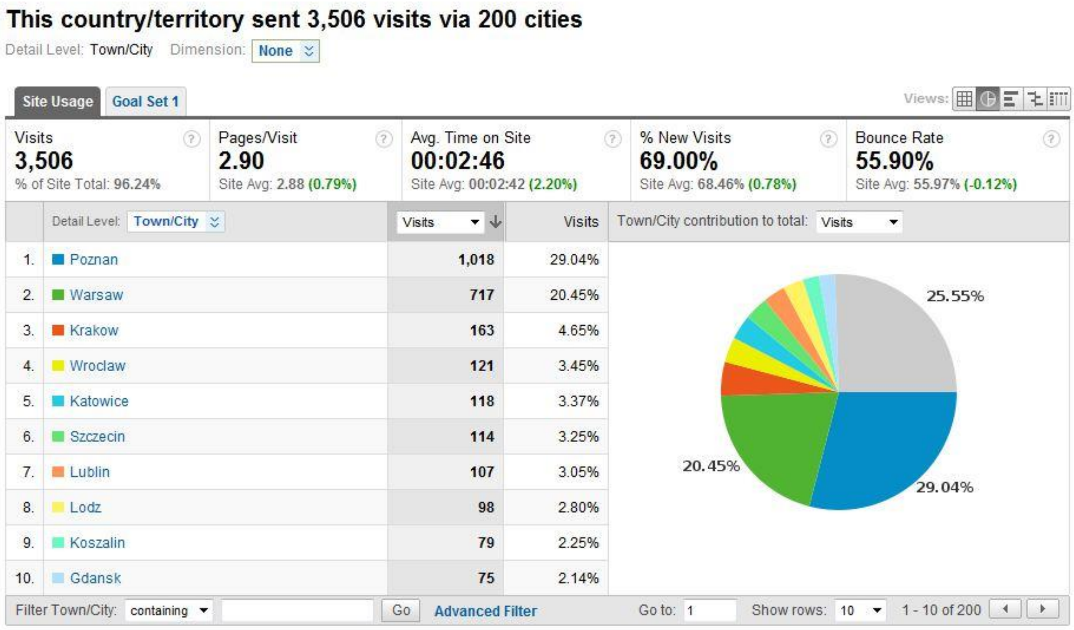


Fig. 2. Details of visits on laboratory website after BWP run

About 30 % of the visitors came from Poznan, which is the city where our University is located (Fig. 3.). Probably several hundreds of that traffic were our students working with the application during their courses but from the direct contacts (via email and phone calls) made with us we know that the Biogas Web Planner was used by the biogas companies as well.



	Detail Level: Town/City	Visits	Visits
1.	Poznan	1,018	29.04%
2.	Warsaw	717	20.45%
3.	Krakow	163	4.65%
4.	Wroclaw	121	3.45%
5.	Katowice	118	3.37%
6.	Szczecin	114	3.25%
7.	Lublin	107	3.05%
8.	Lodz	98	2.80%
9.	Koszalin	79	2.25%
10.	Gdansk	75	2.14%

Fig. 3. Geographic distribution of BWP users from Poland

In order to analyze the data collected from the users activities, we cancelled the users from all University IP numbers (including the numbers from student houses which can be the effect of the projects made by the students). The users of BWP applied in their calculations mainly agricultural substrates like slurry, maize or grass silages and manure (Fig. 4.). However, 28% of future investors take into account usage of biowaste substrates. This suggests that in Poland industrial biogas plants worked with wastes can take much bigger percentage than in Germany (only below 10% of industrial biogas plant, over 90% is agricultural).

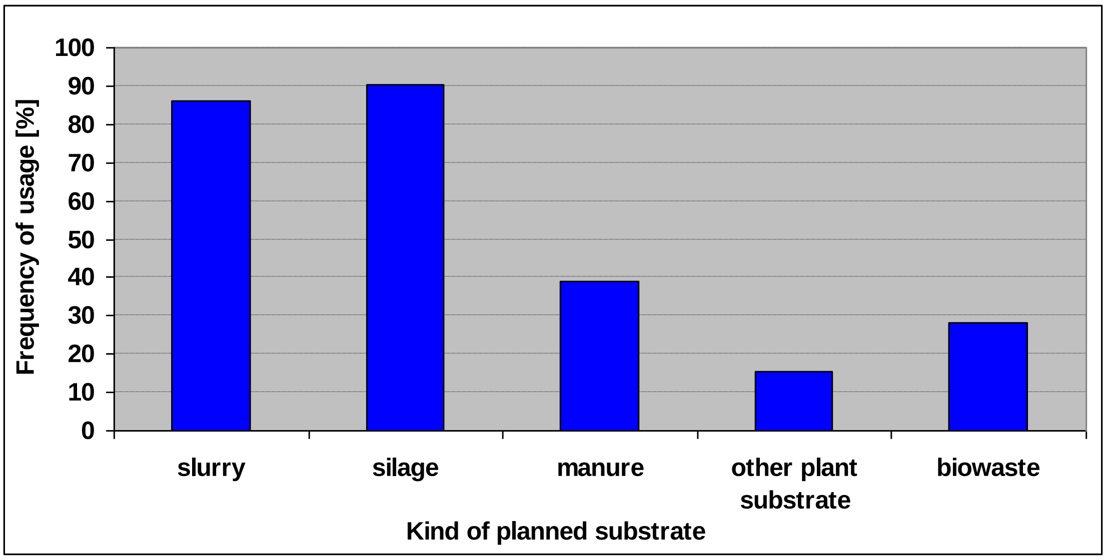


Fig. 4. Frequency of different substrates usage in planned installations.

Analysing the size of planned plants, there are clearly 2 dominant groups of biogas plant size (fig. 5.).

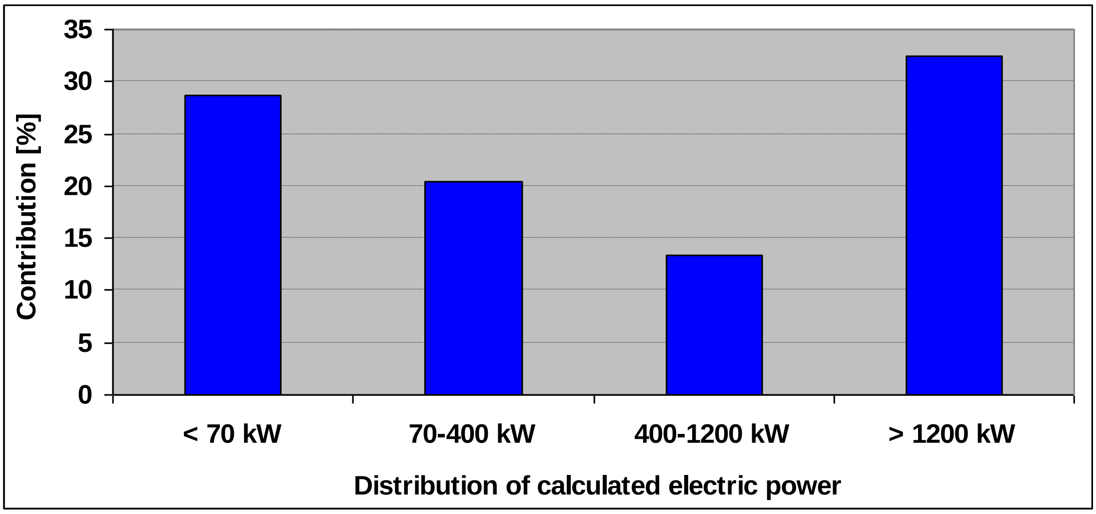


Fig. 5. Distribution of electric power size in calculated installations.

The most often calculated were the installations over 1200 kW of electric power, however small installations (below 400 kW_e) had together 49%. It confirms the prognosis that in Poland two groups of biogas plants will dominate: big (1-3 MW_e) realized within governmental program and small (below 400 kW_e) built by the farmers.

4. Conclusions

During first 2 years of BiogasWebPlanner® working and data acquisition, we came to the conclusions:

1. BiogasWebPlanner® is a good internet tool for planning the parameters of biogas plant installation for future investors.
2. The concept of data acquisition based on open usage internet tool works well and allows to collect the huge amount of information without any costs.
3. The collected data about geographic distribution of planned biogas plant as well as the parameters of installations and used substrates created the biggest database about Polish biogas market. This information will be used in the future in scientific activities but also for governmental and regional projects and planning.

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Prospects on employing microalgae into the production of biofuels: Outcomes from a delphi study

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Abstract

Advanced biofuels such as microalgae are worldwide believed to be a better choice for achieving the goals of incorporating non-food based biofuels into the biofuel market and overcoming land use issues. Main challenges are currently the feasibility of large-scale commercialization, since the majority of economic and financial analyses rely on pilot-scale projects. This article presents the findings of a Delphi study focusing on the prospects of employing microalgae in the production of biofuels. The main aim is to study the obstacles that participants in the survey felt, in particular the most critical ones affecting the potential for microalgae large-scale commercialization in the future biofuel market. The respondents were worldwide market specialists and the themes of the survey ranged from economics to environmental sustainability. One of the key findings is that most of the experts believe that the production of microalgae for biofuels will achieve full commercial scale until 2020 and from 2021 till 2030 it could represent from 1% to 5% of the total worldwide fuel consumption. Environmental issues are most likely to diverge opinions from experts. To the best of these authors knowledge, this is the first Delphi study having this goal.

Kewords: Biofuels; Delphi analysis; renewables; emerging technologies; microalgae.

JEL codes: Q16, C83 and Q42.

1. Introduction

It is consensual today that current production and consumption habits are unsustainable in the medium and long term. This is particularly true when considering energy production and consumption, a cornerstone of modern developed societies. We live in a world where fossil fuels, in particular oil and coal, are still the major source of energy to provide and meet the world needs. Besides that, they have a significant environmental impact, due to their exploration and, in particular, their utilization that contributes to pollution and climate change. Increasingly in the future, cost and supply problems will lead to more significant economic, political and even social problems, as fossil fuels are very dependent on the geopolitical context, leading to oil price volatility. This is a big issue for most countries, threatening energy security as they are very dependent on imports to meet their energy needs. Due to these reasons much effort has being put on research and development of renewable energies, trying to find and develop good alternatives for fossil fuels with the long-term goal of providing abundant and cheap energy sources. On the European context, European Union (EU) has very ambitious targets till 2020, which are known as 20/20/20. Thus, the goals defined in the Directive 2009/28/CE are to reduce the primary energy by 20%, increase the share of renewables in the final energy mix by 20%, and reduce the greenhouse gas emissions by 20% till 2020 compared to 1990.

Despite the challenges, depending on the local conditions and practices, renewable energy sources are already a significant contribution to the energy mix. Two examples are wind and hydroelectric power that, in some European countries, represent more than fifty percent of the electricity consumed, and bioethanol in Brazil that currently represents 30% of fuel consumption in the transportation sector. However, from a global perspective, we are still far from the goal of producing most energy from renewable sources. Although all this condition is common to all activity sectors, the situation is even more delicate in the transportation sector, which has a global energy consumption share of about 30 % (IEA World Energy Outlook, 2012) and the available options are limited and still have a modest impact. Other concerning aspect is that global energy use in transportation is increasing rapidly, especially in developing economies like China and Brazil, joining the fact that the transportation sector heavily relies on oil based products, where 95% of fuels are either gasoline or distillate fuels. Therefore, it is expected that the CO_2 emissions from the transportation sector will continue to rise. For that reason, there is a strong interest, both from companies and governments, to foster the development of renewable energy feedstocks.

Biodiesel and bioethanol are the two liquid biofuel options currently looked upon with more attention and under more vigorous development, since they can be used in today automobiles with little or no modifications of engines, for replacing diesel and gasoline respectively. The Directive 2009/28/CE also targets the transportation sector fuels; in particular each member state should reach a minimum 10% share of renewable energy by 2020. It is to mention that the pace that member states have been tracking is uneven among Europe, depending on their national specificities. (Castanheira and Silva, 2010). Complementary, the Directive also states that this must be possible by using electricity and sustainable biofuels (i.e. based on a sustainable production). It also mentions that correct sustainability criteria should be adopted for biofuels, so that the rising world demand for biofuels do not destroy or damage land biodiversity, and establish many others recommendations to ensure total sustainability of biofuels. An interesting point of this directive is that, it recommends member states to incentive and support the use of biofuels that add supplementary diversifying benefits, such 2^{nd} and 3^{rd} generation biofuels (e.g. biodiesel from microalgae or bioethanol from lignocellulosic materials). Some changes were recently proposed to the Directive 2009/28/CE, in particular dealing with the calculation of the carbon footprint, namely how to account for the ILUC (indirect land use changes), and setting new goals deemed more adequate to promote the growing European biofuels industry.

1.1. What is the potential of microalgae

Of the various potential biofuels' feedstocks much attention is being given to microalgae. This is a class of photosynthetic organisms with more of 30 000 known species that can grow in a wide variety of environments and conditions, including fresh, salty and brackish water. They have higher biomass and energy yield, requiring much less land area of up to 49 or 132 times less when compared to rapeseed or soybean crops, currently used as biodiesel feedstocks, for a 30 % (w/w) of oil content in microalgae biomass (Mata et al, 2010). Also, they can be harvested either daily or every few days (Williams and Laurens, 2010). Generally, they are efficient CO_2 fixers and in converting solar energy into biomass, being also considered carbon neutral, if the CO_2 released on combustion equal the one fixed during plant or algal photosynthesis and growth, and if all the energy needed to process them can be obtained from the residues generated, avoiding the usage of fossil fuel. Moreover, the cultivation requirements are small, as most species only need water, CO_2, and some essential nutrients such as nitrates and phosphates, without needing the use of pesticides or fertilizers (Groom et al., 2008). Besides that, biodiesel and other biofuels produced from microalgae have similar properties to petroleum diesel and to biodiesel produced from agricultural crops, currently named 1^{st} generation. Extensive reviews dealing with the various aspects of microalgae cultivation and usage as feedstock for biodiesel production are available in the literature (Mata et al, 2010; Demirbas, 2010; Tao and Aden, 2009; Chisti, 2007; Brennan and Owende, 2010; Hirano et al. 1997; Ono and Cuello, 2006; Pulz, 2001; Pulz and Gross, 2004; Sheehan et al., 1998; Spolaore et al., 2006; Terry and Raymond, 1985; Ugwu, Aoyagi and Uchiyama, 2008). A complete review of the main problems can be found in Lam and Lee (2012) and Janaun and Ellis (2010). Most hurdles are directly linked with process economics, in particular the energy consumed in the process to obtain the final product, and in the processing of biomass for extracting and refining of lipids, and/or of other biomass contents of commercial value.

1.2. Objectives

Currently, much experimental and even theoretical/simulation work is being done to ensure that biofuels from microalgae become a reality in the short to medium term. Some aspects were already identified as significant for the overall competiveness, such as: the microalgae should have high biomass and lipids productivities (Singh and Gu, 2010; Sander and Murphy, 2010; Pitman et al, 2011); the processing system should be highly efficient and integrated with other processes following the biorefinery concept (Pokoo-Atkins, 2010); there must be markets or valorization potential for the process byproducts or other high value products that may be obtained (Ressureccion et al, 2012); waste streams and/or remaining nutrients should be used to reduce operating costs and increase the process sustainability (Pitmann et al, 2011); among others. Each of the previous possibilities have a positive impact on the competiveness of using microalgae as a feedstock for biofuels, but there is a lot of discussion in which one should focus efforts of research and development.

To fulfill this gap, and building on previous work by the authors (Silva and Ribeiro, 2012), this article presents a study based on the Delphi method to obtain more concrete information and predictions on how this area should be further developed. This way it will be possible to better define which lines of research should be supported, and what policy and funding instruments are more adequate. To the authors' awareness, no study can be found in the literature addressing these questions, involving the usage of microalgae as feedstock for biofuels.

A related work is the National Roadmap Algal Technology Roadmap (2010), the result of a two day workshop that brought together specialists from various areas, including engineers, scientists, policy makers, financiers, and others, to discuss the present and future of microalgae as a feedstock for biofuel production. The final document was intended to serve as a revision of the current state of the art in the area, and to identify which are the key challenges that must be considered to achieve a commercial scale production, serving as a guide to ongoing efforts. The study is rather comprehensive and extensive but fails to highlight which are the areas and aspects that are considered to be more important and should be considered first, from a cost-benefit point of view.

Also related, the EurEnDel project was a European wide Delphi study on the future developments in the energy sector, with a time horizon of 2030 based on the situation up to 2003. Its main goal was to provide advice on energy R&D activities in this key area. Hundreds of responses from experts in a wide range of topics were gathered, several future scenarios were developed, and in which concerns biofuels, there is a short-term need for new production processes and an increase in their market share (Wehnert et al, 2004 and 2007).

In 2009, a Delphi study was published dealing with the potential of biofuels in Alabama (Guthrie, 2009). The information gathered supported the idea that there are no simple and unique technology answers for the commercial implementation, and that local questions and an array of technologies and feedstocks is the most adequate strategy. Similar conclusions were reached by Celiktas and Kocar (2010) in their Delphi study of the renewable energy sector in Turkey, and by Lubienichi and Smyth (2011) in their work on the barriers to biofuels in Canada.

The remainder of this paper is as follows: in section 2 the research design is outlined; section 3 presents and discusses the results; and section 4 concludes.

2. Research design

The Delphi method is a qualitative research aiming to support strategic future-oriented action, such as policy making in the areas of science and technology. It typically entails two or more survey rounds in which the participating experts are provided with the results of the previous rounds. The panel of experts is used as the source of information, and the questionnaires act as the medium of interaction. The key characteristics of a traditional Delphi study are iteration, participant and response anonymity, controlled feedback, and group statistical response. It is especially suitable in judgment and long-range forecasting (20-30 years) situations, when expert opinions are often the only source of information available, due to a lack of appropriate historical, economic or technical data (Blind et al., 2001; McLeod and Childs, 2007; Rowe and Wright, 1999).

2.1. Delphi process

The key objective of our Delphi study was to determine the prospects of employing microalgae into the production of biofuels within a time scale extending to 2030. Before initiating the Delphi study, a brainstorming was organized by four microalgae specialists. In the brainstorming, the participants identified factors affecting production and competition of microalgae biofuels. Subsequently, the factors were categorized into sentences as presented in the Delphi study later on. The brainstorming's participants also suggested panelists for the Delphi survey. Based on this meeting, the statements for the first Delphi survey round were formed by the researchers. The questionnaires were sent to the Delphi experts via e-mail, enquiring about their willingness to participate in the study. In the first Delphi survey round, all statements were presented to the panelists at the same time. In the second survey round, the respondents similarly had the opportunity to comment on the critical factors voted on in the first round.

Our Delphi study included three survey rounds (the workshop and two Delphi rounds), which made it possible to understand the features that may develop or hold back this technology in the future. All three rounds were carried out during three months (from May 2012 to July 2012). There were 55 respondents in the first round, reaching a response rate of 36.7%, and, in the second round, when only were questioned those that answered the first round, the response rate was 54.5%. The Delphi participants were selected based on their expertise on the subject matter, as it is required in-depth knowledge about the microalgae biofuel markets and processes from all the experts.

Overall, the panelists represented 10 countries (USA, Portugal, the Netherlands, Italy, Norway, UK, Spain, Uruguay, Brazil and Australia). The experts can be categorized into three groups based on the field they represented: Academy (38.5%), Government (23.1%), Business (28.8%), Academy/Business (7.7%) and Academy/Business/Government (1.9%). The main focus of this Delphi study was to gather insights from specialists that symbolized distinctive fields, and not specifically the strategies of each country.

In the workshop, participants raised several factors that could affect competition in this particular market and they were categorized into four main themes. The first theme concerned microalgae biofuel economics as it plays a crucial role in establishing well-functioning and competitive market. The second theme studied some future trend hypothesis to be rejected or accepted by participants on the Delphi survey. The third key element in the study dealt with sustainability, which directly affects confidence-building in the development of the microalgae biofuel market. The final group of statements focused on policies and on forecast concerning the future.

The 1st round questionnaire consisted of 50 statements. Those that did not reach an overall consensus (more than 66% agree or disagree) shaped the basis of the second round, which included open-ended fields for further explanations or suggestions. The second round focused on clarifying the answers of the first round. All the questionnaires were pre-tested, and the panelists were given feedback after the first round with all the participants' answers from the first round. The participants in the study were likewise encouraged to provide arguments supporting their views and opinions.

3. Results and discussion

Once all the respondents had completed the first round, each answer was examined. The statements that, in the view of the experts, did not achieve an overall consensus formed the footing for the questions of the second round.

In Appendix 1, it is shown the statements of the first three themes asked in the survey. The question asked in Themes 1, 2 and 3 was "Please rate how strongly you agree or disagree with each of the following statements by placing a check mark in the appropriate box." The respondents could choose in a seven-level Likert scale from "Totally Disagree, Strongly Disagree, Disagree, Neither agree nor disagree, Agree, Strongly Agree and Totally Agree". After the first round of answers, the aggregated results Table 1 were achieved.

TABLE 1: AGGREGATED RESULTS OF THEMES 1, 2 and 3.

Statement	Respondents	Agree (%)	Neither Agree or Disagree (%)	Disagree (%)
1.1	55	94,5	3,6	1,8
1.2	54	68.5	24.1	7.4
1.3	55	63.6	20.0	16.4
1.4	54	42.6	22.2	35.2
1.5	54	85.2	9.3	5.6
1.6	55	94.5	3.6	1.8
1.7	54	66.7	14.8	18.5
1.8	55	81.8	10.9	7.3
1.9	55	78.2	16.4	5.5
1.10	53	83.0	9.4	7.5
1.11	54	79.6	7.4	13.0
1.12	52	94.5	3.8	1.9
1.13	54	83.3	9.3	7.4
1.14	53	67.9	22.6	9.4
1.15	53	84.9	7.5	7.5
Statement	**Respondents**	**Agree (%)**	**Neither Agree or Disagree (%)**	**Disagree (%)**
2.1	52	78.8	15.4	5.8
2.2	52	73.1	11.5	15.4
2.3	51	47.1	25.5	27.5
2.4	52	84.6	7.7	7.7
2.5	52	75.0	15.4	9.6
2.6	50	70.0	14.0	16.0
2.7	50	66.0	18.0	16.0
2.8	51	92.2	7.8	0.0
2.9	49	40.8	24.5	34.7
2.10	51	82.4	13.7	3.9
2.11	51	82.4	9.8	7.8
Statement	**Respondents**	**Agree (%)**	**Neither Agree or Disagree (%)**	**Disagree (%)**
3.1	50	38.0	28.0	34.0
3.2	50	60.0	18.0	22.0
3.3	46	15.2	41.3	43.5
3.4	47	27.7	42.6	29.8
3.5	48	72.9	12.5	14.6
3.6	48	47.9	29.2	22.9
3.7	49	59.2	10.2	30.6
3.8	49	79.6	18.4	2.0
3.9	48	79.2	14.6	6.3
3.10	46	32.6	32.6	34.8
3.11	49	61.2	22.4	16.3
3.12	49	81.6	12.2	6.1

In the economics theme, expressive consensus were achieved on statements 1.1, 1.6 and 1.12 (above 90%), in a way that experts consider that there is plenty of room for innovative and more effective production processes that could lead to economic feasibility, considered one of the main challenges facing large-scale deployment of biofuels from microalgae.

Statements 1.5, 1.8, 1.10, 1.13, 1.15 also revealed a high consensus level (above 80%). From those, it is important to highlight the awareness that R&D subsidies and supporting programmes will be needed to promote improvements in the technology in order to reduce the costs of algal biofuels and speed up development. Moreover, an interesting issue relates the perception that the increase in the overall consumption of biofuels, and the expected growing pressures on currently used feedstocks can be a key factor to the economic viability of microalgae.

The experts also reached an agreed consensus on statements 1.2, 1.7, 1.9, 1.11 and 1.14, but with less intensity (from 66% to 80% agree). Of which, it is important to highlight the interest in other co-products outside the transportation sector, such as nutraceuticals and compounds for the pharmaceutical and/or fine chemistry industries. The commercialization of theses co-products could assist industries to reach economic feasibility of microalgae biofuel.

Questions 1.3 and 1.4 did not reach a clear consensus and were asked again in the 2nd round for further analysis. From the results, 1.3 has a clear tendency on agreement; however, we could not conclude a clear overall consensus, since the sample that agreed now (69.0%) had already agreed on the 1st round (70.0%). Statement 1.4 did not reach any consensus (26.7% disagree / 33.3% neither agree nor disagree / 40.0% agree).

In Theme 2, expressive consensus was reached only on statement 2.8, which reached 92.2% of agreement. Therefore, experts strongly agree that no single microalgae strain will be the dominant one, and that different strains of microalgae will be used depending on the nutrients and/or waste streams available, and particular local climatic and water availability conditions.

High consensus was observed on declarations 2.4, 2.10 and 2.11. In this way, the reduction of oil imports dependence and the potential development of local and national economies is a relevant factor for the development of microalgae biofuels. Experts also believe that biofuels from microalgae will be produced commercially, but only in the mid to long term. This conviction was better described on Theme 5 of this study.

Mild agreement was reached on 2.1, 2.2. 2.5, 2.6, and 2.7 (from 66% to 80% agree). Two factors related to the economic feasibility of algae biofuels are noteworthy to point out. They relate to the sense that not only higher petro-oil prices, but also a more developed, globalized and comprehensive Carbon Market could foster microalgae biofuel to become more economically feasible.

Questions 2.3 and 2.9 did not reach a clear consensus and were asked again in the 2nd round for further enlightenment. Neither an achieved consensus was obtained on the 2nd round nor were some reasons clarified by the experts, for instance: "Hard to make predictions know. Depends on the evolution of other biofuels, technological advances, development of other biofuels... This is one is though..." (Comment on Statement 2.3).

The Sustainability theme was the most controversial one. In which, eight from twelve statements did not show consensus (3.1, 3.2, 3.3, 3.4, 3.6, 3.7, 3.10 and 3.11). All these were asked again in the 2nd round of the survey.

The highest consensus was achieved on 3.12 (82% agree) that said, "The potential to use waste streams and/or easily available renewable nutrients is a key factor in the overall system sustainability."

Agreement was also reached on 3.5, 3.8 and 3.9, but with lower intensity (from 66% to 80% agree). All these statements had in common "carbon emissions", where experts agree that the need to reduce world's CO_2 emissions is a key advantage for microalgae biofuels; and that the actual overall life cycle carbon balance is key aspect to consider in the microalgae biofuel production. They think that being carbon neutral is a key factor concerning microalgae biofuel production sustainability.

From the ones asked on the 2nd round, it is interesting to highlight that because biofuels of this origin do not have a well-known industrial process (there are different methods for producing them) and microalgae are not yet being cultivated commercially for this purpose, it was difficult for the experts to answer questions related to sustainability. Some of the comments to these questions were: "More information and practical data is needed to answer this one" (Statement 3.3 and 3.4); "All these statements are dependent on other factors, therefore difficult to respond with just a simple agree/disagree." (Statement 3.6); "Depends on the processes utilized for product and co-products generation/use." (Statement 3.10).

Theme 4 concerned "Policies", where several prospects of policies were presented and the respondents were asked to choose "How important is each policy below to the success of microalgae biofuels?" The answers were presented in a seven-level Likert scale ranging from "Unimportant" to "Extremely Important". The policies presented are displayed on Table 2 below.

TABLE 2: THEME 4 STATEMENTS AND RESULTS

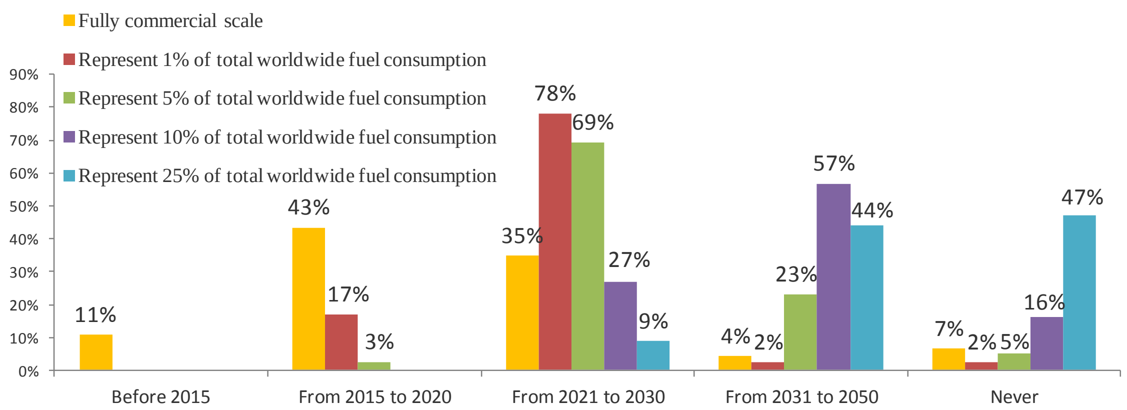
	Theme 4: POLICIES	**Mean**
4.1	Mandatory country objectives;	**5.52**
4.2	Sustainability standards (Emissions, production, etc.);	**5.70**
4.3	Public Investment in R&D;	**6.09**
4.4	Tax incentives and subsidies;	**5.71**
4.5	Certification schemes, in particular those concerning raw materials or the entire fuel life cycle;	**5.48**
4.6	Specific legislation or international agreements (such as European Directives) aimed specifically to biofuels or to specific environmental questions (such as carbon emissions) where biofuels have a pivotal role;	**5.70**
4.7	Development strategies aimed to renewable resources, either research, utilization and integration in existing systems.	**5.91**

All policies were seen by experts as important, in which the sum of "Important", "Very Important" and "Extremely Important" in all items were above 80% of valid responses. In an attempt to rank which were the most important ones, values were set from 1 to 7 to "Unimportant" through "Extremely Important". Consequently, it was possible to estimate the most important policies in the view of the experts interviewed. For that purpose, an overall mean was computed for each policy and is presented in Table 2. Analyzing this data, experts believe that "Public Investment in R&D" is the most important mechanism to develop microalgae biofuels. However, the other mechanisms were also important for this purpose and it is a sum of efforts that makes the development to go on.

In order to better specify which policies were the most important ones, in the 2^{nd} round the same set of policies were given, but this time, the respondents were asked to rank them (from 1-most important to 7-least important) without repeating numbers. The results were similar to the ones from the first survey: public investment in R&D was elected as the most important one, with a statistic mode of 1 (most important) chosen by 34.5% of the respondents. This policy was followed by "developing strategies aimed to renewable resources, either research, utilization and integration in existing systems"; "tax incentives and subsidies"; and "mandatory country objectives", subsequently.

Theme 5 was named "Future" where the question asked was "When do you think the following would happen in microalgae biofuels industry?" Some time scenarios were shown and the respondents could choose one option for each item. The outcomes are shown in Figure 1.

Figure 1: Theme 5 overall results



As it can be observed, most of the experts think that the production of microalgae for biofuels will achieve full commercial scale until 2020. From 2021 to 2030 it is believed to represent from 1% to 5% of the total worldwide fuel consumption and from 2030 onwards it could reach figures of 10% to 25%. However, almost half of the experts (47%) do not believe it could reach 25% of worldwide fuel consumption.

4. Conclusions

The Delphi method proved to be a successful research method when expert opinions are the main source of information available, due to a lack of appropriate historical, economic or technical data and the outcomes herein, provided clearly outline of the main issues of microalgae biofuels' market at present and in the future. In particular, the two-round survey revealed the most important issues affecting this emerging market and also, recommended ways to influence future policies and development of this biofuel.

One of the key findings is that most of the experts believe that the production of microalgae for biofuels will achieve full commercial scale until 2020 and from that period on, it could represent an important share of the total worldwide fuel consumption. On the other hand, environmental issues are most likely to reveal divergent opinions from experts. Conceivably because biofuels of this origin do not yet present a well-known industrial process and microalgae are not still being cultivated commercially for this purpose.

In order to boost development, experts agree that public investment in R&D is the most important policy to be adopted by countries. Developing strategies aimed to renewable resources; applying tax incentives and subsidies; and issuing mandatory country objectives were also encouraged.

Although this research has reached its aims, some challenges ahead still remain. First of all, the sample size could have been bigger and thus, more representative in statistical terms. The authors of this paper are aware that the outcomes might not represent the majority of the microalgae experts' opinion. In the same manner, after analyzing the results, some questions did not reach a consensus and could be further explored in a supplementary study or in a third round. Finally, more robust statistical calculations could have been done with the quality data obtained. However, to the best of these authors knowledge, this is the first Delphi study performed concerning the future of microalgae.

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Appendix A: Statements of Themes 1,2 and 3.

	Theme 1: ECONOMICS
1.1	Achieving economic viability is considered one of the main challenges facing large-scale deployment of biofuels from microalgae.
1.2	The idea of a Biorefinery is considered the business model more likely to ensure the economic viability of microalgae cultivation for biofuel production.
1.3	Microalgae biofuel will become a co-product of future large-scale facilities, where other high-value products are generated.
1.4	The price of competing fuels, especially biobased, will make it difficult for algal biofuels to achieve high growth on the cost only basis.
1.5	R&D subsidies and support programmes will be needed to promote improvements in the technology that reduce the costs of algal biofuels.
1.6	The potential of using waste streams from other processes, industries or systems, as for example waste flue gases or waste waters, can have a significant impact in the microalgae economic process viability.
1.7	Besides biofuels, the more relevant co products that will improve the economic viability of microalgae cultivation are nutraceuticals and compounds for the pharmaceutical and/or fine chemistry industries.
1.8	One of the key advantages of cultivating microalgae is the capacity of producing raw materials all year round, simplifying the process logistics and reducing costs.
1.9	The utilization of Genetic Engineering or more effective selection criteria may lead to more effective strains of microalgae, in particular in terms of overall productivity and/or cultivation robustness.
1.10	The economic feasibility is strongly affected by the amount of energy needed in the process, mainly due to the high water content of the original raw materials that has to be removed before the chemical reaction.
1.11	The limiting steps, in terms or processing costs, are the oil separation and water removal steps. Any improvements in these steps can have a profound impact in the economical feasibility of the microalgae biofuel production process.
1.12	There is still plenty of room for innovative and more effective production processes, from the cultivation, passing through the raw material processing, chemical reactions involved and purification steps.
1.13	The increase in the overall consumption of biofuels, and the expected growing pressures on currently used feedstocks can be a key factor to the economic viability of microalgae.
1.14	The economical viability of the microalgae production can be further enhanced if biofuels applications outside the transportation sector can be found and promoted.
1.15	Microalgae cultivation may become an important factor in the development of local economies and reduce the dependence on non renewable energy sources.
	Theme 2: FUTURE TRENDS
2.1	Higher petro oil prices could make algae biofuel economically feasible.
2.2	A more developed, globalized and comprehensive Carbon Market could make algae biofuel more economically feasible.
2.3	Algal biofuels will be developed, but will play only a minor role in the future mix, in particular for the transportation sector.

2.4	Biofuels from microalgae will be produced commercially, but only in the mid to long term.
2.5	Advances in strain identification and process engineering are key factors in the development of the technology.
2.6	The nature of the cultivation system, closed or open, will depend on the production quantities, type of nutrients required, waste streams available and strains used.
2.7	The microalgae cultivation process will be increasingly used integrated in existing industrial processes, usually not related with energy production and for waste treatment and/or carbon capture purposes.
2.8	Different strains of microalgae will be used depending on the nutrients and/or waste streams available, and particular local climatic and water availability conditions. No single strain will be dominant one.
2.9	Open pond cultivation, or similar, will dominate the future production systems, although for small production involving the processing of waste streams the close cultivation systems will be also used.
2.10	The main aspects that have to be considered in the process development are improving its overall energy efficiency, the ability to produce other high value products, or the possibility to integrate it in other process under the biorefinery concept umbrella.
2.11	The reduction in the dependence in oil imports, and the potential development of local and national economies is a relevant factor in the development of the area.
	Theme 3: SUSTAINABILITY
3.1	The environmental sustainability of microalgal derived biofuels is a potential problem.
3.2	The utilization of genetic modified organisms may represent a potential problem in the diffusion of algal biofuels.
3.3	Open pond cultivation is more environmentally friendly than PBRs cultivation.
3.4	Closed PBRs cultivation is more environmentally friendly than open pond cultivation.
3.5	The need to reduce world's CO_2 emissions is a key advantage for algae biofuels.
3.6	The production of algae biofuels in large scale could generate potential impacts on local ecosystems from new algal species.
3.7	The production of algae biofuels in large scale could generate potential impacts on water reserves.
3.8	Although microalgae can be used to capture CO_2, the actual overall life cycle carbon balance is key aspect to consider.
3.9	The potential of biofuels from microalgae to be carbon neutral is a key factor concerning their sustainability.
3.10	Some potential undesired environmental aspects may arise from microalgae cultivation, as for example, increased emissions of NO_x and/or methane.
3.11	The environmental impacts of energy consumption is the key factor concerning the sustainability of the microalgae cultivation.
3.12	The potential to use waste streams and/or easily available renewable nutrients is a key factor in the overall system sustainability.

Low intensity pretreatment before anaerobic waste activated sludge anaerobic digestion

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Abstract

Anaerobic digestion of waste activated sludge is less effective than primary sewage sludge. Degradation under anaerobic conditions of microorganisms requires a relatively longer time for hydrolysis. In order to upgrade the hydrolysis effects, several pretreatment processes have been investigated. Some of the developed processes have already been introduced in full technical scale, e.g. hydrodynamic disintegration and ultrasound technologies. At present a lot of attention is given to aggressive pretreatment processes based on high temperature (up to 190^{o}C), and or high pressure (up to 120 bar). As aggressive processes also those of high energy consumption can be classified. In general it is difficult to satisfactory justify the high intensity processes in terms of achieved additional digestion effects. Probable low intensity processes, with investigation and operational costs including energy consumption could be an alterative. The effects of a combination of WAS chemical adjustment and nest hydrodynamic disintegration presented seems to be an example of low intensity process with satisfactory results. Efficiency increase expressed as 45 % biogas additional production and about 40 % of total or volatile solids reduction was confirmed.

Keywords: anaerobic sludge digestion, biogas production, sludge disintegration, disintegration degree

1. Introduction

The first stage of anaerobic digestion, the hydrolysis step is regarded as the rate limiting step in the degradation of complex organic compounds, such as waste activated sludge. Therefore several techniques are investigated to upgrade the effects of organics decomposition by introduction pre-treatment hydrolysis. Some of the techniques have already been introduced in full technical scale, among them hydrodynamic disintegration and ultrasound technologies.

A lot of attention is given to thermal hydrolysis as an alternative pre-treatment process. In fact thermal pre-treatment increases the rate of hydrolysis, thus leading to a greater extent of solubilisation of the available chemical oxygen demand. This allows enhanced rates of degradation in the process of anaerobic sludge digestion. It is considered to be a thermal disintegration procedure which substantially hydrolyses the sludge. Saturated steam at a temperature of 165 degrees centigrade at 6 bar pressure, for 30 minutes without addition of chemicals is used for sludge hydrolysis (Kopp and Ewert, 2006). Thermal waste activated sludge (WAS) pretreatment technologies, at high temperatures up 190 ^{o}C are regarded as high intensity or extreme processes. Apart of high investment and operational costs related to the complex system of heat and energy recovery has also some drawbacks.

For example it has been documented that thermal pretreatment of sludge is responsible for the formation of refractory dissolved organic compounds (Climent et al., 2007, Eskicioglu et al., 2006). Among other refractory compounds, melanoidin has been hypothesized to be produced, resulting in an dark brown liquor (Penaud et al., 2000a and 200b). After commissioning of the CAMBI process at the treatment plant Oxley Creek – Australia (Dwyer et al., 2008) a distinctive increase of colour and dissolved nitrogen has been experienced. Colour produced during the thermal hydrolysis of waste activated sludge was found (Dwyer et al., 2008), to be highly dependent on the operating temperature of the process. Also the process is not odour less.

Up to day many other different pre-hydrolysis technologies have been developed, like acidification or alkalization. Chemical sludge conditioning in combination with other disintegration technologies, like ultrasound or thermal treatment (low temperature between 50 and 70^{0}C) was also investigated. In the literature the increase of soluble chemical oxygen demand (SCOD) or decrease of volatile solids especially during alkaline treatment in combining with thermal treatment is stressed, (Athanasouila et al., 2007; Lin et al., 1997; Neyens et al., 2003; Tanaka et al., 1997; Valo et al., 2004; Vlyssides and Karlis, 2004). Another technology of chemical treatment with high pressure treatment - "Microsludge" (Rabinowitz and Stephenson, 2006) has also emerged.

Also physical techniques are investigated aiming both at hydrolysis before anaerobic digestion and at sludge amount reduction due to higher degree of decomposition of organic matter. Among them mechanical milling, homogenizers, or ultrasonic disintegration have found application. Probable the most promising techniques are base on the phenomenon of hydrodynamic cavitation evocation. Under specific condition of water flow through a constriction, like a valve, Venturi or Lavale nozzle, or even orifices (simple holes), a drastic pressure reduction happens at the outflow. Dissolved air appears as micro-bubbles, which implode at high temperature and pressure. Produced hydroxylic radicals with local high temperature are permitting decomposition of complex organic substances (Petrier and Francony, 1997). The hydrodynamic cavitation phenomenon in application to activated sludge disintegration – cell structure disruption - was investigated by many authors (e.g. Kalumuck and Chachine, 2000; Gogate and Pandit, 2004). The phenomenon of cavitation is also associated to the process of ultrasound disintegration and was widely investigated and introduced in the practice (Zawieja et al. 2008).

The technology based on hydrodynamic disintegration was adapted in this presentation. Hydrodynamic disintegration, similar to other disintegration procedures requires energy. The optimal conditions can be readily adjusted by changes of the time of disintegration procedure. Hydrodynamic cavitation is a relatively low power consumption process. As presented by Kalogo and Monteith (2008) the energy demand is in the range of 0.94 to 1.85 kWh/m^3. For example, using the same source of data (Kalogo and Monteith 2008, page 41), the power consumption of the ultrasonic technology is about 3.7 kWh/m^3.

Although low and high dose of sodium hydroxide (NaOH) have been investigated, the utmost attention is devoted to alkalization in the range of 8.5 to 10 pH.

In order to alleviate the power consumption problem, the investigations realized, include a **hybrid technology – alkali combination with hydrodynamic disintegration.** Alkali (especially NaOH) weakens the cell walls making them more susceptible to lysing processes such as hydrodynamic disintegration. The alkali/acidic pretreatment methods are relatively simple, energy efficient and efficient to kill the pathogens. Satisfactory, as demonstrated, disintegration effects are possible by addition of relatively small amounts of alkali.

So far very limited information are available on alkaline treatment at ambient temperature range, and especially less information exist on the hybrid chemical and mechanical treatment – hydrodynamic disintegration approach. This paper aims at filling up the gap.

2. Materials and methodology

Hydrodynamic disintegration

The experimental set up for hydrodynamic disintegration execution consisted of a 12 bar pressure pump, rating 0,54 kWh, output 500 L/h, which recirculated sludge from a 25 litre volume container, through a 1.2 mm nozzle. To force 25 litres of waste activated sludge (WAS) through the nozzle 3 minutes were required. Disintegration was carried out for 15, 30, 60 and 90 minutes.

WAS samples, from the secondary settling tanks - concentration of suspended solids (SS) in average 9.25 g/L, was taken from municipal wastewater treatment plant in the south of Poland, working according to the Enhanced Biological Nutrient Removal (EBNR) processes. The plant was designed for a flow of 120 000 m^3/d. At present the amount of treated wastewater is about 90 000 m^3/d. Solid retention time (SRT) is about 14 days and concentration of mixed liquid suspended solids (MLSS) 4.32-4.64 g/L.

Alkalization

For chemical WAS disintegration (lysis of microorganisms cells) sodium hydroxide (NaOH) 2M was used. NaOH was added to samples of activated sludge in amounts sufficient to maintain a given pH value (8, 9, 10 and 11) for 30 minutes. Approximately from 0.8 to 6 mL NaOH (2M) per L of WAS.

Hybrid disintegration

The hybrid disintegration process of waste activated sludge (WASDH) means, combination of chemical - alkalization of WAS to pH=9, and then hydrodynamic disintegration for 30 minutes.

Disintegration degree

In order to have a quantitative measure of the effects of disintegration a coefficient called the degree of disintegration (DD) was used. The degree of sludge disintegration was determined according to the modified formula as follows:

$$DD = [(COD1 - COD2) / (COD3 - COD2)] \cdot 100(\%) \qquad (1)$$

where:

DD - degree of disintegration, COD1 is the COD of the liquid phase of the disintegrated sample, COD2 is the COD of the original sample, and COD3 is the value after chemical disintegration. Chemical disintegration was done in this case by treating the sludge samples for 10 min, after addition 1 M NaOH, in ratio 1:2.

Analytical methods

All chemical analyses were performed for samples before and after each stage of disintegration and during anaerobic digestion. All chemical and physical parameters were determined according to the procedures given in the Standard Methods for Examination of Water and Wastewater (19th ed.). In the taken samples of activated sludge the COD value and content of suspended solids was analysed (Eaton et al., 1995), the protein concentration was determined by the Lowry method (Gerhardt et al., 2005).

For colorimetric determinations, a spectrophotometer HACH DR 5000 was applied. pH and conductivity measurements were carried out with a WTW inoLab Level2 meter, equipped with a SenTix K1 electrode for pH.

Volatile suspended solids (VSS) concentration was determined according to the Wastewater Engineering Treatment and Reuse (4th edition) (Tchobanoglous et al., 2002).

Anaerobic digestion studies

The anaerobic digestion experiments were performed in glass fermenters (3.0 liters volume). The reactors have been located in thermostatic conditions, with constant temperatures 34±1^{o}C and 55±1^{o}C under mesophilic and thermophilic conditions respectively. Holding time of 12 days for mesophilic conditions and 13 days for thermophilic conditions were used. The volume and quality of produced biogas was determined by liquid displacement method ever each day.

Different rates of Waste Activated Sludge (WAS), Waste Activated Sludge Disintegrated Chemically (WASD) and Waste Activated Sludge after Hybrid Disintegration (WASDH) have been applied:

Fermenter 1 – was fed 70% WAS + 30% digested sludge as inoculums (DS),

Fermenter 3 – was fed 40% WAS + 30% DS + 30% WASD,

Fermenter 2 – was fed 40% WAS + 30% DS + 30% WASDH.

3. Results and discussion

Disintegration

Disintegrated by hydrodynamic cavitation has a positive effect on the degree and rate of sludge anaerobic digestion. Hydrodynamic cavitation results in formation of cavities (bubbles) filled with a vapour – gas mixture inside the flowing liquid, or at the boundary of a constriction devices due to rapid local pressure drop. Subsequently downstream the constriction (valve or nozzle) the pressure recovers causing cavities collapse. The collapse of the cavitation bubbles is defined as implosion and the forces associated with results in mechanical and physique-chemical effects. The physical effects include the production of shear forces and shock waves, whereas the chemical effects result into the generation of radicals e.g. formation of reactive hydrogen atoms and hydroxyl radicals which recombine to form hydrogen peroxide. Hydrodynamic disintegration can activate the biological hydrolysis process and therefore, significantly increase the biogas production in anaerobic stabilization.

Alkalization has a pronounced impact on the organic matter dissolution. Higher effects of combined hydrodynamic and chemical disintegration was assigned to alkali (NaOH) softening of the cell walls making them more susceptible to lysing processes including hydrodynamic disintegration. Subsequent determinations showed an impact of both processes (alkalization and hydrodynamic disintegration) on increase of soluble chemical oxygen demand (SCOD). As expected the increase of SCOD the content of proteines was greater than in the case of the disintegration processes separately. The much more pronounced hydrolysis effects, resulting from the process of pre-alkalization (NaOH addition), and then the hydrodynamic disintegration arise from the "softening" of cells wall of bacteria, and dissolve the non-cellular polymers.

The effects of hydrolysis is strictly related to the achieved disintegration degree. The values of achieved DD are presented in Fig. 1.

Fig. 1. Achieved disintegration degree after alkalization (WASD) and after hybrid method of disintegration (WASDH).

As shown in Fig. 2 and 3 relatively high SCOD values and dissolved proteins concentration are achieved.

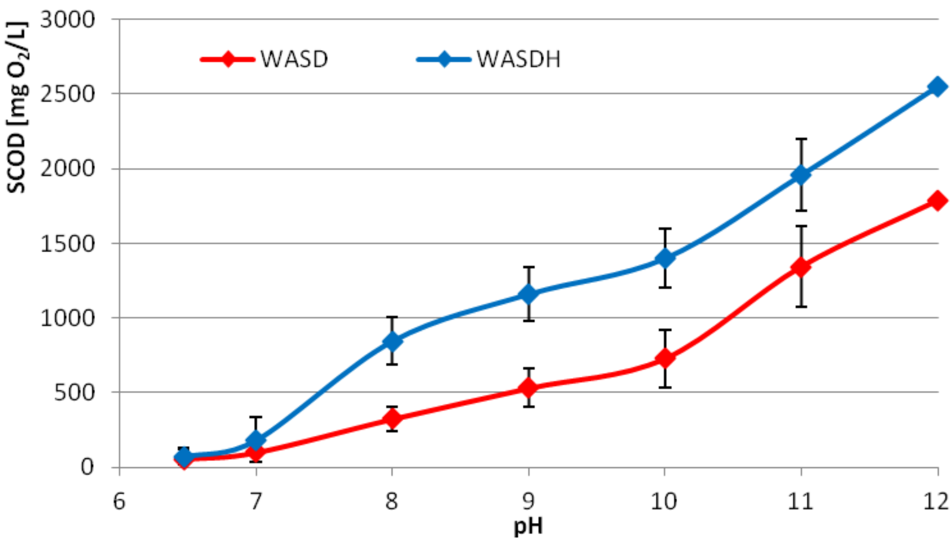

Fig 2. Changes of SCOD [mgO_2/L] after alkalization only and after hybrid method of disintegration

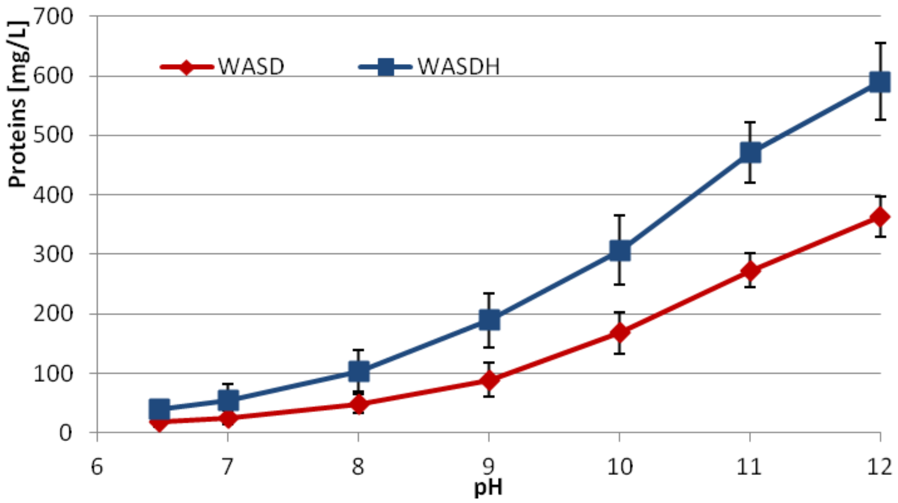

Fig. 3. Proteins dissolution in the process of alkalization and hybrid method of disintegration

The dissolution results are comparable to achieved by many other low intensive disintegration procedures presented in the literature. Here it has to be stressed, that alkalization in front of hydrodynamic disintegration increased distinctively the overall disintegration effect determined as SCOD increase. The adding NaOH resulted in the SCOD value increase at least twofold after hydrodynamic disintegration in the range of pH from 8 to 10.

The disintegration effects, expressed usually as soluble COD, as a measure of organic matter dissolution, have no direct correlation with the achieved results of the anaerobic sludge digestion, i.e. rate of biogas production and solids decomposition. Reasonable (optimal) degree of disintegration has to be sought. For this end, combinations of soft alkalization – up to pH between 9 and 10, and disintegration of only a part of WAS added to the anaerobic digesters are investigated.

The obtained results are demonstrating the effects of biogas production increase caused by partial sludge disintegration. For the extreme cases; non disintegrated activated sludge and 30% chemically disintegrated sludge added, there is over 46% higher production of biogas in the first mesophilic stage of anaerobic digestion. Respectively 1950 ml/L for no disintegrated sludge and close to 2850 ml/L for disintegrated. A relatively moderate biogas production was observed under thermophilic condition. Respectively 2450 ml/L for no disintegrated sludge and close to 3130 ml/L for disintegrate sludge, that is 27,7% higher biogas production.

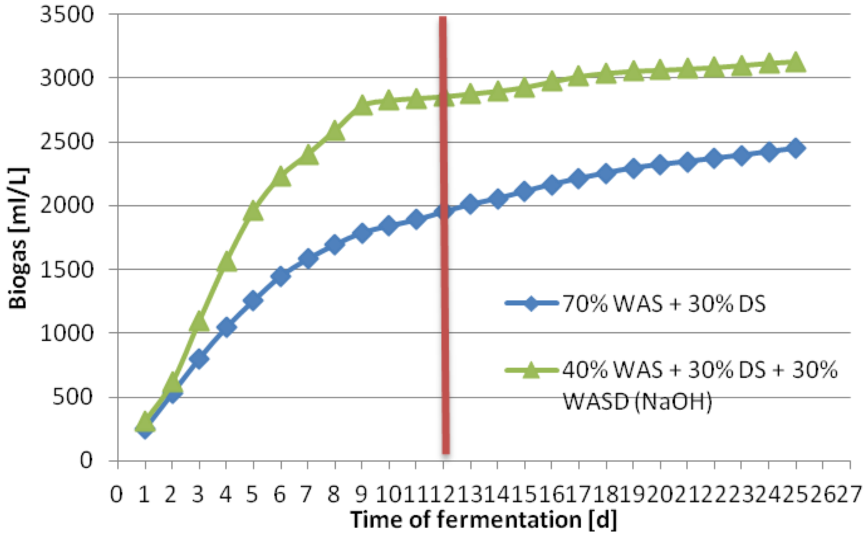

Fig. 4. Biogas production in the mesophilic and thermophilic conditions for composition with the sludge after alkalization.

Significantly higher amounts of biogas were produced in the fermenters fed with WASDH (30% volume of fermenter). Hybrid disintegration accelerates the biological degradation of sludge. The cell liquid contains components, which upon being released, can be easily assimilated. The released organic substances (expressed here as SCOD) as a result of activated sludge floc disintegration, lead to a substantial increase of biogas production in the subsequent anaerobic sludge digestion process. There was observed an over 82% higher production of biogas in the first mesophilic stage of anaerobic digestion for sample with hybrid disintegrated activated sludge added. Respectively 2010 ml/L for no disintegrated sludge and close to 3665 ml/L after disintegration. A relatively moderate biogas production was observed under thermophilic condition. Respectively 2450 ml/L for no disintegrated sludge and close to 3820 ml/L. Thus a 55,9% higher biogas production (Fig. 5).

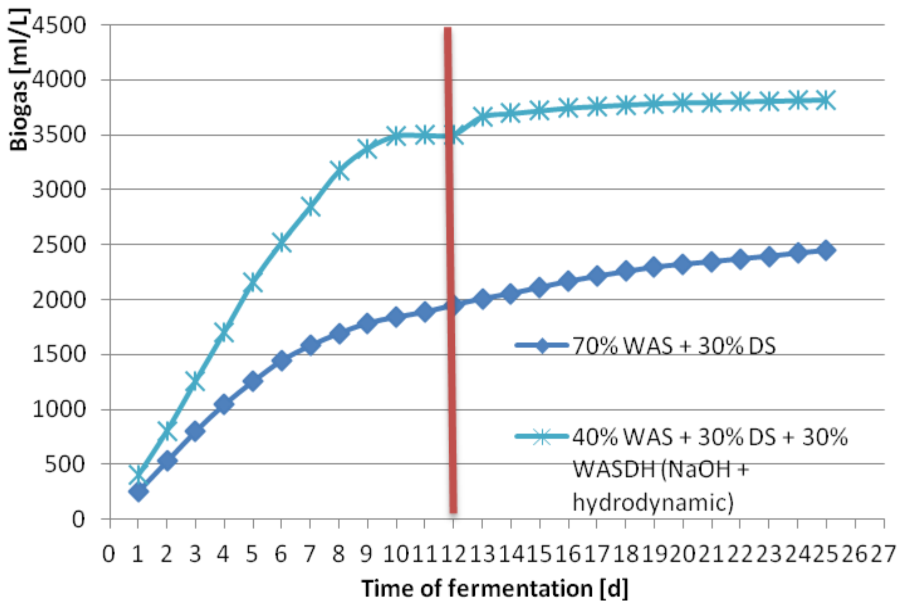

Fig. 5. Biogas production in the mesophilic and thermophilic conditions for composition with the sludge after hybrid disintegration.

With high effects of total and volatile solids removal in the range of 35 to 45 % in the various alternatives of WAS pretreatment processes investigated, the biogas yield, expressed as the volume of biogas produced in relation to VS removed increased from 22 % to 45 % in comparison to control (Fig. 6).

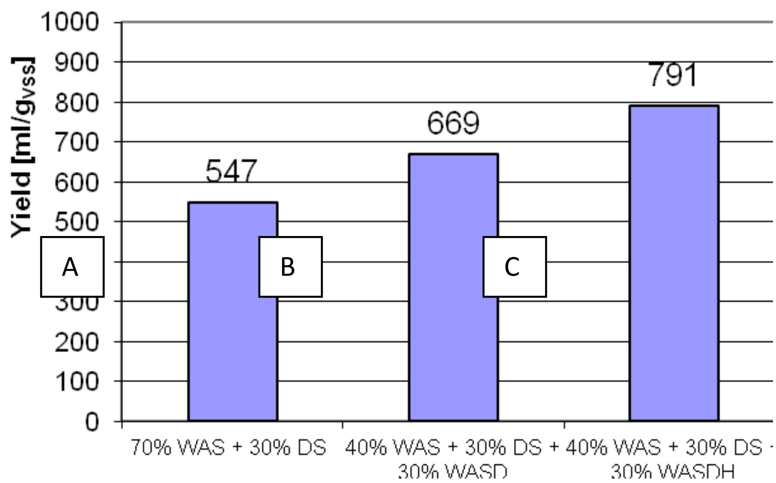

Fig 6. Biogas yield for control sample (A) and sample included a part of chemically disintegration WASD (B), and a sample included a part of alkalized and next hydrodynamic disintegrated WASDH (C).

Carried out experiments demonstrate the possibility to obtain high effects of WAS anaerobic digestion, both in terms solids removal and biogas production. The advantage of the applied low intensity pretreatment process is a low investment and operational cost technology, as well permit easy adjustment to requirements, what means high flexibility.

4. Conclusions

Low intensity waste activated sludge pretreatment before anaerobic digestion permit achievement of high effects, in terms of: microorganisms degradability (lysis) increase, and additional (up to 45 %) biogas production. Similarly to other processes, including high intensity processes, such as thermal hydrolysis, it is possible to decrease sludge anaerobic digestion time and digester volume decrease. The presented technology is low energy intensive and offer high flexibility in operation.

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Influence of sewage sludge content in the mixture with sawdust and maize straw on composting process dynamics

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Abstract

After entrance to EU in 2004, the management of sewage sludge has become more and more important problem for the new members. In Poland, one of the most promising technologies is composting process of sewage sludge with carbonaceous materials. However, the high price of typically used cereal straw forces the specialists to look for new and cheap materials used as donor of carbon and substrates creating good, porous structure of composted heap. This work presents the results of sewage sludge composting mixed with sawdust and maize straw used to create structure favorable for air exchange. The results show dynamic thermophilic phase of composting process in all cases where maize straw was used.

Key words: sewage sludge, composting, process intensity, gases emission

1. Introduction

The amount of produced sewage sludge has been constantly increasing along with the development of humanity, improvement of sewage sludge treatment technology and increased sewerage level of developed and developing countries [Singh and Agrawal, 2008]. This type of waste can be implemented as organic fertilizer, valuable in nitrogen and others macronutrients [Cheng et al., 2007]. However taking into account numerous requirements of environmental management, sewage sludge become a problem [Harrison et al., 2006; Khadhar et al., 2010]. An unfavorable feature of this waste is specific, amorphous structure, which favors anaerobic decomposition and production of gases harmful for health and environment such as ammonia, hydrogen sulfide, aromatic hydrocarbons and others. The most problematic issue concerning sewage sludge is their sanitary conditions and lack of stability. In order to reduce this negative factor, the discussed waste can be composted within presence of clear thermophilic phase [Wéry et al., 2008]. In consequence, the sewage sludge will be subjected hygienisation and obtained compost will be a stable, fully environmental friendly fertilizer. However it is extremely important to maintain the proper C:N ratio in order to run the composting process in the right direction. Lack of corresponding relations between these elements perturbs the composting process and causes the emission of gases harmful to environment. The optimal C:N ratio at the beginning of the process should amount 20-30 Pakou et al., 2009]. Sewage sludge because of high content of nitrogen (approx. 50 g N/kg d.m.) become a difficult material for composting. Addition of different materials with high carbon content (like different kind of straw, sawdust) can be used in order to support the possibility of aerobic decomposition [Himanen and Hänninen, 2011]. Its amount permits to extend the relation which causes better conditions for the process initiation. Materials useful for increase of the carbon amount can be straw and sawdust. Another valuable straw feature is creation of the structure. It allows the proper pile's oxygenation which in turn can prevent the occurrence of anaerobic conditions and finally contributes to more rapid degradation [Sundberg and Jönsson, 2008].

Obviously for economic reasons there is no possibility that any sewage sludge composting plant could function rationally if the mass of sewage sludge (measured in dry mass) would be lower than mass of carbon additives (straw or sawdust) because of high market price.

However it should be remembered that composting process of the material with low initial C:N ratio is a guarantee of the strong ammonia emission [Amon et al., 1998; Matsumura et al., 2010]. Moreover the deficiency of structural materials rich in carbon is the reason of faster collapse of the pile and creation of anaerobic conditions leading to the emissions of hydrogen sulfide, methane and odors. Towards the commonly observed on national composting plants tendencies to reduce the mass of applied organic materials with high carbon content, raises the question what is an acceptable level of additive, where ammonia emission during composting process is on the acceptable level and leads to nitrogen losses not exceeding 10-12% (level in properly conducted manure composting process) [Dach 2010].

2. Research aim

The aim of the study was to compare the composting process run (with special regard of gaseous emissions) of sewage sludge mixed in different proportions with maize straw and sawdust, under controlled laboratory conditions using specialized research equipment (isolated 4-chamber bioreactor) and standard research methodology. The work was realized in the frame of the project financed by the Polish Ministry of Science and Higher Education entitled "Technology of harvest and storage of maize straw as an energy biomass and structural substrate for composting process".

3. Materials and methods

The studies on sewage sludge composting process were carried out during 2011 in Ecotechnologies Laboratory at Institute of Biosystems Engineering (Poznan University of Life Sciences, PULS). In the experiment 4-chamber isothermal bioreactor was used. It was constructed in 2002-4 in the frame of ministerial grant entitled “Gaseous emissions in different technologies of manure management” [Dach 2005] and then rebuilt during the realization of the project within 6th European Union Framework Program “Technology of compost production from sewage sludge with reduction of ammonia emission and heavy metal content” (acronym CleanCompost).

As a part of these projects, a number of comparative studies have been carried out and it has been stated that the bioreactor truly reproduces composting processes running in the real conditions, and in particular long, few weeks lasting thermophilic phase. Such a dynamic thermophilic phase with temperature exceeding 70-75^{o}C is typical for research conducted under real conditions [Wolna-Maruwka and Dach, 2009].

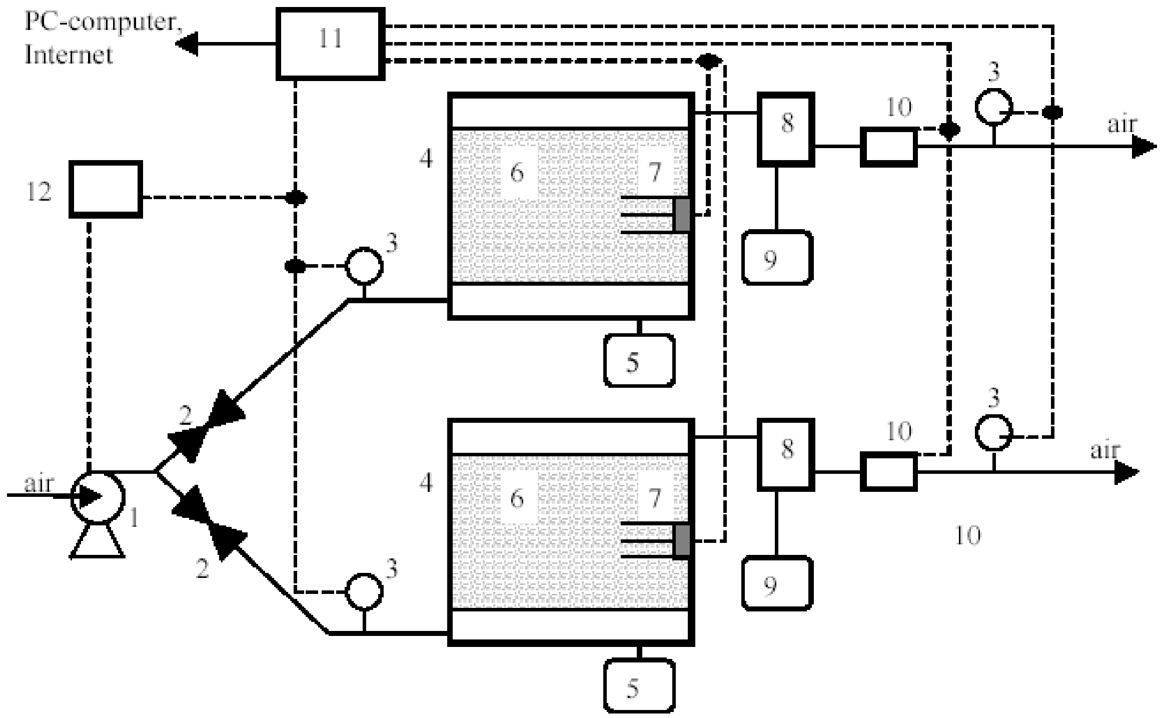

Fig. 1. Schematic diagram of the 2-chamber bioreactor:

1. Pump,
2. Flow regulator,
3. Flow meter,
4. Isolated chamber,
5. Drained liquids container,
6. Composted mass,
7. Sensors set,
8. Air cooling system,
9. Condensates container,
10. Column of gases content analysis (NH_3. O_2. CO_2. CH_4. H_2S),
11. 16-channel recorder,
12. Air pomp steering system.

Tested sewage sludge was taken from a sewage sludge treatment plant in Szamotuły near Poznan. It is typical small installation producing 5-7 thousands t of sewage sludge per year. This kind of biological treatment plants is very common in Poland, there are more than 1500 units. Sewage sludge from Szamotuły treatment plant was used as an agricultural fertilizer, but because of changing legal requirements in Poland since 2013 it will be impossible to use this kind of sludge without its processing. Hence occurred a need for sewage sludge treatment technologies, where the composting seems to be the most environmental favorable and the cheapest one. It is worth to highlight that sewage sludge were collected from the typical wastewater treatment plant in a small town (40.000 inhabitants) with lack of heavy industry and sewage sludge have a minimum content of heavy metals.

The mixtures of sewage sludge (75, 60, 45 and 30% of dry mass in particular chambers K1, K2, K3 and K4) and 5% maize straw have been prepared in order to investigate. The rest was a hardwood sawdust complement from the carpenter of Faculty of Wood Technology (PULS). As a structural material for research the maize straw has been chosen because it is a cheap material (below 12 euro/t), commonly available, giving better effects in composting (also decreasing the ammonia emission) in relation to traditionally used cereal straw (price in Poland above 40 euro/t).

After mixing and sampling for the analyses, sewage sludge mixtures were placed in isolated bioreactor chambers and then undergo the composting process. The precise analysis of the mixtures initial parameters is shown in Table 1.

Table 1. The content of mixtures prepared for composting calculated in dry matter

	Sewage sludge [%]	Sawdust [%]	Straw [%]
SS_75%	75	20	5
SS_60%	60	35	5
SS_45%	45	50	5
SS_30%	30	65	5

It is worth to highlight that in order to compensate the level of initial humidity in composted mixtures to the level of the mixtures SS_45% and SS_30% the water has been added (respectively 8 and 18 dm^3). It was necessary because as a result of the reduced content of sewage sludge in SS_45% and SS_30% the humidity level would be even twice lower than in SS_75%, making difficult comparison of research results and their reference to the real conditions (initial humidity at the level of 60% which is very rare in composting plants and it usually varies between 70-80%). The sewage sludge in all chambers were aerated by the air flow of 3.5 $dm^3 min^{-1}$. Two types of chemo-electrical sensors MG-72 (scale 0-1000 ppm) from Alter S.A. firm have been used in the experiments [Boniecki et al., 2012]. The gauge Metex M3870D allowed to read the data subsequently. The temperature variation was registered by means of temperature sensors connected to 16-channel recorder and read manually during the gaseous measurement. The air flow through the bioreactor chambers was adjusted manually using the rotameter (flow readability of 0.05 $dm^3 min^{-1}$), whereas the constant control was by means of electronic flow sensors and connected to the register. Moreover the amount of air flow was also measured with analog counters.

The physical as well as chemical analyzes (dry matter, organic dry matter, pH, C_{org}, N_{tot}, N-NH_4) were made at PULS laboratories with the standard procedures [Piotrowska-Cyplik et al., 2009; Wolna-Maruwka et al., 2009].

4. Results

Comparison of the initial parameters of all studied mixtures are presented in Table 2.

Tab. 2. Basic physical and chemical parameters of the composted mixtures

	SS_75%	SS_60%	SS_45%	SS_30%
Fresh mass [kg]	60.2	50.2	44.2	48.2
Dry mass [kg]	11.2	12.6	11.23	12.53
Humidity [%]	81.5	74.9	74.6	74
Density	506.82	380.57	327.75	431.91
C:N ratio	9.2	12.1	17	26.4
O.M.	90	88.7	90.3	86.8

The higher density of mixture SS_30% than SS_45% was related with watering of material prepared for composting. Because of large content of sawdust, without additional water input this mixture should be too dry for composting and whole process could be incomparable to the other mixtures.

Temperature changes

One of the basic parameters testifying the possibility of normal composting process run is to obtain the appropriate temperatures during the experiment. The temperature courses in the investigated composts are shown in Figure 2.

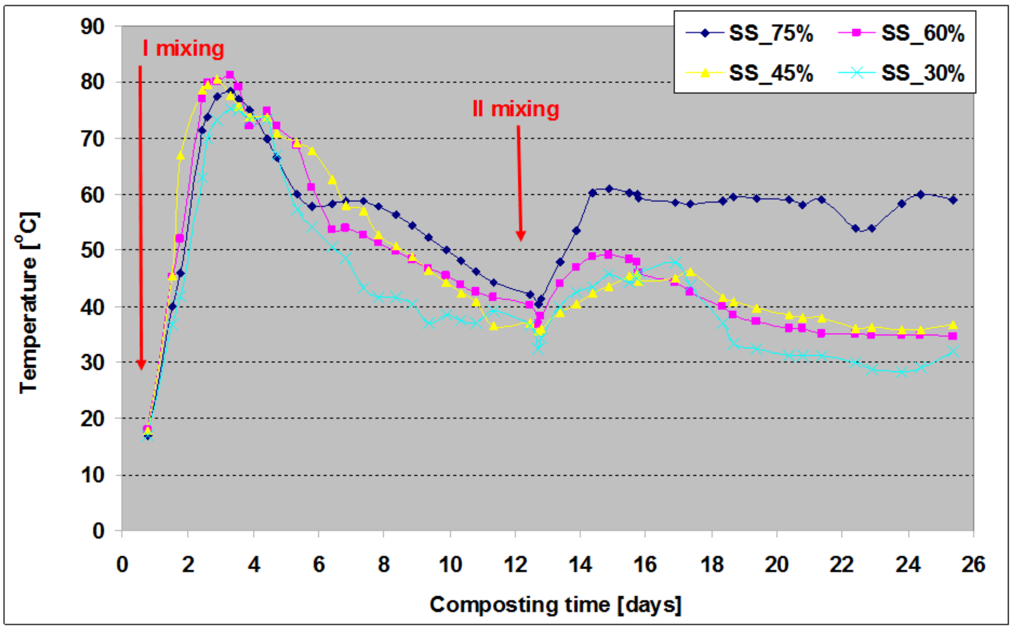

Fig. 2. Temperatures of the mixtures during the experiment

In all four tested mixtures it has been significantly exceeded the level of 70°C, which is considered as an indispensable for hygienisation and sanitation of composted wastes. The highest temperature 81.3°C was achieved on the third day in compost SS_60%. Analyzing the data on Figure 2 it can be stated that in each compost there were all

4 phases of the composting process. An intense thermophilic phase (phase 2) undoubtedly occurred in all four mixtures undergoing the decomposition process under aerobic conditions.

On the 12th day of the process the second mixing took place (simulation of tractor aerator passage throughout composting pile). The aim was to improve the material structure and facilitate oxygen transfer as well as increase of the organic materials decomposition period. And the next day the effects were visible as evidenced by the temperature increase lasting several next days. Definitely the most favorable effect was observed in the compost with the highest content of sewage sludge. This mixture temperature amounted 60.9°C. Since the 22 day of composting process the temperature in all four chambers started to fall down systematically, that proved an initiation of the last composting phase – maturity one (Fig. 2).

Figure 3. presents the course of cumulative temperature for selected mixtures for the whole experiment period. There was kind of dependence between this and the mixtures content. Cumulative temperatures were increasing along with the growth of the sewage sludge content in the mixture (Fig. 3).

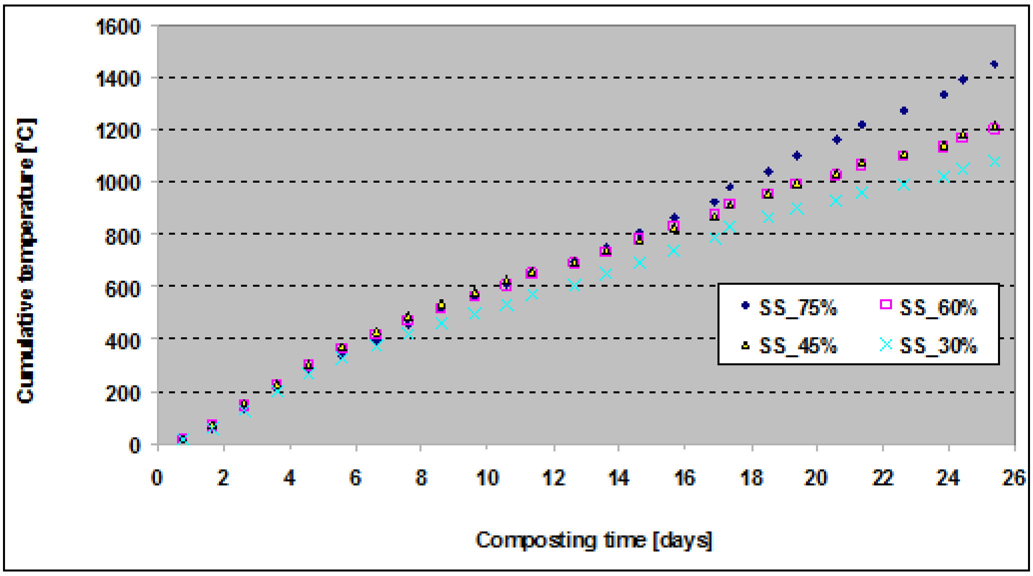

Fig. 3. Cumulative temperature in studied mixtures during composting process

It can be noticed that the strongest increase of temperature was in case of mixture SS_75%, and the weakest for SS-30%. Apparently the mass dominant fraction of sawdust with the lowest nitrogen content did not foster an intense heating of the mixture.

Dynamics of oxygen changes in the bioreactors

The oxygen content is one of a most decisive factors of oxygenic decomposition which is directly related to compost self-heating properties as well as other gases emissions. The proper content of this gas creates the possibility for organic matter decay without fermentation process. Taking into account the nature of this parameter, it was measured twice a day and directly after aeration three times. At the beginning of the experiment its content in bioreactors amounted about 21%, which was identical with its amount in the atmosphere (Fig. 4). Since the second day of the experiment its amount started to decrease rapidly, yet the amount of carbon dioxide was increasing. This is related with the presence of thermophilic phase in composts. Along with the temperature stabilization the oxygen amount was decreasing, which indicated the reduction of time of organic matter decomposition. Stabilization at the level of 19-21% occurred in all chambers on the 23th day of experiment that is along with initiation of maturity phase (Fig. 4).

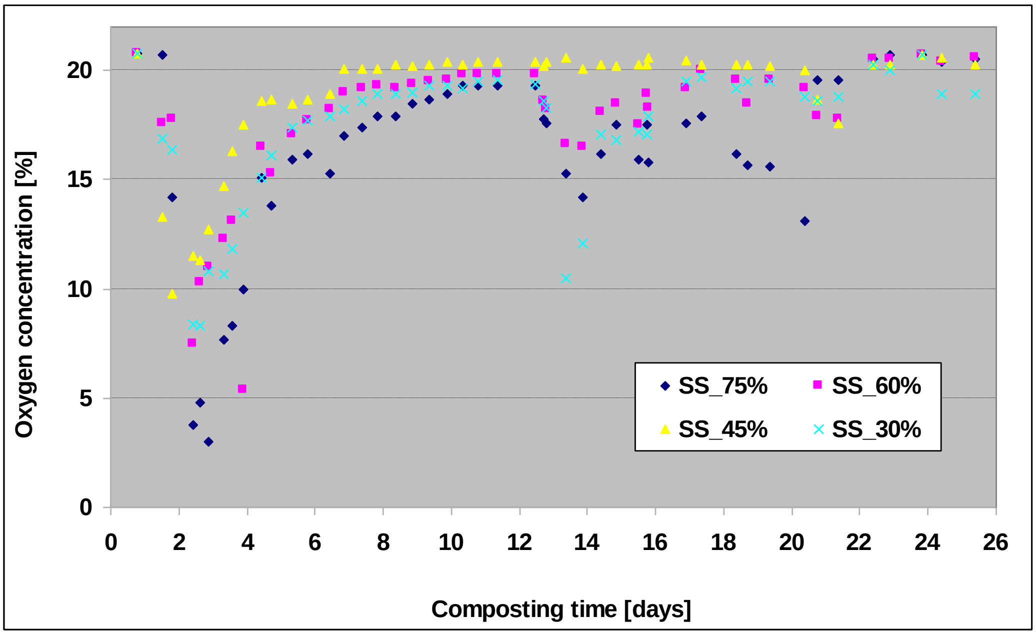

Fig. 4. Oxygen concentration in studied mixtures during composting process

During the whole period of the experiment the air flow was under control, so that there were no anaerobic conditions. The changes depended on oxygen concentration inside the chamber (Fig. 4). The oxygen content level less than 5% was assumed as the beginning of the anaerobic zone, while the level of 8% required more attention. Average air flow amounted between 2.95 dm^3/min for compost SS_75% up to 2.7 dm^3/min for compost SS_30% (Fig. 5 and Fig. 6).

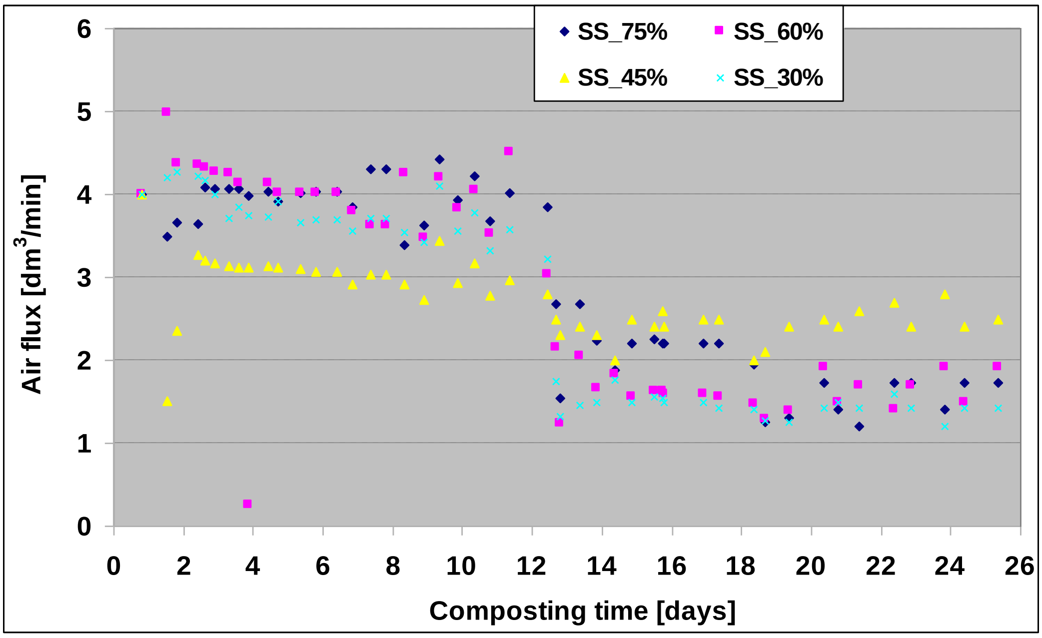

Fig. 5. Air flow daily measurements in studied mixtures

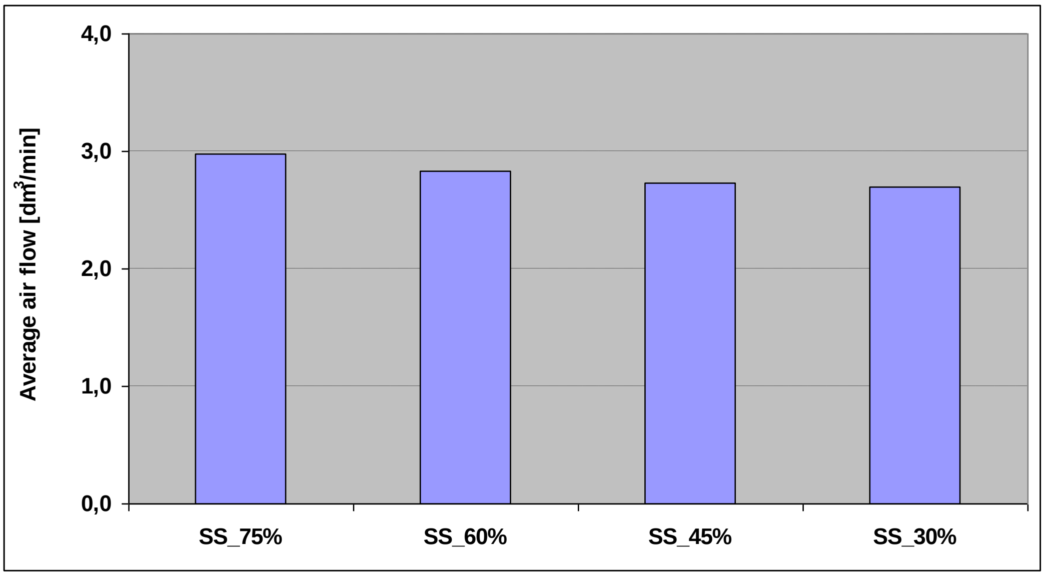

Fig. 6. Average air flow for studied mixtures

Dynamics of CO_2 and ammonia changes in bioreactors

Carbon dioxide emission was caused by organic matter decomposition. Increase of CO_2 in the exhausted gases proves the proper decomposition of sawdust, straw and sludge, the materials with high carbon content. From the moment of maximum temperatures occurrence in all four bioreactors a strong decrease of carbon dioxide was noticed, which graph was exponential. Only aeration made on 12th day of the experiment has initiated another increase in the decomposition intensity, which was proved by the growth of the content of discussed gas in exhausted gases mixture. What is interesting after second aeration the highest CO_2 level, amounting 10.3% was noted in compost SS_30%, the one with the lowest content of sewage sludge (Fig. 7).

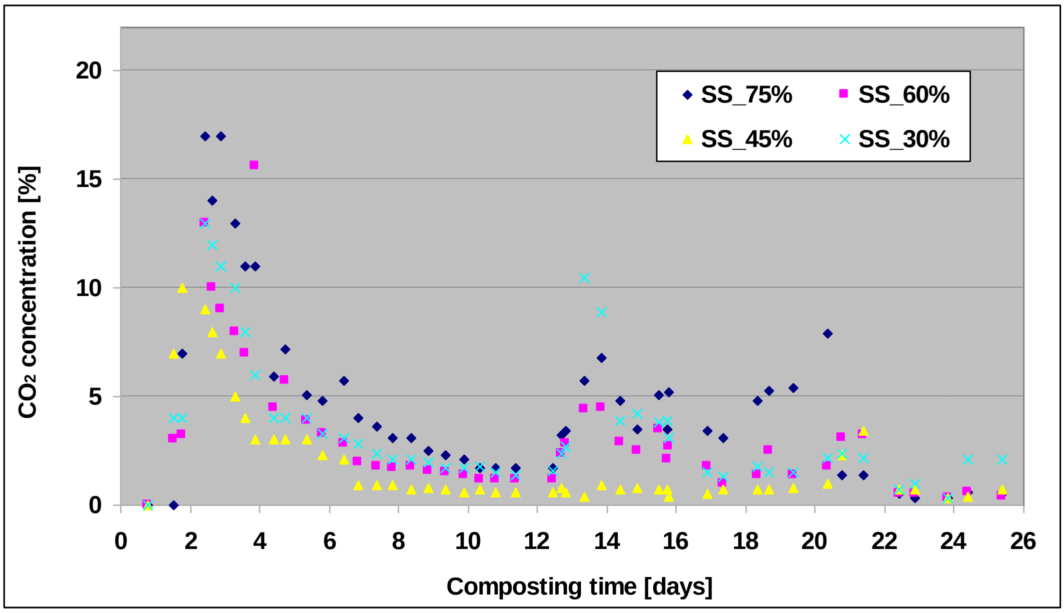

Fig. 7. CO_2 emission in gasses emitted from bioreactors

Ammonia was the last tested gas in the composts. Although the emission range of the discussed gas amounted from 0-1476 ppm its size is an important parameter. It is related with the fact that agriculture is an important producer of ammonia, which passing into the atmosphere makes worse its quality. The emission amount of the discussed inorganic nitrogen compound is closely related to the content of the sewage sludge in the compost. Thus, the highest emissions were recorded in heaps SS_75% and SS_60% (Fig. 8).

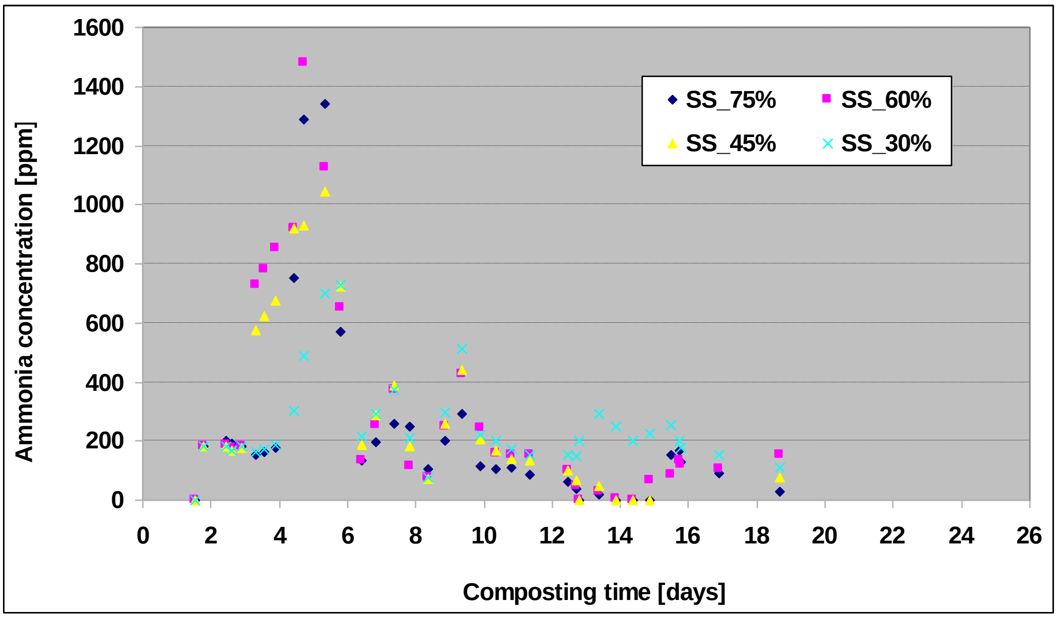

Fig. 8. Ammonia emission in gasses emitted from bioreactors

Similarly as in case of CO_2 emission the highest ammonia emissions were noted during the thermophilic phase and immediately thereafter, regardless the initial mixture. The highest cumulative ammonia emissions occurred in compost SS_60% and the lowest in SS_45% (Fig. 9).

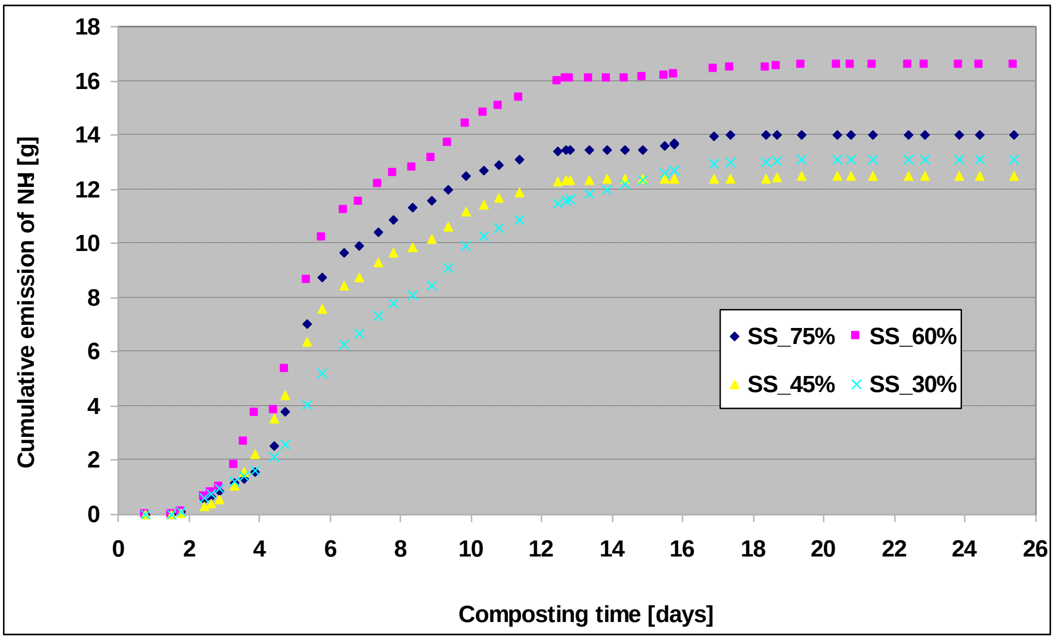

Fig. 9. Cumulative ammonia emission in gasses emitted from bioreactors

It has to be underline that important amount of nitrogen were also found in leakages, especially in case of SS_75% and SS-60%.

Dynamics of changes of composted mixture fresh mass

A typical phenomenon for the composting process is the loss of mass along with the experiment duration. Although the fresh mass of the composted mixtures were significantly different (Table 2), however it was possible to compare the dynamics of changes on the basis of the percentage content before and after the experiment.

The largest mass loss occurred in the compost with the highest content of sewage sludge (SS_75%), which was caused by high water content in this component of the mixture (Fig. 10). In the rest of the heaps there was also a considerable mass loss, however it was not as significant as in compost SS_75%, and amounted at the level of 26-27%.

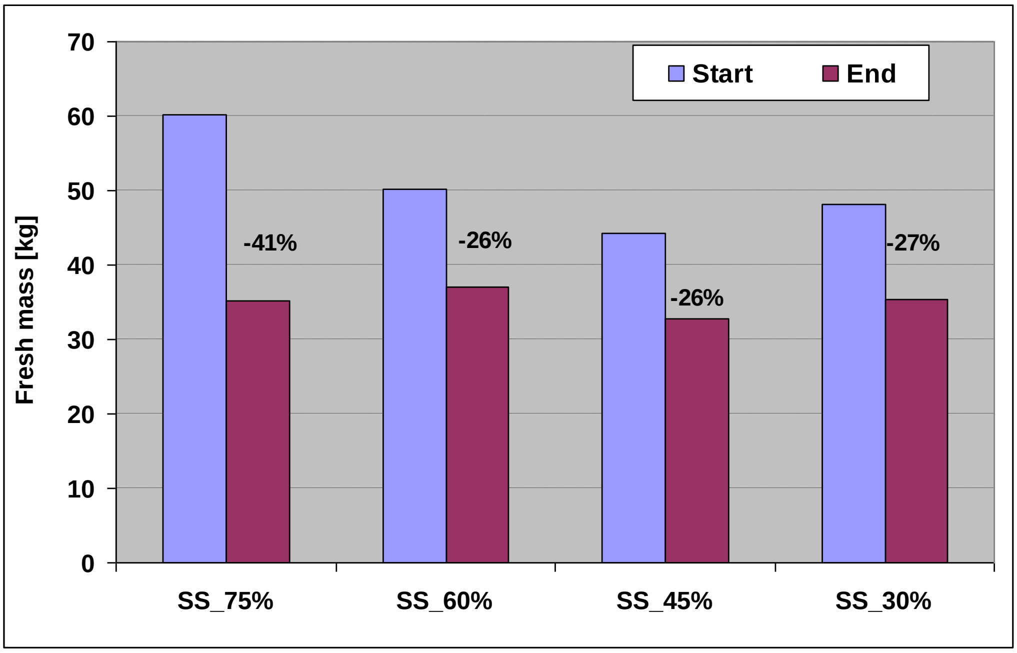

Fig. 8. Strong reduction of the composted mixture fresh mass

The mass losses from composted mixtures occurred mainly throughout gaseous way in consequence of water vaporization and CO_2 emitted during OM decomposition. The leachates collected from bioreactor chambers were lower than 1550 g for all mixtures except SS_30% which produced 2381 g of leachate, mainly during first day of experiment, as a result of strong artificial watering of mixture contained large amount of dry sawdust.

5. Conclusions

On the basis of the research it can be concluded that all studied mixtures have passed through the long and significant thermophilic phase and reached maximum temperature over 75°C. With almost the same aeration level and similar initial dry mass, the cumulative temperature was the highest in SS_75% mixture and the lowest in SS_30% which suggests that sewage sludge content is important factor of compost self-heating.

It was also noticed that the highest cumulative temperature in SS_75% is related with the deepest losses of fresh mass in this mixture by 41%. The mass losses were related with water vaporization and CO_2 from organic matter decomposition. However, the deep fall of oxygen content and strong CO_2 emission during the period of the highest temperature of composted mixtures (between 2nd and 5th day) suggest the needs of higher aeration within initial period of decomposition. The effect of temperature growth after second mixing of composted materials has been also noticed.

The ammonia content in exhausted air was very high in all studied mixtures (from 730 ppm for SS_30% to 1480 ppm for SS_60%). However, the important losses were also found in leachates collected during the experiment.

Acknowledgements

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Analytical and Computational Study of Utilising LSCs Luminescent Solar Concentrators Incorporated With Multi-Junction Photovoltaic Cells in the UAE

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Abstract

To meet future energy demand, it is necessary to focus on renewable resources. The most realistic renewable energy technology that UAE can harness is its year round sunshine. With the variety of solar energy technologies available to generate electric power, the main drawback towards the usage of solar power from photovoltaic cells is the cost of the silicon cells. This paper brings forth a concentrating technology that uses waveguide technology of glass with the application of a coating of thin film organic dye on the surface of the glass and multi-junction solar cells arranged at the edges. The coating absorbs light and re-emits into the waveguide form for the PV cells. The efficiency of the PV cells increases due to this increase in sunlight intensity. This concept is examined with the help of Computational Fluid Dynamics (CFD) analysis on a case study in the UAE, by utilizing the windows as the concentrator.

Keywords: Luminescent solar concentrators, Technology, Organic dye, Multi-Junction solar cell, Photovoltaic, Semiconductor, CFD,

1. Introduction

1.1. Demand for Solar Energy

According to 'Suntech Power' [1], The UAE can outshine the targets set by US and European countries in the production of 20% to 30% energy from renewable resources with the help of solar power. However, it is reasonable to debate that renewable energy will face immense competition from existing highly-subsidized grid electricity generation already established and available in the UAE. As can be seen from Fig. 1 below Dubai is well equipped to meet the demands pertaining to its growth [2].

However with the increasing uncertainty of fossil fuel production, renewable resources need to be exported. Industries are willing to follow the green path in order to gain recognition and secure various benefits obtainable from the Government of UAE. Initial small scale solutions in buildings signify a shift in focus; however, it is imperative to ensure the sustainability and viability of the projects for the given economic situation.

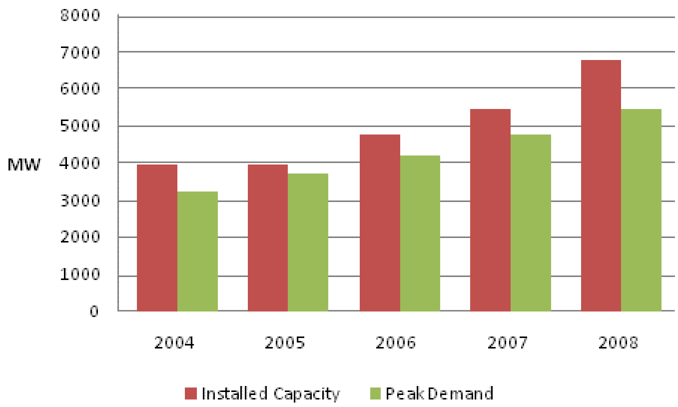


Fig. 1: Generation capacity of power plants and generation at peak demand [2]

Fig. 2 below shows that the demand of electricity in the summer is extremely high when compared to the other months. This is because air-conditioning demands are greater in these conditions. This peak can definitely be reduced considerably with the help of a suitable solar photovoltaic technology especially during the summer when the sun is at its highest intensity. Currently there are 487 existing tall buildings in Dubai, 483 planned buildings, 330 under construction and 34 built [3]. With 1334 tall buildings it is reasonable to conclude that more power is required. Though Dubai has the resources to erect more power grids it is possible to use solar energy to meet this energy demand.

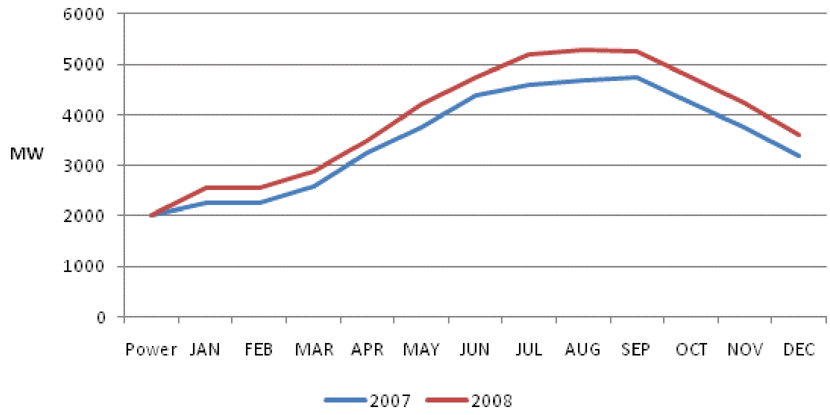


Fig. 2: Energy demand over the months 2007 and 2008 [2]

1.2. Photovoltaic Cells

Photovoltaic cells translate solar energy to electrical energy because of the photovoltaic effect. The photons (packets of energy) in sunlight include energy corresponding to the diverse wavelengths of sunlight. When light strikes upon a photovoltaic cell these photons may pass through, be reflected or absorbed by the panel. On absorption of photons the energy contained in the photon is redirected to an electron contained in the atom of the semiconductor material the photovoltaic cell is made of [4].

General photovoltaic cells contain two layers of silicon wafers doped with phosphorous and boron. The layer doped with phosphorus (called the n-Layer) contains excess free electrons and the layer doped with boron has a tendency to attract electrons (called the p-Layer). Though neutral individually when stacked on top of each other a “p-n junction” is formed due to transfer of electron from the “n-Layer” to the “p-Layer” creating a barrier to prevent more electrons from moving between the layers and also reversing their polarity. This leads to poles, negative for the “n-Layer” and positive for the “p-Layer”. When placed under the sun photons in light strikes electrons in the “p-n junction”, energizing them and knocking out the atoms, thus attracting the electrons to the positive n-layer and repelled by the negative “p-layer” and hence generating electricity [5].

The simplest photovoltaic cell can produce much less energy as it does not fully utilize the entire spectrum of light. Photovoltaic cells are distinguished between each other by the type of the crystal used. As can be seen from Table 1 below, Multi-junction cells boast the highest efficiencies in photovoltaic technology and are best with concentrators, however due to their expense Multi-junction are mostly used in aerospace operations

Table 1: Comparison of various Photovoltaic cells [6] [7] [8]

Type	Material	Lab Efficiency	Electricity Generated
Mono-crystalline silicon	Molten purest silicon	24%	12 W/cm^2 [9]
Poly-Crystalline Silicon	Liquid silicon allowed to form crystals of various shapes	13%	5.75 W/cm^2 [10]
Amorphous Silicon/ Thin Film cells	Silicon film deposited on substrate material	General – 5-7% Developments – 20%	1.34 W/cm^2 [11]
Multi-junction Cells	Multiple layers of thin cells.	40% with 240 (III-V) sun concentration	24 /cm^2 [12]

1.3 Solar Concentrators

Solar photovoltaic technologies have always been undermined because of its cost, long payback time period and its requirement of large empty spaces for the placement of the solar cells. Hence solar photovoltaic technologies can be used. In general, solar concentrators concentrate sun's rays to a region so that the light intensity can be increased. Hence the efficiencies of the solar panels are increased. There are various types of concentrators available for use in today's market. These are shown in Table 2.

Most of these techniques are expensive, unfeasible and very difficult to implement for individual buildings. The structural designs on the top of these buildings make it difficult to install the necessary equipment for such solar technology. However, a solution for this can be found as the Dubai skyline contains large glazed surface areas. Hence, utilizing these windows' vast surface areas to generate electricity efficiently and more economically may be possible.

Table 2: Comparison of various concentrator techniques for photovoltaic use [13]

Concentrator Types	Concentration	Cooling required	Tracking required
Parabolic Dish	1000 suns	Yes	Yes
Round Lens	1000 suns	Yes	Yes
Parabolic Trough	100 suns	No	Yes
Fixed mirror moving focus	100 suns	No	No
Linear Lens	100 suns	No	Yes
Sphere	80 suns	No	No

2. Literature review

Various work on the utilisation of Luminescent Concentrator and Multi–junction solar cells have been carried out. A few journals reviewed for this work are therefore listed below.

Goldschmidt *et al.* [14] demonstrated two independent measures in order to boost the gathering efficiency provided by fluorescent concentrator systems (using combinations of dyes to expand the usable range of the spectrum and for the application of the structure of the photon performing the role of band stop reflection strain in the range of emission of the dyes). Experimentation shows each process to increase the power output of the panels by 3.7 times of the GaInP cell alone.

Van Sark *et al.* [15] presented an overview of the results obtained within the Full spectrum project. A thermodynamic and ray trace model is discussed and verified using experimentation. New dyes and the usage of quantum dots have been proposed that allow a wider range of the spectrum to be utilised effectively. 2 years testing demonstrates LSCs to be a good candidate commercially and recons cost-optimisation study should prove economic viability.

Rowan *et al.* [16] outlined the loss mechanisms of the various Luminescent technologies available and emphasized the role that can be played by advanced materials in order to reduce them.

Currie *et al.* [17] brought forth a single and tandem waveguide with organic solar concentrators projecting quantum efficiencies of more than 50% and power conversion efficiencies of 6.8%. The power output from the cells is increased to more than 10 times without the requirement of any cooling or solar tracking.

Chatten *et al.* [18] discussed the thermodynamic and 3D flux model of Luminescent solar concentrators and experimentally demonstrates the requirement of cholesteric coatings along with dyes and quantum dot doped concentrator slabs for large areas of concentrators for use in applications in windows.

Tanabe [19] reviewed the efforts made towards high efficiency multi-junction Photovoltaic cells solar cells.

Previous research have pointed at the importance of LSCs and Multi-junction cells in establishing solar power as one of the major sources of energy. Though faulty still in its application, LSCs have developed rapidly in the last decade and recently with the inclusion of quantum dots promised to be the greatest breakthrough in solar power technology. None of the research mentioned above has incorporated and analysed the use of LSCs as windows.

This paper proposes LSC technology to the UAE in the form of electricity generating windows in the aim of creating carbon neutral housings through a solar loading model, obtained with the help of CFD analysis, to calculate the power output by obtaining radiation through a LSC window.

3. Background research

3.1. Solar Energy Potential in the UAE

Solar Energy potential can be predicted from the amount of solar radiation that falls on the surface of the earth. The solar power density (amount of solar energy on a meter square area) on surface of the earth depends on the extraterrestrial power density (ρ_0, considered to be 1.353 kW/m^2), the zenith angle (ξ , angle from the outward normal from the earth's surface to centre of sun) and clearness index comprising of, α_{dt}, the direct transmittance of gases except for water vapour, β_{wa}, the water vapour absorptions of radiation and α_p, the transmittance of aerosol. These relations can be formulated as [20]:

$$\rho=\rho_0\cos\xi\left(\alpha_{dt}-\beta_{wa}\right)\alpha_p \qquad (1)$$

The power that can be generated by a solar panel P_{Panel} (of efficiency η) per meter square area as a result of this can be obtained from the equation [20]:

$$P_{Panel}=\eta P \qquad (2)$$

Considering a pleasant day of April – May in the UAE (taking different Zenith angles based on the position of the sun, α_{dt}= 0.7, β_{wa}= 0.05 and α_p= 0.9 [20]), the average power density on the surface is 510 W/m^2, with the peak power density reaching almost 800 W/m^2 (Fig. 3).

Sun power on the panel, $P_s = \rho A$, where A is the panel area. Thus the power generation from the solar panel, $P_{Panel} = \eta P_s$, where η is the efficiency of the solar panel [20].

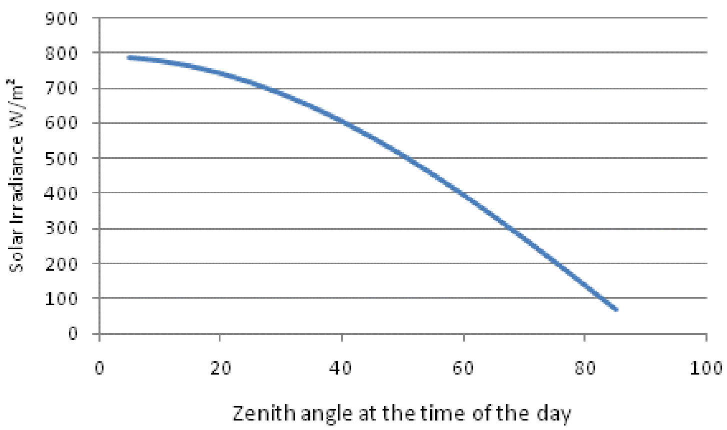


Fig. 3: Solar irradiance on the surface of the earth

Research done by the Petroleum Institute's Department of Mechanical Engineering in Abu Dhabi [21] confirms that the "daily average solar radiation data recorded from one minute average" is more than 400 W/m^2. The highest daily average direct beam was recorded to be 730 W/m^2 on March 30 where as one minute maximum of 937 W/m^2 was recorded on February 22 (Fig. 4). These figures suggest extensive solar energy potential in the UAE.

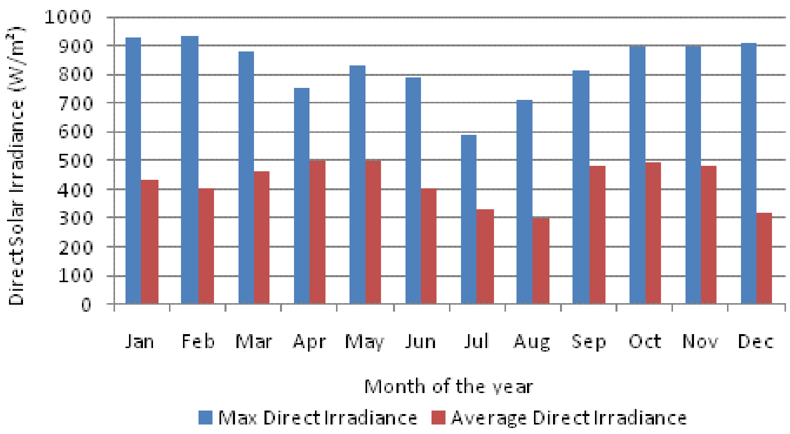
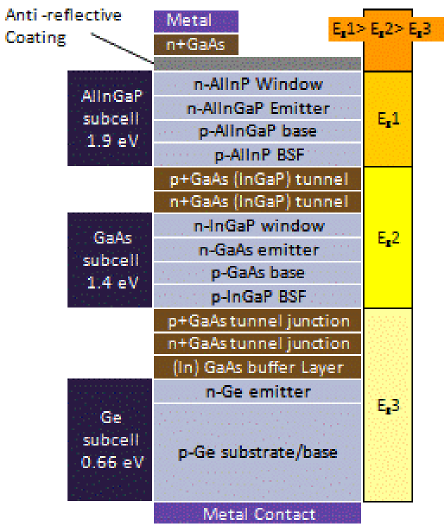


Fig. 4: Solar Irradiance observed over a period of a year for the year 2009 [21]

3.2 Multi-junction photovoltaic cells

Multi-junction photovoltaic cells offer high-performance scientific development passageway for low cost electricity generated by concentrating sunlight. These photovoltaic cells consist of several thin films/layers that allow them to confine more solar spectrum to translate to electrical power. Semiconductors have a distinguishing band gap energy that allows absorption of light (electromagnetic radiation) very efficiently for a certain colour (spectrum portion). These semiconductors are needed to be cautiously selected to take up most of the spectrum of sunlight, leading to higher electricity generation [19].



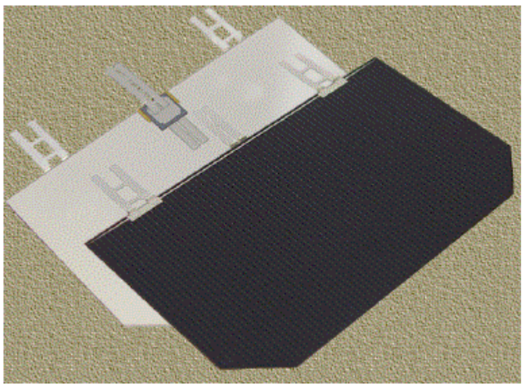


Fig. 5: GaInP2/GaAs/Ge Photovoltaic cell [19]

Multi-junction PV cells use numerous layers of PV films, made of differing alloys of III–V semiconductor material. The band gap of each layer can be adjusted to allow the absorption of a specific band of electromagnetic radiation from the sun. However, it should be ensured that each layer is lattice matched to the other. The Layers are aligned optically in series with the largest band gap material on top. The top layer receives entire range, the photons with band gap higher than the layer are absorbed and the rest is channelled through to the lower layers [19].

The best known and available Multi-junction cells for terrestrial use are produced by "Spectrolab" called Ultra Triple Junction (UTJ) solar cells consisting of $In_{0.56}Ga_{0.44}P$ / $In_{0.08}Ga_{0.92}As$ / Ge layers (Fig. 5). Tests have shown such cells to provide efficiencies of 40.7% with a concentration level of 240 [19] suns and a general efficiency of 24.3 % [22].

3.3. Luminescent Solar Concentrators

Luminescent Solar Concentrators (LSCs) are a type of Concentrating Photovoltaic devices. Without focussing the rays of the sun onto the cell (like solar trackers), LSCs trap the rays and carry them to the Photovoltaic cells utilising waveguide technique. Thus there are no moving parts; this reduces the expenses of installation and running costs. Also this technique does not cause severe heating of the cells which reduces the efficiency and cause damage to the cells [14]. LSCs are generally compiled with sheets of plastic/glass having dyes and then stretched within its frame; this in effect demonstrates one thin – solar cell. Working of LSCs is similar to optical fibres. The dye takes up inward solar radiation, and then re-emits it. The light which is re-emitted is contained in the plastic/glass sheet because of "total internal reflection". This helps guide light towards the circumferential Photovoltaic cell [15].

Plastic LSCs causes the trapped light to be reabsorbed, so the light is lost as heat. [17] The greater presence of molecules of the dye more light is lost as heat. Spraying a glass sheet with combination of dyes and "tris (8-hydroxyquinoline) aluminium" can alleviate this deficiency (Fig. 6). This combination of dyes and glass acts as waveguide. Also the interface linking the dissimilar dye molecules and "tris (8-hydroxyquinoline) aluminium allows a quantum-mechanical phenomenon – Foster energy transfer" [17] [16], eliminating re-absorption losses by making sure that the light which is re-emitted at certain regularity which the dye cannot re-absorb.

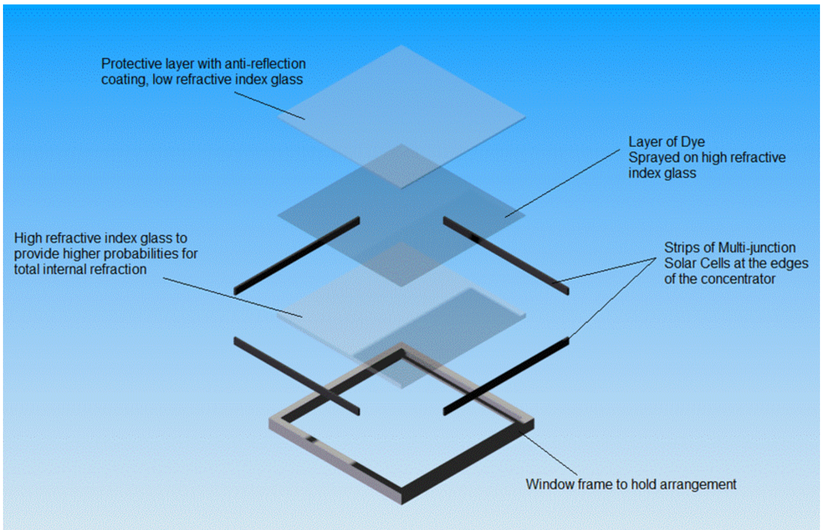
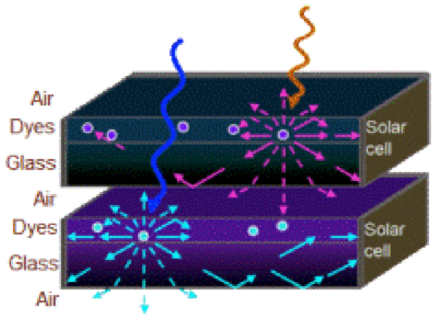


Fig. 6: LSC Configuration

Recent research has concluded that the best combination of the dyes and "tris (8-hydroxyquinoline) aluminium is 5.9× 10^{-6} m thick film – 2% DCJTB and 4% Pt (TPBP) in ALQ_3" [17]. This concentration is chosen to minimize concentration quenching of photo-luminescent efficiencies. The thickness is adjusted to obtain the desired optical absorption. Film thickness and deposition rates need to be controlled using quartz crystal monitors. A recent study has shown that 74.5 % of the solar spectrum can be absorbed [16].

With reference to Fig. 7, the efficiency of the system can be further improved by placing another layer of the previous configuration below the top layer.



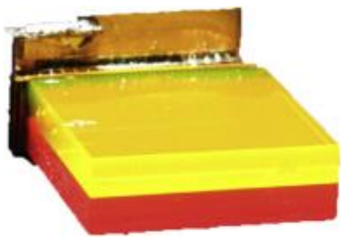


Fig. 7: Physical Configuration of a double layered OSC [14]

The top layer of the LSC absorbs high-energy light. The lower layer of the LSC absorbs longer wavelengths which pass at ease through the top layer. Also, any lower-energy light re-emitted from within the top layer of the LSC and someway escaped can be used by the lower LSC. Even as a prototype this technique has proved to convert "ten times more of the incident light into electricity in comparison to a conventional photovoltaic cell" [18].

4. Case study: Royal City

Royal City Contracting are a G+1 (ground + first floor) licensed construction company involved in all forms of building and turn key projects in the UAE, with a vision to be the most desirable partners for the construction industry. In partnership with the Emirates Green Building Council (EGBC) Royal City Contracting are involved in various projects all over the UAE to establish green buildings boasting an elite research and development section.

4.1 Dr. Matar Villa Project

Based in Oud Al Muteena Second in Dubai, it is one of the first projects in the UAE to use eco-blocks to build the structure. Eco-block is a type of Insulated Concrete Forms (ICFs) that consists of two panels of polystyrene foam as insulation held together with recycled nylon or metal webs. (Fig. 8) The gaps in the eco-block are filled with concrete and the structures are built. The eco-blocks have been proven to have generated 50% energy savings and reduced HVAC requirements to 30% [23]. Other advantages of eco-block include high tensile strengths, quieter, high resistance to fire, moisture, mould and elements but providing a positive ecological impact.

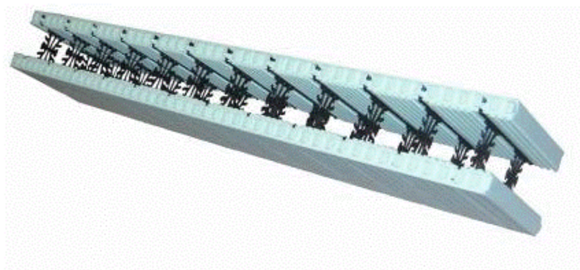


Fig. 8: Eco-block ICFs

Already in the path way for a greener society, Royal City Contracting aim to create a carbon neutral building in the harsh conditions of the UAE. Thus study helps to see the implications of the Luminescent Solar Concentrator as windows of the villa and thus further reduce the HVAC requirements with the help of CFD analysis.

5. CFD Setup

The CFD model was developed using FLUENT package of ANSYS 12.1. The software uses Finite volume method and employs “Semi-Implicit Method for Pressure-Linked Equations solver algorithm”. Standard K-epsilon model (governed by Navier-Stokes and energy equations) was used to demonstrate the turbulent flow pattern.

5.1 Geometry Modelling

The geometry of the villa was constructed using GAMBIT (FLUENT pre processor) and the dimensions for the villa were obtained from Royal City Contracting. Apart from the villa geometry an external geometry has been created all around the villa to apply environmental conditions and air flow conditions which will affect the temperature conditions and the solar loads on the villa. Fig. 9 shows the actual villa project at 'Oud Al Muteena' and the graphics created using Gambit are shown in Fig 10.

Fig. 9: Oud Al Muteena Project

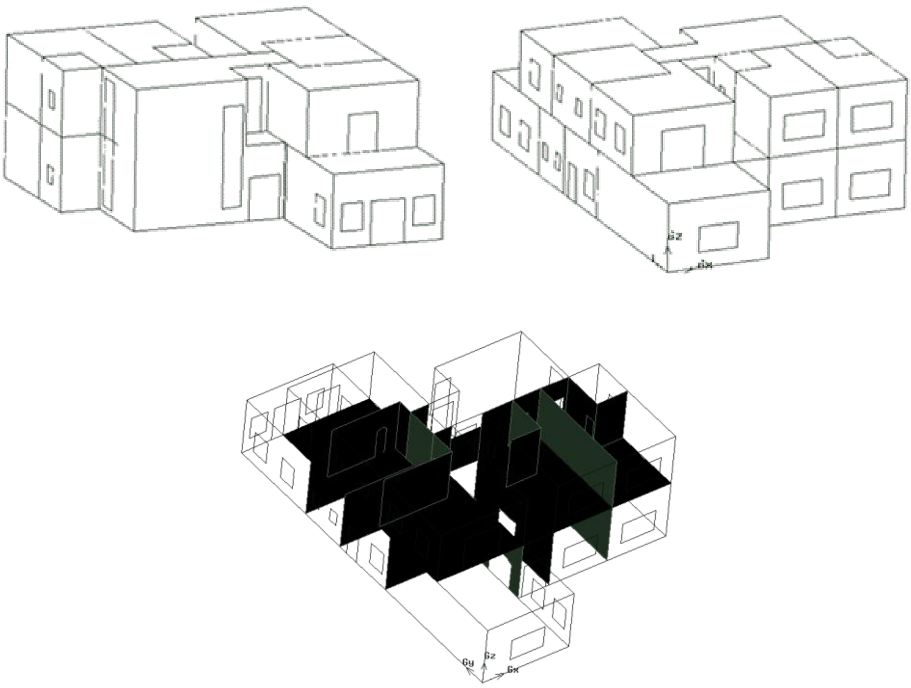


Fig. 10: Geometry construction in GAMBIT

5.2 Geometry Meshing and Boundary Conditions

Tetrahedral mesh type was used to create the mesh for the villa. The dimensions of the villa are in millimetres hence a mesh size of 200 was used to mesh the rooms of the villa and a mesh size of 800 was used to mesh the environment. Table 3 lists the nodes and elements of the mesh for the model. Fig. 11 shows the meshed model.

Table 3: Model Mesh Data

Domain	Nodes	Elements
Environment	54533	278932
Villa	18491	85035
All Domains	73024	363967

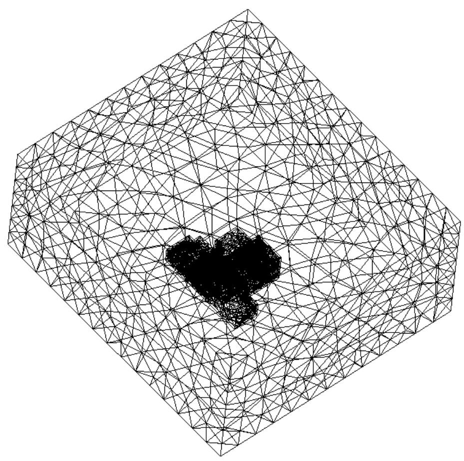


Fig. 11: Meshed Model of The Villa and Environment

Inlet conditions (Velocity Inlet) are set to be 4.5 m/s for velocity flow and 315 K as ambient air temperatures. Outlet set as pressure outlet kept to ambient temperature 315 K. The walls for the villa are set according to the properties of eco-block, density – 2560 Kg/m^3, Specific heat capacity – 1400 j/ kg K and Thermal Conductivity 0.26 W / m K and are set to a temperature of 300 k to show air-conditioned state. Doors are set to default wood from the fluent database. Finally the windows are set as tinted glass as per CIBSE guide to represent the concentrator, density – 2400 Kg/m^3, Specific heat – 840 j/ kg K, Thermal Conductivity – 1.45 W / m K average incident irradiation set as 510 W / m^2. Boundaries set, the solar load on the model are obtained for 10000 Iterations. [24].

6. RESULTS

6.1. CFD

On compilation of the analysis the following results were obtained via CFD-POST module of ANSYS 12.1:

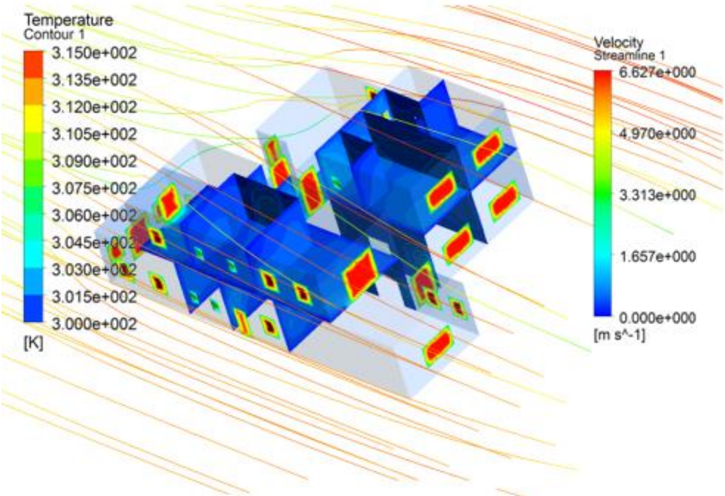


Fig. 12: Velocity Profile and Temperature Contours of the Model

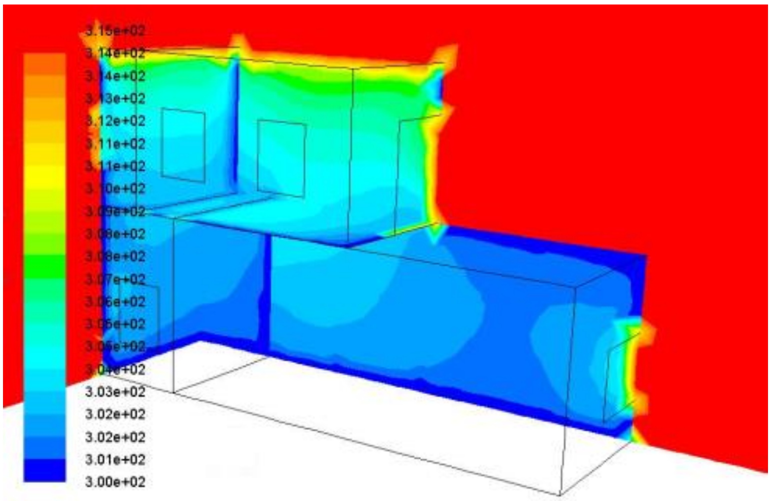


Fig. 13: Temperature Contour Profile at Villa Intersection

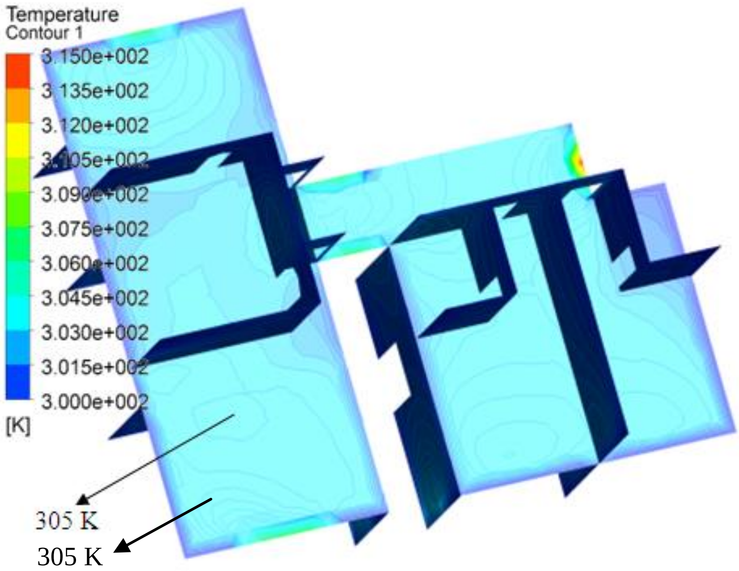


Fig. 14: Temperature Contour Profile in the Interiors of the House

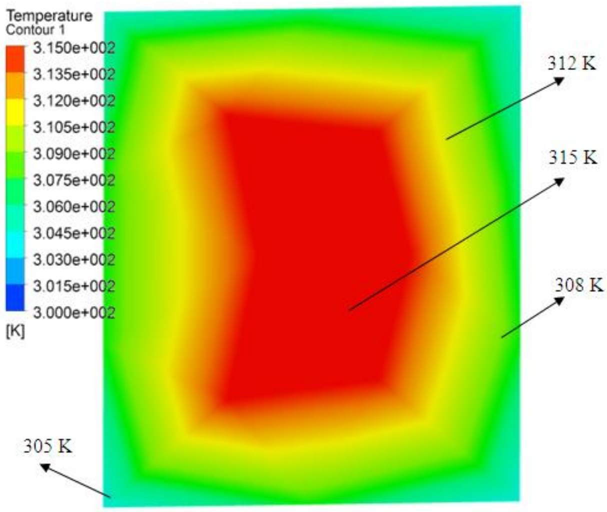


Fig. 15: Temperature Contour on Window Face

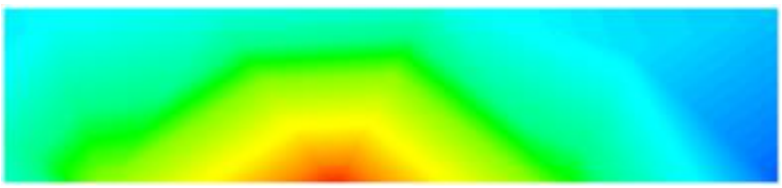


Fig. 16: Temperature contour through window thickness

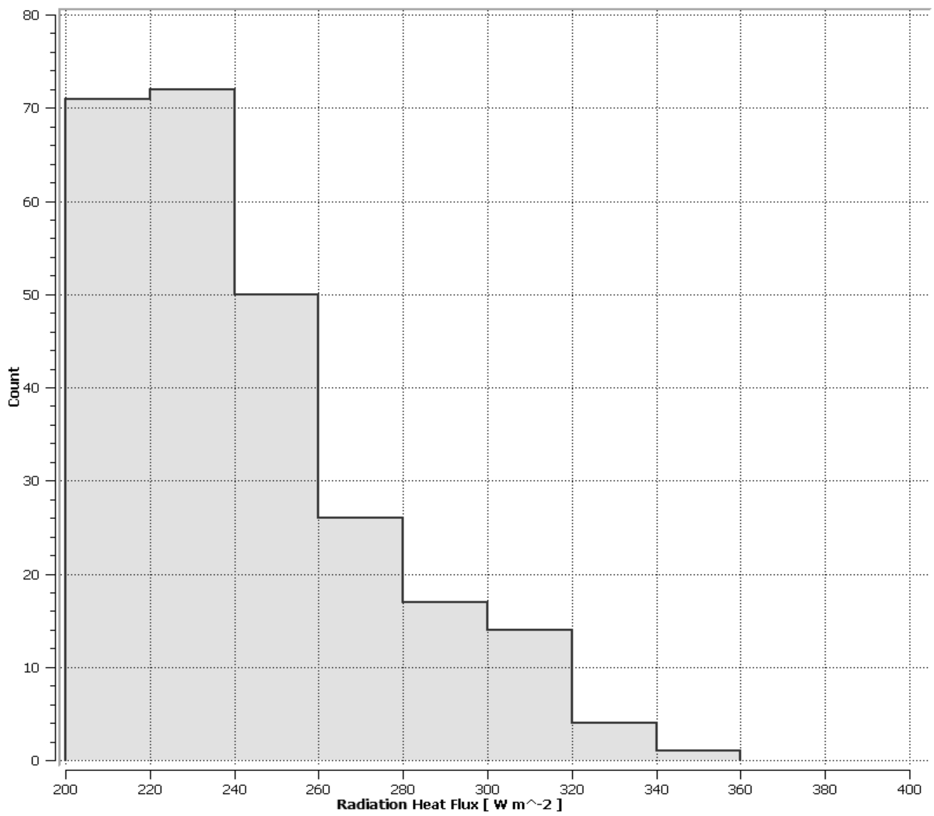


Fig. 17: Radiation on Window Surface Inside the House Over a Day

6.2 Energy Generation

The solar intensities for the Zenith angles are obtained and tabulated in Table 4. While the average daylight hours data recorded in UAE for the duration of one year is tabulated in Table 5.

Table 4: Cell Area and Window Face Area for Villa

Window	Cell Area (m^2)	Window Face (m^2)
W1	0.324	8.28
W2	0.264	6.05
W3	0.228	6.3
W4	1.188	19.8
W5	0.423	3.84
W7	0.780	18

Table 5: Average daylight hours in the UAE [21]

Month Average	Daylight hours
January	10.6878
February	11.20107
March	11.88231
April	12.59827
May	13.19577
June	13.47368
July	13.33593
August	12.82337
September	12.10818
October	11.39402
November	10.80012
December	10.53767

Efficiency of solar panel = 24.3% [22]

Average insolation on outer window surface = 510 W / m^2

Average insolation on the inner window surface = 220 W / m^2

Percentage usable are of LSC = 56.8 %

Fig. 18 shows the power generation of the PV module with and without concentrators.

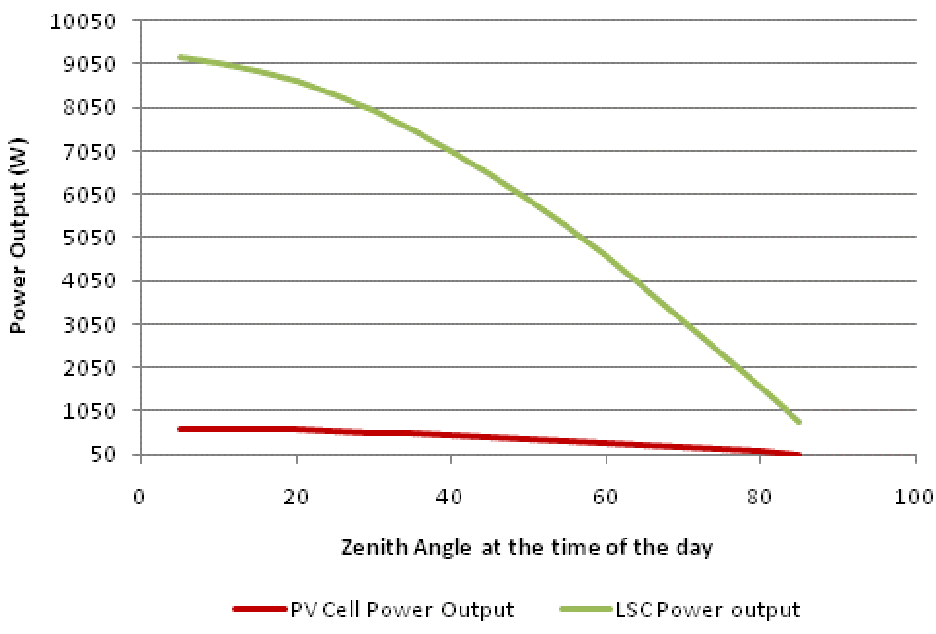


Fig. 18: Variation in the Power Generation using only PV Cells (lower curve) and With the LSC Unit (higher curve)

7. Discussion

7.1. CFD

The CFD analysis has been carried out to effectively establish the solar loads on the windows of the villa. Light is incident on the windows of the villa, however light is also reflected off the surface of the walls inside the villa. This phenomenon is taken in to consideration in the CFD solar load analysis. Because of the well insulated eco-block design the main sources of heat in the villa is the windows and doors. This is clearly seen from the orientation of the contour lines in Fig. 12, 13 and 14. Fig. 12 also shows the velocity profile on the villa and the legend to demonstrate the velocities on the villa. The colours showing the change in temperature can be seen from the legend on the figures Red contour is at a higher temperature than blue. The heat can be seen spreading out from the windows and doors to the interiors of the room. The average temperature in the house comes to 305 K. Focusing on the windows, the temperature is higher at the centre of the window face and recedes as it moves to the outside edges. This trend shows the absorption of energy by the edge material (Fig. 15). Fig. 16 shows the heat absorption by the window thus causing lower HVAC requirements already by providing tinting effect. CFD post determines the radiation flux on the window surface. The solar radiation flux on the outer face of the window was set as 510 W / m^2 and as per results the average radiation flux on the inner face of the window is 220 W / m^2. Consider the window to be a black body due to the application of anti reflection coating it is safe to assume that 290 W / m^2 of the radiation can be utilised for solar energy generation.

7.2. Electricity Generation

Considering the window as a black body, 510 W / m^2 radiation falls on the window surface and an average of 220 W / m^2 of the radiation is on the inner face of the window. Then 290 W / m ^{2} are usable for energy generation i.e. 56.8% of the incident light. Thus for the LSC system the area can be used ro multiply the power generation of the PV panel by a factor of 1.568.The amount of electricity generated also depends on the sun hours available. On an average the sun hours available is minimum of 10 in the UAE (table 5 section 5.2) [21], however factors such as clouds, shade etc disrupt the available sun hours, hence for calculation purposes 8 sun hours have been taken into consideration. Based on the above estimate and section 4.2 the daily average electricity production using simply the solar panels is 3.283 kW. However, using the same panels in the LSC configuration can generate 36.216 kW of electricity.

7.3. Model Validation

A model was created to explain the working of the concentrator and the orientation of the solar panels with the concentrator (Fig 19). The model is a magnified version of actual model. The layers of coloured plastic sheets are acrylic sheets which demonstrate the concentrator property of total internal reflection to the edges of the sheet, 6 cm x 6 cm solar panels available readily in the market was used and the items brought together with the help of wire meshes. Primary testing results demonstrated that unless the light source is directly on top of the concentrator combination the power output obtained is lesser than that is already produced. This can be attributed to the shadows that are formed due to the various layers. In the actual model the layers are much touching each other and a maximum of 3 layers of dyed glass may be used.

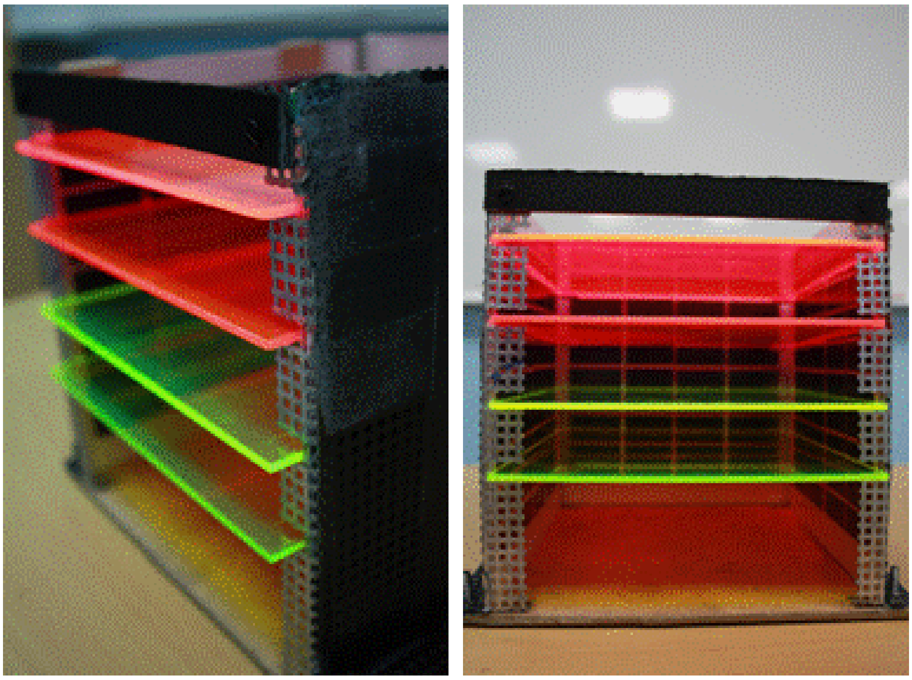


Fig. 19: Concentrator prototype, orientation

8. Conclusions

Close examination of the results concludes that Luminescent Concentrators increased the efficiency of the solar panels to a great extent. Especially in the UAE where blocking out the sun is high priority especially in the summers, the concentrator may also double up as tinted windows. 56.8% of the incident light on the concentrator can be used for the generation of electricity saving the cost to cover up half the area of the total window area with solar panels.

The validation of the model is required to be made with the help of a full scale model testing. This will affirm the credibility of the substantial increase in the overall efficiency of the Luminescent Concentrators technology. Furthermore a more analytical solution can be provided with a higher accuracy of the technology.

Acknowledgement

I would like to express my sincere gratitude to The Emirates Green Building Council and Royal City Contracting for their permissions to use some parts of their premises for data collections and analysis.

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DAY 10 - 9:30		
Room 613 - Environmental and Social Impact Assessment 1		
An integrated modeling approach for greening commuters' transportation and parking	Luis Cruz[1]; Fausto Freire[2]; João-Pedro Ferreira[1]; Eduardo Barata[1]	[1]GEMF, Faculty of Economics, University of Coimbra; [2]ADAI-LAETA, DEM, University of Coimbra
Reducing energy use by dialogue marketing. A combined approach for mobility and households' energy use	Reinhard Hössinger[1]; Christoph Link[1]; Ulrike Raich[1]; Wiebke Unbehaun[1]	[1]Institute for Transport Studies, Department of Landscape, Spatial and Infrastructure Sciences, University of Natural Resources and Life Sciences Vienna, Austria
Wind Energy and local community perceptions	Fátima Lima[1]; Paula Ferreira[1]; Filipa Vieira[1]	[1]University of Minho
Economic, social, energy and environmental assessment of inter municipality commuting	João-Pedro Ferreira[1]; Pedro Ramos[1]; Luis Cruz[1]; Eduardo Barata[1]	[1]GEMF, Faculty of Economics, University of Coimbra
Evaluation of Post-2012 carbon policies	Dr. Olga Diukanova[1]	[1]Foundation for the Development of Environmental and Energy Markets

An integrated modeling approach for greening commuters' transportation and parking

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Abstract

This study uses an integrated modeling approach to support the derivation of contributes and recommendations regarding more adequate traffic and parking management policies. The area considered is the University of Coimbra Campus, which has an outstanding artistic and architectural value but to where a large number of commuters travel daily causing high socio-economic and environmental costs. The quantitative and qualitative analysis of the campus' situation allows for the understanding of different impacts on parking and traffic inside the UC Campus that may occur with the introduction of specific measures. Improvement opportunities identified suggest that an effective control of illegal parking may contribute to reduce nearly 10% of GHG emissions, and that different forms of modal shift from private cars towards public transportation can contribute to emissions reductions above 50%. Further, the survey's results revealed the commuters' availability to participate in the collective effort to tackle traffic and parking problems at the UC Campus, therefore challenging the authorities to take action, adopting the measures required. Finally, this comprehensive approach is illustrative of the importance that integrated traffic and parking management measures can have for greening commuters' transportation and parking in urban areas.

Keywords: Transport Demand Management; Parking; Commuting; Life-Cycle Assessment; Travel Mode; Public Transport.

JEL codes: Q4 – Energy; Q5 - Environmental Economics; R4 - Transportation Systems

1. Introduction

Transport Demand Management is a critical urban strategy which is mostly applied with the aim of rebalancing the modal split between private car and alternative public transport systems. Often, the management of parking places can constitute one of the critical elements to change behaviors, supporting the move from individual/private car use towards collective/public transports. Thus, parking is a central topic in urban transportation planning and traffic management (Verhoef et al., 1995; Marsden, 2006; Shoup, 2006; Waters et al., 2006; McCollum and Yang, 2009; Davis et al., 2010; Lior, 2010). Cars cruising for parking further exacerbate traffic congestion, origin accidents, waste fuel and other resources, pollute the air, degrade pedestrian environment and restrain levels of accessibility (Arnott and Rowse, 2009; Shabbir and Ahmad, 2010).

The provision of parking constitutes one of the most troublesome transportation problems at many universities campuses (Balsas, 2003; Shang et al., 2007; Alshuwaikhat and Abubakar, 2008) and the University of Coimbra (UC) campus (Polo I), in Portugal, with a large number of commuters travelling to University campus using their own car, is not an exception.

The University of Coimbra is positioned on a hill overlooking the city and the Mondego river, and comprises a cluster of historical buildings, which has grown and evolved over more than seven centuries, and which unquestionably constitutes its own noble and well-defined urban area within the city. The need to ensure a balance that does not jeopardizes the normal fruition and preservation of these cultural heritage goods constitutes a challenging research agenda. Barata et al. (2011) offer a first and important contribute in this endeavour, establishing solid basis for further analysis regarding the assessment of integrated parking management policies. The current paper intends to go beyond establishing additional contributes addressing another important dimension of this challenge, namely assessing environmental impacts associated with changes in traffic and parking management within the UC campus.

Accordingly, this study explores the importance of integrated parking management policies with two main ambitions: first, to characterize and confront supply and demand for parking at the UC Campus, supporting the derivation of specific contributes and recommendations regarding more adequate traffic and parking management policies; and, second, to assess potential environmental impacts associated with possible corresponding changes in traffic and parking management.

For this an 'integrated modelling approach' is used, combining, among others: an *ad-hoc* computation process concerning the existing places available for parking, their location and characteristics; the analysis of reports from the local transport authorities and semi-structured interviews of their managers concerning the analysis of road public transport services supply and characteristics; the counting of traffic flows in order to estimate demand; the creation and implementation of a survey regarding commuters' characterization and their answers to potential measures towards car use abandon and/or increases in public transportation; and a Life Cycle Assessment (LCA) approach focused in 2 types of Life-Cycle (LC) impacts, namely primary energy and greenhouse gas (GHG) emissions. The analysis is structured as follows.

Section 2 provides a quantitative and qualitative analysis of the situation regarding parking demand and supply, as well as on the use of public transport services, within the UC Campus. Section 3 presents the main methodological issues regarding the calculation of LC energy requirements and GHG emissions associated with the alternative scenarios to address potential changes in parking and traffic policies. Section 4 concludes.

2. Supply and Demand for Parking and the use of public transportation

This section briefly characterizes supply and demand for parking at the UC Campus, with the aim of allowing for the understanding of different impacts on parking and traffic inside the UC Campus that may occur with the potential introduction of specific measures. For this, regarding supply, an analysis was made concerning the existing places available for parking, their location and characteristics. Accordingly, the number of available parking places by type, as well as the number of (electric and diesel) buses that serve the Campus, is presented in sub-section 2.1. Demand characterization requires a more detailed analysis, with the aims of identifying peak congestion periods, as well as the type of parking places preferred by those who try to park in this area. The most relevant results regarding demand characterization, as well as their appraisal against supply, are offered in the sub-section 2.2. In sub-section 2.3 are presented some of the most relevant components of the survey applied, in order to allow for the socio-economic characterization of UC campus commuters and to evaluate their (actual and potential) travel options.

It is worth to note that the elements to be offered in this section are confined to what is considered to be more relevant regarding the understanding of different impacts on parking and traffic inside the UC Campus that may occur with the introduction of specific measures that will be identified and assessed in section 3. Those interested in further details on the methods followed and results achieved regarding supply and demand for parking, as well as in a more comprehensive and detailed analysis of the survey implemented can see Barata et al. (2011).

2.1 Supply of Parking Places and Public Transportation Services

Regarding parking at the UC Campus, the results of an *ad-hoc* computation process concerning the available parking places within the study area can be found in Table I. The figures are displayed according to the various types of parking places identified.

Table I – Parking places available at the UC campus

Type of parking places	Number of places	% of total supply
Free parking (legal)	484	35.8
Reserved parking for occasional non-UC staff, and for people with disabilities	25	1.9
Conditional parking access for UC staff (distributed through six sites)	574	42.5
Non-regular parking[1]	136	10.1
On-street paid parking	132	9.8
Total	1359	100.0

These data show that more than 45% of the parking places are free of charge. Parking places with conditional access to UC staff are managed by the university administration. On-street paid parking places, all located at Padre António Vieira Street, are managed by the Coimbra City Council.

Besides the supply for parking places, the supply of road public transport services in the Campus was also estimated. According with information available through the local transport authority, there are 117 (approximately 80% diesel and 20% electric or trolley) buses per day that flow through the Campus, running an average path of 1.7 km and altogether travelling nearly 149 Km per day. Then, the values obtained were projected to one year according with the provision of bus services (distinguishing the periods of the academic year with and without classes).

2.2 Demand for Parking Places

The estimation of demand for parking is not as straightforward as for supply. Vehicles that circulate and park at the Campus should be considered to explain the corresponding demand for parking. Accordingly, the empirical approach selected to describe, and quantify, the parking demand at the UC campus was the counting of traffic flows. For this, the inflow and outflow of vehicles was computed in order to assess the quantitative dimension of the potential parking problem at the UC Campus. The idea is that the volume of vehicles coming in and out, in articulation with the parking average occupancy rates, can be used to evaluate, at a specific moment in time, how many vehicles might be (potentially) benefiting from a specific type of parking place on campus. It is important to mention that different parking options are also associated with different travelling distances inside the Campus.

Regarding the demand for the parking sites with conditional access for UC staff, average occupancy rates reveal that those parking facilities are not totally saturated, varying from 59,1% to 86,9% among the six sites. Furthermore, the modelling approach used indicate that, on average, the supply saturation for each type of parking places is expected to be achieved as follows: free places by 8:30-8:40, parking at non-regular spaces by 9:00-9:10, and on-street

[1] It is worth note that there is a generalized practice of occupying non-regular spaces, assuming the risk of being fined. Nevertheless the current parking control level at the UC campus is sporadic and drivers are expected to have the perception that the risk of being fined is very low. Indeed, during the period this study took place, not a single situation of parking intervention by authorities was noticed.

paid parking by 9:20-9:30. Average numbers also indicate that nearby 8:00 a.m. parking demand grows faster, ascending to a maximum near 9:00 a.m., and then declining until 10:00 a.m..

The counting process was also used in order to estimate total in-flows of cars in the UC Campus and associate each car to a specific occupied parking place and to the path travelled inside the Campus (and corresponding distance). Accordingly, it was estimated that approximately 5 500 cars enter the Campus every day, travelling approximately 7 600 kilometres per day (and nearly 1 640 000 kilometres per year).

To sum up, comparing supply and demand estimations, the results indicate that the parking facilities are underpriced and that there is overcrowding. Actually, at the early morning hours the parking places are fully occupied, or nearly, while many drivers continue to enter the Campus searching for something that they can hardly find. Moreover, while searching for a parking place, drivers continue to consume fuel, pollute and mischaracterize an area with outstanding artistic and architectural value (confirmed by an ongoing candidacy to UNESCO world cultural heritage site). This conclusion is strengthened by the circumstance that non-regular parking has actually become a ‘valid parking alternative’ (inducing even more externalities).

2.3. The Survey

Further, a survey regarding commuters’ characterization and their answers to potential measures towards car use abandon and/or increases in public transportation use was built and implemented by the authors. The survey form was organized in two groups that include questions about mobility characteristics and the respondent him/herself.

The group of questions, about UC campus users’ mobility considers issues relating to the number of weekly commuting trips, arrival time on each day, the frequency of public transport use (last month) and the predominant transport mode. Depending on the transport mode most used by the respondent there were made a different set of questions. Those who indicate the predominant use of private car were asked, among other issues, how much they would be willing to pay for having guaranteed parking on campus, and (by hypothesis or not) in the case of having access to conditional parking, how much they would accept to receive as a compensation for giving up of this privilege. Further, those usually going by car were also asked about the value of the city's urban transport pass free percentage that they would be willing to consider as ‘enough’ to make then change the transport mode towards the public service. The idea is that this process further allows the study of commuters’ reaction to potential suggestions that have emerged regarding the attribution of a price to parking (Tolley, 1996; Kadesh and Roach, 1997; Brown et al. 2001; Balsas, 2003; Shang et al., 2007; Vadas et al., 2007; Anastasiadou et al., 2009; Khodaii et al., 2010).

Concerning the regularity of commuting travels to the UC campus, from the sample of 217 individuals, 75.6% have reported travelling five or more days per week and 14.7% four days per week. 41.5% of respondents revealed that they regularly walk to the UC Campus, 32.3%

drive (of which, 82.9% drive their own car, and 42.9% travel alone), and 25.3% stated that they regularly take public transport. However, when questioned if they had ever used a public transport alternative during the previous month (even if this option is not the most frequent one), the majority (51.2%) answered positively.

Those who mainly use cars were also asked to indicate their satisfaction with parking availability and the flow of traffic within the campus. Most of them (52.2%) reported being very dissatisfied with the availability of parking, and 40% declared the same attitude towards the traffic flow. A similar question was asked exclusively to respondents who indicated that they commute mainly using public transport. Half of these individuals gave a positive evaluation of the public transport service, and only 25.9% declared their dissatisfaction in this respect. The disparity between the levels of satisfaction for these two groups of respondents also suggests the existence of significant welfare losses associated with travelling to the campus by car.

Concerning the 10 statements about potential measures that could lead to an individual public transport increase, 87.7% of the car drivers declared that they would be receptive to use public transportation on the basis of a waiting time reduction; 79.7% stressed the role of increasing public transportation feasibility and 77.1% considered a reduction on travel time as critical. Comfort improvements were mentioned by 63% of the respondents. Finally, only 4.4% of the drivers said that they would not abandon the use of car in favour of public transportation in any circumstances. Car drivers were also invited to reply to several questions about their willingness to accept compensation in return for a modal change to public transport. One of these questions concerns the minimum percentage of the pass for unlimited access to public transport that they would be prepared to accept in order to change their method of commuting to the Campus by car. Surprisingly, 49.1% were prepared to accept a compensation equivalent to 50% of the cost of it, and only 26.4% said that this remedy would be totally unavailable to them irrespective of the subsidy.

Accordingly, the analysis demonstrates that decreasing parking subsidization should not only reduce car driving (relative) attractiveness, but can also constitute an important source of revenues to encourage car drivers to use public transport. Indeed, an important number (73.6%) of car drivers exhibit a positive willingness to accept compensation in order to use public transport.

3. Measuring environmental impacts of changes in commuters' modal split

This section presents the main methodological issues regarding the calculation of life-cycle energy requirements and greenhouse gas (GHG) emissions associated with the alternative scenarios to address potential changes in parking and traffic policies. This section also presents the foundations for settling six specific scenarios, as well as the corresponding estimated changes in final fuel and electricity consumption by passenger cars and buses, life-cycle energy requirements and greenhouse gas (GHG) emissions.

3.1. Methodology: Life-Cycle Energy requirements and Greenhouse gas emissions

To calculate the overall impacts associated with alternative parking and traffic scenarios a Life-Cycle (LC) approach must be employed. The LC approach offers a comprehensive picture of the flows of energy and materials through a system and gives a holistic and objective basis for comparison among the various alternative scenarios. The most well-known LC approach or tool is the Life-Cycle Assessment (LCA) methodology (ISO 14040, 2006). LCA is based on systems analysis, treating the product process chain as a sequence of sub-systems that exchange inputs and outputs. The results of an LCA quantify the potential environmental impacts of a product system over the life-cycle, help to identify opportunities for improvement and indicate more sustainable options where a comparison is made. The LCA methodology consists of four major steps (ISO 14044, 2006): definition of the goal and scope; Life-Cycle Inventory (LCI); Life-Cycle Impact Assessment (LCIA) and Interpretation.

The calculations performed in this research and presented in this section followed the LCA methodology but focus in 2 types of LC impacts: primary energy and Greenhouse Gas (GHG) emissions.

Primary energy is the sum of the final energy with all the transformation losses, with fuel primary energy values being greater than their final energy values. In fact, consumers buy final energy, but what is really consumed is primary energy, which represents the cumulative energy content of all resources (renewable and non-renewable) extracted from the environment. Life-cycle GHG emissions can be calculated by summing up the GHG emissions of the several LC stages, namely: vehicle and all infrastructure production; fuel production and/or electricity generation and, last but not least, the transportation process itself with fuel combustion (in the case of vehicles with internal combustion engines). A number of GHG have been considered in the calculations, but the most important one is carbon dioxide (CO_2) followed by methane (CH_4) and nitrous oxide (N_2O), with average global warming potentials (GWP) of 25 for CH_4 and 298 for N_2O, in 100 year-time horizon. The Global Warming Potentials used by the IPCC provide "CO_2 equivalence" factors for greenhouse gases other than CO_2, which allows aggregation of emissions of different gases into a single metric (IPCC, 2007).

Finally, the GHG emissions of the overall transportation scenario can be calculated for the 6 scenarios presented in Table II, relatively to the BAU situation. The calculations have been performed based on the total number of kilometres driven per type of transportation mode associated with each of the scenarios. Table II summarizes the final energy (fuel/electricity) consumption required by the various types of transportation vehicles. Diesel and electric bus consumption was calculated from fleet actual annual consumption data, collected from the City bus company (SMTUC, 2010). Data for passenger electric car was estimated based on Marques and Freire (2012). Consumption data for diesel and petrol car is based on European fleet average data (Spielmann, 2007).

Table II – Final vehicle energy consumption

Vehicle	Fuel/electricity	Units
Diesel car	6,6	L/100 km
Petrol car	8,1	L/100 km
Electric car	16	kWh/100 km
Diesel bus	51,2	L/100 km
Electric Bus	300	kWh/100 km

3.2. Scenarios definition

This sub-section presents the main reasons and assumptions taken to define several scenarios on potential changes in parking and traffic policies, which are focused on eventual modifications in commuters' behaviour, namely changes in the modal split towards the use of public transport. Indeed, changes in the number of cars crossing the Campus, as well as in students and workers modal choices influence transports' environmental impacts at the UC Campus.

Through the counting processes explained in section 2, it was estimated the total amount of kilometres per year travelled by cars and (electrical and diesel) buses within the UC Campus. This allowed the depiction of the *Business as Usual* (BAU) scenario. Then, considering the hypothetical application of different parking and traffic policies, six different scenarios were derived. Before defining each scenario, it is worth note that all of them consider an increase in public transportation efficiency. Indeed, it is considered that the observed average occupation rate (32%) in the buses that serve the Campus can increase up to 70% without the need to bring additional buses to the Campus. In other words, the reductions in the use of cars (and taking into account the observed average occupancy rate of 1.2) to travel to the Campus considered in the scenarios, are 'compensated' by a corresponding increase in the number of bus passengers, which will result in a greater number of buses travelling through the Campus only when the occupation rate would surpass 70% if the number of buses remained equal.

The first scenario considers that an effective control of illegal parking banishes this practise, contributing to reduce the number of cars in the Campus by approximately 10%. Accordingly, the corresponding growth in the number of bus passengers would be completely absorbed by existing buses (with an occupancy rate below 70%).

The second scenario considers banishing all the parking places except the conditional parking access for UC staff. This would result both in a decrease of approximately 55% in the number of cars and in an increase of one bus per day travelling in the Campus.

The third scenario is similar to the previous one, with the exception of the hypothesis that all the diesel buses travelling in the Campus would be 'substituted' by electric ones.

The fourth scenario considers a new traffic policy that would only allow electrical vehicles (either private or public) in the UC campus. Further, it is assumed that electrical cars can represent, in the near future, nearly 5% of the present number of cars. Concerning the public transportation service, these hypotheses would mean the need to increase the number of (electric) buses travelling in the Campus in 44 buses per day.

The two last scenarios consider a traffic policy less restrictive than the one in the previous scenario, namely that regarding public transportation services only electrical buses would be allowed to circulate in the UC campus (but diesel or petrol cars can circulate). The distinctive additional assumptions taken in each of these scenarios result specifically from the survey analysis, namely regarding the application of the “Willingness to Pay” and “Willingness to Accept” concepts.

Thus, the fifth scenario considers drivers’ reaction to the introduction of a parking price of two Euros per day for all places in the Campus. Indeed, according with the survey results, only 11% of the drivers are available to pay an amount over two Euros per day to park at the Campus. Thus it is considered that 89% of the drivers would stop driving to the Campus, implying the need to reinforce (more 38 buses per day) the provision of (electric) public transportation.

The sixth scenario reflects driver’s answers concerning the Willingness to Accept concept. In the survey, drivers were asked about the value of the city's urban transport pass free percentage that they would be prepared to accept in order to consider a modal change in favour of public transportation services. Thus, as 73.6% of the drivers stated that they would be available to take the decisive step of changing to public transportation if there is a reduction in the cost of this service, we consider that all of these will cease using their cars if the University or the City Council take any kind of policy that could result in a reduction of the public transport cost supported by UC campus commuters. Further, in order to accommodate this modal change, the supply of public transportation services in the Campus would have to increase 20 buses per day.

3.3. Results: estimated environmental impacts

Table III presents the results of all the scenarios in terms of *total km driven* by each transportation type: fuel and electric cars; diesel and electric buses. The variation relatively to the BAU situation is also presented (Dif. BAU).

Table III – *Total km driven* by transportation mode in the scenarios considered

		Fuel Cars	Diesel Buses	Electric Buses	Electric Cars
BAU		1 640 000	25 500	6 400	--
Scenario 1	Value	1 474 852	25 500	6 400	--
	Dif. BAU	*-165 148*	--	--	--
Scenario 2	Value	727 012	25 718	6 455	--
	Dif. BAU	*-912 988*	*218*	*55*	--
Scenario 3	Value	727 012	--	32 391	--
	Dif. BAU	*-912 988*	*-25 500*	*25 991*	--
Scenario 4	Value	--	--	44 176	82 000

	Dif. BAU	*-1 640 000*	*-25 500*	*37 776*	*82 000*
Scenario 5	Value	175 480	--	42 399	--
	Dif. BAU	*-1 464 520*	*-25 500*	*35 999*	--
Scenario 6	Value	436 240	--	37 441	--
	Dif. BAU	*-1 203 760*	*-25 500*	*31 041*	--

These estimations allow asserting that Scenario 4 is the one that considers the most relevant decrease in terms of fuel cars use in the Campus. However, it is also worth to note that this is the single scenario where the existence of electric cars is considered, and further that it is the one where the most significant use of electric buses is considered. Scenario 5 follows as the best in terms of reduction in car use, suggesting that the attribution of a price to parking can effectively contribute for reducing the number of cars in the Campus.

Following the methodology presented in section 3.1 and considering the *total km driven* by transportation mode in each of the scenarios considered, it was possible to calculate the final electricity and fuel required, as well as the Primary Energy consumption and LC GHG emissions, as presented in Table IV.

Table IV –Energy Consumption and LC GHG Emissions

	Electricity consumption (kWh)	Fuel (Liters)	Primary Energy (MJ)	LC GHG Emissions (kg CO_2eq)
BAU	19 456	133 809	5 695 718	501 718
Scenario 1	0.0%	-9.1%	-8.8%	-9.1%
Scenario 2	0.9%	-50.2%	-48.3%	-50.3%
Scenario 3	406.1%	-60.0%	-45.8%	-49.5%
Scenario 4	656.1%	-100.0%	-76.7%	-83.7%
Scenario 5	562.5%	-90.3%	-70.3%	-76.8%
Scenario 6	485.0%	-76.0%	-58.9%	-64.0%

The results show that scenarios 4, 5 and 6 present significant reductions in LC GHG Emissions, due to important decreases in Fuel Energy consumption, but also to the technological change towards electric buses (as well as to electric cars in scenario 4).

The results for Scenario 1 show that if local authorities really control illegal parking it would have relevant effects, not only in terms of fairness, but also in terms of the quality of life associated with both the reduction in GHG emissions and more and better areas for walking (as non-regular parking occurs predominantly in pedestrian walking zones). Through scenario 2 is possible to conclude that restricting private car use at the campus for those who have access to UC staff conditional parking can result in a reduction of Primary Energy consumption and GHG emissions to nearly half of the current ones. Scenario 3, where diesel buses are 'substituted' by electric ones, presents savings in Primary Energy consumption and GHG emissions almost as important as the ones in the conditions of scenario 2.

Scenario 4, the most extreme one, where only electrical vehicles can circulate, is the one in which parking and traffic management is more efficient regarding (final and primary) energy consumption and GHG emissions. Indeed, the results underscore the positive environmental impacts of substituting the intensive use of cars by well-organized public transportation services. Additionally, the estimations for scenarios 5 and 6 show, as in the previous scenario, that well applied parking policies may also contribute to important reductions in energy consumption and GHG Emissions. The attribution of a price to parking and the change in the transportation mode used inside the Campus could significantly contribute to a much more environmental sustainable solution and, in addition, to generate new revenues that can be consigned to contribute for improvements in the service provided by local public transportation authorities. Actually, according with the results presented, the isolated introduction of a parking price of 2 Euros per day has the potential to reduce GHG emissions in more than 75%, while the subsidization of the public transportation pass can contribute to reduce GHG emissions in 64%.

4. Conclusions

This study explores the importance of integrated parking management policies: (*i)* to ensure more rational use of the available parking spaces, and (*ii)* to reduce greenhouse gas (GHG) emissions, fossil fuel consumption and primary energy requirement by commuters to the University of Coimbra (UC) Campus.

The area studied is the UC Campus, considered to have an outstanding artistic and architectural value, where approximately 45% of the parking places are free and without any kind of access restrictions. Further, the analysis showed that there are an important number of illegal parking places being used every day. This fact is especially worrying considering that Universities have the potential to influence not only the student's mobility choices in the present, but also the environmental awareness and habits they can develop in the long term, i.e., they can become powerful forces to reshape the future society's transportation patterns (Barata et al., 2011).

It was demonstrated that a policy measure as simple as controlling illegal parking may contribute to reduce nearly 10% of GHG emissions due to the transportation use in the Campus. Further, as showed in scenarios 2 to 6, different forms of modal shift from private cars towards public transportation (in this specific case to buses) can also contribute to important emissions reduction. Noteworthy, among the results achieved, the introduction of a parking fee may result in an overall reduction in GHG emissions above 75%. Concurrently, these revenues can be used by the University Administration and/or Local Authorities to subsidize the price of the public transportation pass and/or to improve the quality of the service, promoting the reduction of some resistance to decrease the use of the private car.

Certainly, these results should be considered by local transportation authorities and the University Administration, in order to study the implementation of solutions capable of allowing people to park farther from the University and simultaneously the provision of bus services able to carrying them with feasibility and comfort to anyplace inside the Campus. And one of the most interesting aspects of this comprehensive analysis is that the ones that can take the decisions have the comfort of knowing that UC campus commuters are available to accept such kind of changes and, reinforcing this, are willing to contribute (even if involving some payment) for it. In other words, if commuters' current behaviour is part of the existing problem, it is clear that there is important commuters' disposition to become part of the solution for greening transportation and parking at the UC Campus.

Finally, it is worth note that although the results of this research are limited to the UC case, an integrated modelling approach as comprehensive as the one here used has the potential to be illustrative of the importance that integrated traffic and parking management measures can have for greening commuters' transportation and parking in urban areas. Indeed, "big universities resemble small cities" (Shoup, 2008:147), and the interventions in traffic and parking demand management at UC can provide important lessons concerning the (positive) environmental impacts that could result of the generalization of this type of policy in most of the University Campus and in historical downtown areas that face the same kind of problems regarding overcrowding, traffic congestion, non-regulated parking and exacerbated car use.

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Reducing energy use by dialogue marketing.

A combined approach for mobility and households' energy use

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Abstract

Dialogue marketing is one of the most frequently used soft measures to limit road traffic induced GHG-emissions within transport science. It is a multi-step marketing approach aiming of voluntary changes in mobility behavior towards a more environmental-friendly mobility. This objective should be reached by both, resolving information paucities concerning PT services, and by overcoming subjective barriers to PT use. Although the achievements gained by this approach are quite impressing, strategies are being sought to improve this tool. One possibility is to extend the thematic focus from a monothematic approach to an interdisciplinary campaign. As a dialogue marketing aiming on private energy use would have the same target group as a mobility dialogue marketing campaign, a combined conduction is obvious. Within the research project DIALOG such an approach was developed; a combined dialog marketing campaign for energy use and mobility was prepared, conducted and evaluated. Both, a survey as well as a measurement of energy consumption figures was used to calculate short- and long-term impacts of the dialogue marketing campaign. The different evaluation methods consistently show the fulfillment of the intended results. Within almost all categories covered, energy saving behavior is more commonly applied. Potentials of energetic refurbishments could be shown to owner-occupiers. Their intention to invest in their flats or houses could also be increased. By an economic evaluation it was shown, that the benefits of the campaigns conducted overweigh their costs by a factor of 4.4 to 5.4. However, it is not absolutely unambiguous, that the combination of two aspects – energy use and mobility – in one dialogue marketing campaigns has clear advantages against two separated campaigns.

Keywords: Dialogue marketing, evaluation, environmental impacts, economic evaluation,

Problem

A significant share of total greenhouse gas (GHG) emissions is evoked by private households' energy consumption in both, Austria and the European Union. In 2010, 27 % of the total Austrian GHG emissions stem from the transport sector. Within the transport sector, passenger road transport was by far the largest emitter. Households were also responsible for most of the emissions evoked by the sector "heating and other small-scale consumptions" (13 % of the Austrian GHG-emissions) and for a significant share of the emissions arise from energy production (17 %) (Umweltbundesamt, 2012).

Thus, there are high potentials for energy savings, if households change their behavior in terms of energy use and mobility just a bit. Every avoided car trip reduces the GHG-emissions; by a conscious use of electrical devices a significant amount of energy can be saved. Even more important with regard to the energy consumption are energetic building refurbishments. By a consistent improvement of the insulation, up to 60 percent of the energy needed for room heating can be saved; energy efficiency of new water heating devices is 35 percent higher as compared to older appliances (Umweltbundesamt, 2011).

Various measures are applied to limit the GHG emissions induced by car traffic. A frequently used measure is the so called dialogue marketing (Brög, et al., 2009). It is a multi-step marketing approach aiming to persuade people to voluntary change their mobility behavior. For this reason, individualized, demand-orientated information materials as well as personal advisories are provided.

Although dialogue marketing is not an exceptional tool anymore, there is a continuing need for additional research to further improve the measure. Concerning dialogue marketing campaigns in the field of mobility behavior, improvement potential denoted in literature affects particularly:

(1) There are uncertainties concerning the stability of the achieved impacts over time. Some authors argue that the impacts are, due to the "voluntary nature" of the measure, constant over time (Brög, 2008). However, valid investigations are sparse.
(2) The objective of dialogue marketing is to promote environmental friendly mobility behavior. Besides additional earnings gained by the PT operators, a mode shift from car to more sustainable modes has further positive effects – to make a trip by bus or by feet is cleaner, saver, and more healthy. However, these impacts are often not valued. This raises the question for an overall assessment of all impacts of a dialogue marketing (Richter, et al., 2009).
(3) Several authors see a potential for a combination of different topics within one dialogue marketing campaign. Heller (2003) argues that energy use fits very well to a mobility behavior campaign, as both affect daily life decisions.

Among other things, these three topics were addressed within the research project DIALOG (Individual motivation for climate-friendly energy use in transport and household). In detail (1) the impact stability over time was assessed and (2) an overall assessment of the impacts was conducted for (3) an interdisciplinary dialogue marketing campaign covering private energy use and mobility behavior. For this purpose, a campaign was developed, conducted and evaluated. The evaluation approach included both, an analysis of short- and long-term impacts, as well as an economic assessment consisting of cost-benefit- and cost-effectiveness-analyses. The research project was conducted by the Institute for Transport Studies, University of Natural Resources and Life Science, Vienna, Austria and Socialdata GmbH between 2009 and 2012. It was funded by the Austrian Climate and Energy Fund within the funding scheme "New Energies 2020".

In addition to mobility behavior households' energy use was selected as topic of the dialogue marketing campaign. This decision was made, because (i) both topics are highly relevant for private energy consumption, and (ii) private households can achieve energy savings in both areas by adapting their behavior. As both project partners have their professional focus in mobility research, resp. mobility consultancy an advisory board was founded once the decision to select energy use as the second focal point was made. Participants of the board were mainly energy suppliers; they provided technical, personal and professional support to the project team.

This paper focuses on the evaluation of the combined dialogue marketing campaign for energy use – in terms of behavioral changes and their economic evaluation. The paper's structure is as follows: First, some general remarks on a mobility dialogue marketing approaches are made. This is important from our view, as we see the treatment of energy issues as an extension of a mobility marketing approach. Afterwards, the applied dialogue marketing approach and its evaluation within the research project DIALOG is presented. In the third part we show behavioral changes in terms of energy use caused by the dialogue marketing campaign. Finally, results of the cost-benefit-analyses and cost-effectiveness-analyses are presented.

Dialogue marketing to influence mobility behavior

Since private car use is responsible for most of the emissions evoked by the transport sector, strategies to limit traffic induced GHG-emissions have to point on the avoidance of car trips (Umweltbundesamt, 2012). Existing strategies can be distinguished in hard and soft transport policy measures. Hard measures include a wide range of different approaches as financial policies, infrastructural projects or direct mandatory regulations. All attempts to promote a voluntary change in mobility behavior are referred to as "soft" measures (Cairns, et al., 2004).

Car trips can be distinguished in those, for that car use is inevitably for any reason – whether no alternative means of transport is available or heavy goods or persons have to be carried – and non-mandatory car trips. In fact, at least every second trip made by car can also be conducted using alternative modes (Brög, 2008). Common arguments not to use public transport services are general preferences for other modes, security concerns, insufficient level of PT services, high fares, inadequate comfort, and its image (Stradling, et al., 2007). Most of these arguments can be summarized as subjective constraints. Additionally, some of the supposed problems are prejudices raised from poor information.

Soft transport policy measures focus on those constraints. Cairns et al. (2004) distinguish between ten different kinds of soft measures (Cairns, et al., 2004). Three of them are personalized travel planning, travel awareness campaigns, and public transport information and marketing. At least if these just slightly different approaches are treated as one, they are probably the most important one in terms of the frequency they are used and evaluated in literature (Möser, et al., 2008). We refer to this kind of policy measure in the following as dialogue marketing.

Dialogue marketing in transport sector is characterized by a repeated, intensive and demand-orientated communication process between PT operators and their potential as well as actual customers. It seeks to overcome both, a lack of information concerning existing PT services and subjective barriers to their use. While doing so, all efforts are concentrated on persons that (i) are willing to participate in the campaign and (ii) have an insufficient level of information on PT services or other constraints towards their use. This clearly-focused strategy makes this approach more effective than other marketing measures (Brög, 2008). By showing that PT services are better than assumed to be, participants can be influenced to voluntary change their mobility behavior (Cairns, et al., 2004). More resent approaches do not strictly focus on public transport, but on all environmental friendly modes (Brög, et al., 2009). However, most car trips over a critical length can only be replaced by public transport.

Up to now, dialog marketing campaigns in transport sector have been applied in nearly all European countries such as Austria (Waldhör, et al., 2009), Italy (Ker, 2003), Germany (Ker, 2003), Great Britain (Cairns, et al., 2004), Spain (Ker, 2003) or Sweden (Cairns, et al., 2004). Evaluation studies show a clear positive effect with 15 up to 40 additional trips made by public transport per person and year – with a higher increase in areas with a below-average PT use (Ker, 2003). Cairns et al. (2004) states reductions of 7-15 % of car driver trips. Accompanying research has shown, that dialogue marketing approaches are particularly successful if they are conducted in combination with infrastructural improvements (Ker, 2003). The various results stated in literature are consistent to a degree, that Möser and Bamberg (2008) assume that dialogue marketing is either an extremely successful approach or a kind of publication bias is present.

Although the general concept is sound and thoroughly tested, need for additional research or pilot projects exists in different terms (Richter, et al., 2009). As nearly no dialogue marketing campaigns were conducted in rural areas and only few in suburban areas so far, knowledge is missing on the effectiveness of the approach in areas with a suboptimal PT availability (Richter, et al., 2009). To the best of our knowledge, no dialogue marketing campaign ever included more than one topic. However, some authors assume that considerable synergy effects could be achieved by an interdisciplinary combination of more than one topic in one dialogue marketing campaign. Possible extensions could be water savings, energy consumption as well as waste prevention (Heller, 2003). Only little empirical findings exist with regard to long-term changes in mobility behavior covering at least a period of six month (Cairns, et al., 2004). Apart from a very few exceptions, no assessments of the overall impacts in terms of cost-benefit-analysis – also including environmental or health issues – are available (Richter, et al., 2009).

Research project DIALOG: dialogue marketing campaign

Several of the issues mentioned above were treated in the research project DIALOG. As the objective of the research project DIALOG was to break new ground in realms of (i) the application area, (ii) multi-themes, and (iii) the evaluation, we avoided further innovations with regard to the preparation and conduction of the campaign. Thus, we used a standard dialogue marketing approach. It consisted of a multi-step approach including:

(1) Contact stage: Randomly chosen persons are contacted using a cover letter and asked for participation. Afterwards, households with known telephone number are called; most of the others are visited at home. They are asked for both, information demand, and travel behavior.
(2) Segmentation stage: According to their information demand, their willingness to participate, as well as their mobility behavior, people are divided into groups. Different segmentation rules are used for the energy and mobility marketing. Within the mobility marketing, all households that (i) are willing to participate, (ii) have information needs, and (iii) seldom or never use public transport are selected for the further campaign. For the energy campaign, the last category has no meaning as most households act environmental friendly in some regards and do not in others. Instead, they were asked if they are (i) occupier-owner or tenant of the flat or house they are living, and (ii) a demand for information exists.
(3) Encouragement stage: This stage is limited to the mobility marketing. Households without information needs that actually have an environmentally friendly mobility behavior are encouraged in their behavior by a small gift such as an umbrella or a calendar.
(4) Motivation stage: A list of available information material and small gifts is send to the participants. Additionally, individualized information materials such as personal PT schedules are listed. Participants select all the material they are interested in. They can also denote a need for personal consultancy.
(5) Information stage: The chosen material is handed out personally by trained personal. The delivery should be done by employees of the mobility operators or energy suppliers.
(6) Conviction stage: Personal consultancy is conducted.

Regarding the contents, the energy marketing was twofold. One part aimed on reducing energy consumption by attitudinal and behavioral changes. Target group were all Austrian households. The second concern was energetic building refurbishment. Only owner-occupiers of a flat or house have the possibility to implement such measures. According to this, only these households belong to the target group. Within DIALOG, the second group was a subsample of the first one.

The dialogue marketing campaign for mobility behavior was conducted from May to July 2010, the one on energy use in October 2010. They took place in three different areas. Two of them were in the outskirts of major Austrian cities (Graz and Linz); the third was in the suburban region of Linz (municipality of Ottensheim). Within given areas, the target households were randomly selected.

The dialogue marketing concept includes the primarily use of existing information material. For Graz twenty different information materials on energy savings and energetic refurbishment were collected, for Linz eleven and for the suburban area of Linz also twenty. In each application area different gifts such as Music-CDs, umbrellas, and ammeters were provided by energy suppliers. For the conviction stage, personal consultancy was prepared by energy suppliers or local environmental agencies.

Research project DIALOG: performance indicators

Performance indicators refer to the conduction of the dialogue marketing campaign. Households living in Graz and the suburb of Linz ordered nine different information materials in average, whereas the participants living in Linz just ordered five materials. Most popular were general information brochures such as "energy saving tips for home" (ordered by 72 % of the households living in Graz) or "great tips for electricity saving" (ordered by 64 % of the people living in the suburban area of Linz). These numbers clearly show the demand for materials summarizing existing knowledge: also if there are a lot of possibilities to inform about these topics on their own, many people often do not.

Contrary to the great demand for information materials, only few households asked for personal consultancy. One reason might be that consultancies in Linz and its suburban area were explicitly targeted to owner-occupiers. As a result, only one consultancy was conducted in Linz, and two in its suburb. The consultancy conducted in Graz focused on general possibilities to save energy. Eight households accepted this offer. The most frequently asked gift was the ammeter.

Research project DIALOG: evaluation concept

The evaluation concept of the direct impacts evoked by the dialogue marketing included both, a telephone panel survey and a measurement of the energy consumption.

The survey consisted of two parts: All participants were asked for certain behavior with a high relevance for energy consumption. Additionally, owner-occupiers were asked for energetic building refurbishments. The survey was conducted as panel survey at three different points in time – that means that the same households were asked several times. The first questioning, aiming to identify mobility behavior previous to the dialogue marketing was carried out in October 2010. The second one was in January and February 2011; the last one took place one year after the completion of the dialogue marketing campaign. The comparison of the results enables the detection of both, short-term and long-term behavioral changes. In this way, the direct impacts as well as their consistency can be assessed.

All three interviews include a set of equal question. They refer to behavior that is highly relevant for energy consumption or private GHG-emissions. Those six questions were:

- What is the medium heating temperature in your flat/house during winter months? (referred to as “Winter temperature” in the following)
- Do you turn down the heating at night? (Night temperature)
- Do you take a shower instead of a bath more often? (shower/bath)
- Is energy efficiency relevant, when you purchase electrical appliances? (electrical appliances)
- Do you use green electricity? (green electricity)
- Do you use a water-saving shower head? (shower head)

The first question was answered in degree Celsius; the latter two can only be answered with yes/no. All of the other had four answer possibilities ranging from “I never do this” to “I always do this”.

Owner-occupiers were additionally asked for energetic building refurbishments. This contained questions on insulation, room heating and water heating. For each, owner-occupiers were asked if (i) within their house or flat possibilities for energy savings in one of these areas are given, and if (ii) they have intentions to invest in one of these areas.

Additionally, specific questions were asked within every survey step. In the first interview, characteristics of the living situation (size of the household, size of the flat/house, heating system,…) were recorded. In the second and third survey, questions on the perception and the impacts of the campaign were asked such as “Would you again participate?”, “Have you talked with your family, colleagues or friends about the campaign?” or “Do you feel better informed about energy savings?”.

The answers given were checked for plausibility. Afterwards the data were analyzed using comparisons of mean for dependent samples (t tests). However, the answers are not used to calculate the amount of energy savings due to the dialogue marketing approach. We refused to do this, as a clear specification of the energy consumption related to the answers given in the survey cannot be clarified in a satisfactory manner. For example, an answer like “since the dialogue marketing campaign, i always pay attention for energy efficiency if I buy electrical appliances” does not give any indication on the absolute change in energy consumption: Will the next refrigerator be of the energy class A+, A++ or even A+++? And what is the energy class of the existing refrigerator? Due to this problem, we interpret the answers given as an indicator for a change in problem consciousness. An exception is the survey of owner-occupiers. There answers were used to calculate energy savings by building investments using average values on saving potentials.

The second evaluation approach was a measurement of the energy consumption based on actual power consumption figures. For the suburban area of Linz, measurements for the year 2009, 2010 and 2011 were made available by an energy supplier. As the dialogue marketing was conducted in October 2010 a pre-post-comparison is possible. For this reason, power consumption of households participating in the marketing campaign was compared to those of a control group. The latter one included all households living in similar structured areas as the participants, but had not attended the dialogue marketing. The comparison of a treated group with a control group allows excluding general developments with regard to private energy consumption.

Both evaluation concepts – the survey and the use of consumption figures – have pros and cons. The measurement of the power consumption is strictly objective. However, it also has disadvantages. Besides data availability – that is closely related to the topic of data security – time requirement of energetic refurbishments is a major problem. Such investments have to be prepared, conducted and need some time to show an impact. For example, if the decision to improve a buildings` insulation was made as a result of the dialogue marketing in October 2010, it will barely has a significant impact on energy consumption in 2011. Surveys, on the other side, have the principal problem, that not objective information, but its subjective perception is recorded; real actions and behavior stated in a survey need not agree. Additionally, every further survey step lowers the response rate – whether it is because people move, cannot be reached by other reasons or just do not want to answer the same questions again. In fact, it has to be assumed, that not-participating people act exactly as those who participated at every stage of the survey, but this is not for sure. On the other side, all aspects of a dialogue marketing campaign can be captured within a survey. This refers to behavioral changes, actual and planed investments in the building, and also the assessment of the dialogue marketing campaign. Due to the advantages of both evaluation concepts, we decided to combine them.

Finally, separated cost-benefit-analyses and cost-effectiveness-analyses were conducted. For this purpose it was assumed, that either all Austrian owner-occupiers would be contacted within a big-scale dialogue marketing campaign or all Austrian households. Different cost and benefit issues were analyzed. Those were direct costs related to the preparation and conduction of the campaign, climate costs, costs for energy production, costs for refurbishments, and costs of private energy consumption. Except of direct and investment costs, all aspects are based on a change in energy consumption. The size of the effect of the dialogue marketing campaign was based on the calculation of the measurement of the energy consumption as described above.

Results – survey on behavioral changes

The dialogue marketing for sustainable energy use was conducted during October and November 2010. The total gross sample included 1.963 randomly chosen households living in the outskirts of the Austrian cities of Linz and Graz or in the suburban region of Linz. Sample losses due to e.g. invalid addresses accounted for 273 households. In total, 828 households were successfully contacted with 404 of them indicating a demand for information. Since not all of them send back the information list, and some who did, did not order any material, the resulting number of participating households was 209. The response rate – defined as the share of households sending back the information list on the adjusted gross sample – accounts for 17 percent.

However, behavioral changes can only be analyzed for people, who participated not only in the dialogue marketing campaign, but also in the two following surveys. The number of answering households varies between 56 (green electricity) and 163 (shower/bath). The behavioral changes as stated in the surveys are shown in table 1. The categories denoted in frequency, ownership, use or importance have a range from zero to 100 percent. 100 percent indicates that all people stated they would always do the corresponding action. For example, a value of 100 percent in the row “Night temperature” means, that all households always turn down the heating at night.

As it can be seen, the general degree of awareness for environmental friendly or cost-efficient energy use is high. This is also true for the time before the dialogue marketing was conducted. For example, energy efficiency is highly relevant for the purchase of electrical appliance. The value of 94.0 percent in status quo indicates that almost all households pay attention on the energy consumption when buying electrical devices. This also applies to the use of green electricity. As water is an important primary energy source in Austria, the share of green electricity use is higher than in other countries.

Due to the conscious energy use in the status quo, clear improvements in terms of a percentage change are not possible. However, with two exception (shower/bath and winter temperature remaining constant), behavioral changes towards a more environmental energy use can be identified in the short-term perspective. Due to the small sample size (green electricity) or small impact size, these changes are not significant. Be it because of general preferences or inadvertency, a level of 100 percent can hardly be achieved in reality. Thus, significant changes cannot be expected with regard to the impressive status quo and the limited sample size.

In the long-term perspective, there is a further slight increase in conscious energy use. Again, this does not apply to the categories winter temperature and shower/bath. In fact, the only statistical significant impact of the dialogue marketing on energy use is an increase in the category “taking a bath” at the expenses of “taking a shower”. To be honest, we cannot imagine a rational explanation for this. In all of the other categories, there is an increased in the intended behavior, if the answers given in the first and the third survey are compared. With exception of the use of green electricity, this is also true for the comparison of the second and the third survey. That means, that the impacts achieved by the dialogue marketing, are constant over time.

Table 1: Behavioral changes

Category	n (households)	1st survey	2nd survey	3rd survey	Change 1st -2nd (%)	Change 1st -3rd (%)
Night temperature [frequency, %]	138	87.9	88.7	88.9	1 %	1 %
Shower/bath [frequency, %]	163	90.6	90.6	85.7	0 %	-5 %**
Shower head [ownership, %]	130	57.7	60.8	63.9	5 %	11 %
Winter temperature [°C]	160	21.4	21.4	21.4	0 %	0 %
Green electricity [use, %]	56	26.8	32.1	30.4	20 %	13 %
Electrical appliances [importance, %]	160	94.0	94.8	95.5	1 %	2 %

** sig. influence, significance level: 5 %; ** sig. influence, significance level: 1 %*

There are evidences, that dialogue marketing supports households to change their behavior towards a more sustainable energy use. In most categories, a slight improvement in reported behavior can be measured. However, due to sample size and the environmental friendly behavior in status quo, significant impacts cannot be detected.

Results – survey on refurbishment investments of owner-occupiers

Households living as owner-occupiers were additionally asked within the survey, if

- energy can be saved by refurbishments with regard to insulation, room heating and water heating in their flat/house, and, if yes
- they are willing to invest in one of these areas.

Only owner-occupiers were asked these questions, as tenants have only limited decision-making possibilities in this case. Thus, the number of answering households was small compared to the questions aiming on energy use (Table 2).

Table 2: Changes in owner-occupiers opinion towards refurbishment: Can energy be saved by refurbishments in your flat/house?

Category	n (households)	1st survey	2nd survey	3rd survey	Change 1st -2nd (%)	Change 1st -3rd (%)
Insulation [agreement, %]	67	19.4	28.4	35.8	46 %*	85 %**
Heating [agreement, %]	72	13.9	19.4	37.5	40 %	170 %**
Water heating [agreement, %]	72	12.5	25.0	33.3	100 %**	167 %**

** sig. influence, significance level: 5 %; ** sig. influence, significance level: 1 %*

In the beginning, one fifth to one eighth of the households see a possibility to save energy by refurbishment measures in their flat or house. The highest share is achieved in the category building insulation. It cannot be stated, if this is due to a particular bad current status compared to the other categories or if the level of consciousness is just higher.

In all of the categories, a clear increase in the number of households assuming an energy-saving potential can be detected. In the long-term perspective, the share of households is more than doubled for both, room and water heating; it increases to 33.3 percent for water heating and 37.5 percent for room heating. In the long-term perspective, also more than one third of the households affirm potentials by improving insulation.

The increase is highly significant in most categories. However, the continuing increase over time may indicate, that further advisory services were asked by the respondents. However, also if this is true, the dialogue marketing has a function as door-opener for these additional services.

The identification of energy saving potentials is important; however, it is only getting decisive if it also leads to investments. Thus, all owner-occupiers who said that an energetic refurbishment of their flat or house would help to save energy were asked if they intend to invest.

At the beginning, only few households had intentions to invest in one of these fields (Table 3). Their share lies between 5.4 and 12.1 percent of the households with identified energy-saving potentials in the corresponding topic. Again, it is highest for insulation. The willingness to invest is increasing over time in all categories. However, contrary to the identification of investment possibilities, most parts of the increase are in the long-term perspective. This can be seen as an even stronger indicator for additional external advisories.

Table 3: Changes in owner-occupiers opinion towards refurbishment: Do you have intentions to invest in these areas?

Category	n (households)	1st survey	2nd survey	3rd survey	Change 1st -2nd (%)	Change 1st -3rd (%)
Insulation [agreement, %]	33	12.1	18.2	21.2	50 %	75 %
Heating [agreement, %]	37	5.4	5.4	10.8	0 %	100 %
Water heating [agreement, %]	34	8.8	8.8	14.7	0 %	67 %

** sig. influence, significance level: 5 %; ** sig. influence, significance level: 1 %*

Results – measurement of the energy consumption

In addition to the survey, that only allows capturing oral information on behavior, a measurement of the actually energy consumption by means of annual consumption figures was conducted. For this purpose, the energy consumption of households living in the suburban area of Linz was analysed. In more detail, the development of the energy consumption between 2009 and 2011 of households that participated in the dialogue marketing was compared to those of a control group. All households that lived in areas with a similar settlement structure as the participating households belonged to the control group.

The sample of the participating households consisted of 72 households; the size of the control group was 776. As only two participating households use electrical heating, this aspect was excluded. Therefore, only energy consumption for electrical devices and water heating was analyzed.

Table 4: Average absolute energy consumption per year and household

Category	Participating households [n=72]			Control group [n=776]		
Year	2009	2010	2011	2009	2010	2011
Electrical devices [kWh]	3,271	3,206	3,150	3,221	3,219	3,160
Water heating [kWh]	2,270	2,260	2,157	2,274	2,300	2,247

Energy consumption for electrical devices of the participating households was in 2009, the last year before the dialogue marketing was conducted, a little bit higher than those of the control group. In contrast, energy needed for water heating was almost the same (Table 4). 2010, the energy consumption for electrical devices was unaltered for the control group, while energy consumption for heating increased. In 2011 the energy consumption of the control group was declined against the status of 2009 for 1.9 percent (devices) resp. 1.2 percent (heating).

In contrast, energy consumption of the participating households decreased steadily. Between 2009 and 2011 the reduction accounts for 3.7 percent for electrical devices, and for 5.0 percent for water heating. The total amount of the reduction in energy consumption is higher for the comparison of 2010 and 2011, than for 2009 and 2010. As the dialogue marketing campaign was conducted in October 2010, most of the year 2010 belongs to the category "before the dialogue marketing". Thus, the impact of the dialogue marketing was to be expected to arise in 2011.

The decrease in energy consumption is considerable higher for the participating households. To detect the part of the reduction achieved by the dialogue marketing, the energy consumption of the participating households has to be adjusted for the development over time – expressed as change in energy consumption of the control group. The decrease for the participating households is 1.8 percentage points higher for electrical devices and 3.8 percentages points for water heating adjusted for the control group effect.

Results – changes in mobility behavior

Within the telephone surveys, information on the frequency of mode choice was collected. It can be shown, that the use of environmental friendly modes – to walk and to use public transport – increases, while car use decreases. This is true in the short- and long-term perspective. The changes in mobility behavior are more distinctive than those in energy use. A significant increase in walking-frequency for 6.3 percent and in public transport use for 6.0 percent can be stated in the long-term perspective.

Results – further survey results

Within the second and third survey wave, questions on the participant's assessment of the dialogue marketing campaign were asked. 49 percent in the second (48 percent in the second wave) said, they had talked about the campaign with friends, relatives, and/or colleagues. This multiplier effect is important, as advices on environmental-friendly behavior given by well-known persons are seen as very credible. The participating households therefore act as multipliers in their networks. 82 percent in the third (91 percent) support the idea of conducting dialogue marketing in whole Austria. Additionally, 81 percent (82 percent) would again participate in such a campaign. Concerning energy savings, 71 percent (72 percent) of respondents feel better informed, while 52 percent (60 percent) are motivated to save energy.

Results – economic evaluation of the dialogue marketing with regard to behavioral changes

Two different economic evaluations to assess the impacts of the dialogue marketing approach were conducted. The first one concerned behavioral changes. It is based on the measurement figures of energy consumption. The second one focuses on energetic refurbishments. Bases are the answers given by the owner-occupiers on their willingness to make energetic investments. The target group of these evaluations differs. The first one refers to all Austrian households, while the second one only affects owner-occupiers. Within both economic evaluations a dialogue scenario is compared to a trend scenario. Both assessments cover a time period of two years.

To evaluate the campaign aiming on energy use, different cost and benefit items are considered. Those are related to (i) preparation and conduction of the campaign, (ii) private energy consumption, (iii) energy supply, and (iv) changes in CO2-emissions (Table 5). The second evaluation for energetic refurbishments includes additionally the investment costs (Table 6). Negative values in the two following tables indicate a cost surplus due to the dialogue marketing.

The figures used in Table 5 are based on the measured changes in energy consumption; that were a decrease of 3.7 percent for electrical devices and 5.0 percent for water heating. Using information published by the federal Austrian statistic – such as a GHG-emission intensity of the current Austrian energy supply of 74.6 tons CO2/TJ and external costs per ton CO2-emissions of 245 € – the single cost items can be calculated. Additionally, information needed is the costs of the dialogue marketing campaign conducted within the research project DIALOG per household. The total reduction of CO_2-emissions in 2010 and 2011 due to the dialogue marketing accounts for 144.955 tons CO_2. From this it follows a benefit surplus in terms of climate costs.

Table 5: Benefit items of the economic evaluation aiming on energy use

Utility item	Preparation/ conduction of the campaign	Energy supply	Private energy consumption	Climate costs
Difference between dialog-scenario and trend scenario [1,000 €/(2011-2012)]	-30.468	26.991	70.943	35.514

The comparison of the dialogue-scenario and the trend-scenario shows a benefit surplus in three of four categories: Energy supply, private energy consumption, and climate costs. In these three categories, a benefit can be achieved by conducting a dialogue marketing campaign. On the other side, costs occur only for the preparation and conduction of the campaign. The benefit-cost-ratio reaches a value of 4.4. This means that the utility gained is 4.4 times as high as the costs associated with the campaign. If the costs are compared to the CO_2-emissions, a cost-effectiveness of 210.2 Euro per omitted ton CO_2-emission is calculated.

The second economic evaluation treats energetic refurbishments by owner-occupiers. Calculations are based on the average increase of the intention to invest by seven percent achieved in the dialogue marketing (Table 3) and the response rate achieved within the survey. Premise of the calculation is that those additional seven percent of owner-occupiers make all possible investments in insulation and heating.

As the number of participants is smaller, the dialogue marketing campaign is considerable cheaper (Table 6). However, its impacts are more relevant. The benefits gained by emission reductions are three times as high as in the former evaluated campaign, and also the benefits achieved by energy supply and private energy consumption are higher. However, while behavioral changes as turning down heating are free of costs, investments in refurbishments are expensive. Nevertheless, the benefit-cost-ratio is 5.4, and the cost-effectiveness is 189.2 Euro per omitted ton CO_2-emission.

Table 6: Benefit items of the economic evaluation aiming on energetic refurbishments

Utility item	Preparation/ conduction of the campaign	Energy supply	Private energy consumption	Climate costs	Investments
Difference between dialog-scenario and trend scenario [1,000 €/(2011-2012)]	-1.442	192.782	125.509	101.263	-76.724

Conclusion

Within the research project DIALOG a combined dialogue marketing approach for energy use and mobility was prepared, conducted and evaluated. Two evaluation methods were used. The first one was a survey on both, energy use and refurbishment measures. The second approach was based on figures on energy consumption. Both methods prove an increase of environmental friendly energy use, resp. a decrease of energy consumption in the pre-post-comparison. Additionally, it could be shown, that the achieved impacts are stable over time.

The behavioural changes with regard to energy use are comparatively small. For most parts, this is due to the fact that already in the starting survey most people stated to use energy consciously. In this situation, a strong performance cannot be expected. Contrary, showing potentials for energy savings by energetic refurbishments was particularly successful. In the end, one third of the owner-occupiers said energy savings could be achieved by energetic refurbishments in their house or flat. This applies to both, the short- and long-term perspective. The share of owner-occupiers willing to invest in their buildings has also increased. Most parts of the increase were in the long-term perspective.

The success of the dialogue marketing campaign can also be shown by changes in energy consumption. The decrease in energy consumption of the participating households is higher than those of a control group. In particular, the differences between both groups are high for the energy needed for water heating.

The economic evaluation shows a benefit surplus achieved by the dialogue marketing campaign. It is slightly higher for a dialogue marketing campaign aiming on energetic building refurbishment, but also for a campaign aiming on behavioural changes benefits outweighs the costs.

While good results were achieved in both dialogue marketing campaigns, it cannot be clearly decided, if the interdisciplinary campaign covering energy use and mobility has advantages against two single campaigns. Synergy impacts can be gained within the evaluation process and partly during the preparation and conduction of the campaign; several measures to be carried out have comparatively high fix costs, while the marginal costs for an additional household or topic are small or even zero. One example is the selection of target persons. By providing more than one topic, there are no additional efforts to be made; from this it follows that the average costs for the selection of target persons are lower for a combined dialogue marketing campaign. This also applies to a survey based evaluation.

However, an evaluation is not necessarily required – also other marketing approaches are usually not evaluated. Benefits gained within the preparation and conduction of an interdisciplinary campaign are comparatively small, while additional efforts for the collection of materials or the communication process with regional stakeholders – such as public transport operators or energy suppliers – is needed. These additional efforts largely coincide in time, when workload for the preparation of the campaign is already high. Additionally, there is a fear to overload participants with information.

Thus, a clear conclusion cannot be made: If a survey-based evaluation is planned, and personnel resources are available, a multi-themes dialogue marketing approach can make sense. Otherwise, a more focused dialogue marketing approach has advantages.

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Wind Energy and local community perceptions

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Abstract

Portugal has seen in recent years an increased growth of wind farm's deployment in its northern region, in accordance with national legal framework and current energy policies. The majority of existing academic studies approaching impacts (benefits or costs) resulting from deployment of this technology, mainly focus these aspects from a global point of view, nonetheless wind power projects have also been associated with significant impacts directly affecting local communities where they were implemented. This paper aims to identify such local impacts, reflecting local community's perspective through the use of interviews. A comparative analysis of the main impacts and the way they are being perceived by the local stakeholders, with previous studies focusing this area of expertise was attempted. Results demonstrated that the majority of interviewees did not point out disadvantages that significantly altered their quality of life, revealing a consensual acceptance of benefits from these projects. The major importance of this sort of energy investments and of associated benefits was recognized. Revenues attributed to Communal Land Commission, in charge of managing the land destined to wind farm deployment, were perceived as highly favorable, allowing to answer local community's needs.

Keywords: Wind Power; social impacts; local sustainability.

JEL Classification: Q20; Q42

Introduction

Europe is facing nowadays one of the greatest challenges concerning energy sector; the continuous rise of energy prices along with a high level of dependency on “energy imports” jeopardizes countries “security and competitiveness” (European Union, 2011a). The use of Renewable Energy Sources (RES) has been seen as an effective way to tackle this problem, and particularly wind energy, being considered one the foremost promising technologies, currently contributing to generate an available greener and ever more competitive electricity system (European Union, 2011b).

Similarly to the European scenario, Portugal’s energy scenario has been characterized by considerable dependence on external energy resources, mainly due to energy system’s reliance on fossil fuel derivates (oil, natural gas and coal) (Portuguese Directorate for Energy and Geology (DGEG), 2012).

In order to reduce Portugal’s external energy dependence, while increasing energy efficiency and reducing CO_2 emissions, national government has developed strategic guidelines for energy sector stimulating the contribution of RES, focusing among others on wind energy (Institute of Systems and Computer Engineering of Oporto (INESC Porto) and AT Kearny, 2012). The investment in such option has revealed a positive outcome, since wind energy currently represents a key aspect in national energy context, with increasing deployment throughout national territory (Institute of Mechanical Engineering and Industrial Management (INEGI) and Portuguese Renewable Energy Association Wind Farms in Portugal (APREN), 2011). These authors further underlined that over the last decade, RES has taken an important role in “national energy mix”, particularly with the “increasing number of wind farms” located in national territory. This assessment has emphasized the “fundamental role RES played for the reduction of the external energy dependency, actively contributing to increasing the security of supply” (Ferreira, 2007:17).

The proposed work aims to address the local and regional social impact of wind energy projects, focusing on developing a methodology to assess them from a stakeholder’s perspective, applying it to a Municipality or Village case study. Public insight has been gathered through qualitative methodology, since it enables to better capture its changing character, influenced by several variables including “geographical, temporal, socio-political or cultural contexts” (Aitken, 2010:1835), capturing information that otherwise would be omitted, making it appropriate to establish relationships at a local scale (Del Rio and Burguillo, 2009). A theoretical framework was developed helping to define several steps of a dynamic nature that ultimately lead to interviews with different local stakeholders. The adoption of such strategy has facilitated the accomplishment of abovementioned aims, i.e. demonstrating the major impacts perceived by the stakeholders and the benefits or social costs ascribed to RES projects.

Social research of Wind Power Projects

A recent literature review concerning social issues and qualitative research methodologies in RES projects, showed that despite the increasing relevance of the theme, social dimension is far from being fully explored. Mainly because as Ribeiro; Ferreira and Araújo(2011) have stated economic as well as environmental issues, are more easily measurable, being addressed more extensively than the social concerns.

Nonetheless, social aspects have been analyzed from a global scale, generally focusing on employment generation; community funds and partial project ownership.

According to several authors (Sastresa, Usón, Bribián and Scarpellini (2010); Allan, Mcgregor and Swales (2011); Blanco and Rodrigues (2009); Del Rio and Burguillo (2009) and Cuartas and Menéndez (2008)) one of the most common social aspects, within RES projects is the positive impact as far as employment generation is concerned. Notwithstanding, Del Rio and Burguillo (2009) also underlined that, for rural communities, other aspects (namely payment of rents and investment in the educational system) should not be overlooked, ultimately contributing to increase local social welfare.

Although community benefit schemes have been considered a common practice in RES projects, it is still not a formal institutionalized practice (RenewableUK, 2011). Despite this, a recollection by abovementioned author, showed the nature of different benefit schemes, encompassing social, economic and environmental areas, as being a positive rapport between the promoters and local stakeholders.

Munday, Bristow and Cowell (2011) suggested that RES project ownership might increase the socio-economic outcome in rural areas. Allan et al. (2011) considered this option as being vital to ameliorate socio-economic standards in regions that such projects were implemented, implying that, community benefit's positive effects were even stronger when combined with "shared-ownership scheme", overshadowing one of the most focused aspects within social research, the employment issue, registering a considerably minor effect.

Methodology

Methodology has been viewed as being essential to define a research study. To develop a successful field social research investigation it is necessary to have an integral perception of what it entails. Rubin and Babbie, (1997: 94) stated that viewing research process holistically has been fundamental to "create a research design". Despite the research strategy adopted, the most important issue is that it should allow answering the research question and attending its main purpose (Saunders, Lewis and Thornehill, 2007). The main goals of the investigation were expressed in the form of a research question: "What are the main social impacts (positive and negative externalities) of RES projects implementation, from a stakeholder's perspective?", which led later along the research process to focus on "how are those social impacts being perceived by focal stakeholders?".

The main questions of what is considered important and how it is viewed by the interviewees, were answered by following an integrated research design featuring interpretative insight, along with an exploratory research purpose applied to a case study scenario. In order to obtain an accurate description and interpretation of social phenomena from the perspective of the stakeholder, semi-structured in-depth interviews were selected. This technique was viewed as being appropriate due to its flexibility characteristics, allowing to achieve a detailed account of social impacts (King, 2004). A known advantage for the use of such qualitative methods in “exploratory research” has been, according to Mack, Woodsong, Macqueen, Guest and Namey (2005: 2) that by employing “open-ended” questions participants tend to “bring out rich and meaningful answers, that were not expected by the researcher”.

Case Study Characterization

The case study was developed in a rural area, located in the north region of Portugal, a region characterized by the high density of wind turbines, as shown in Figure 1.

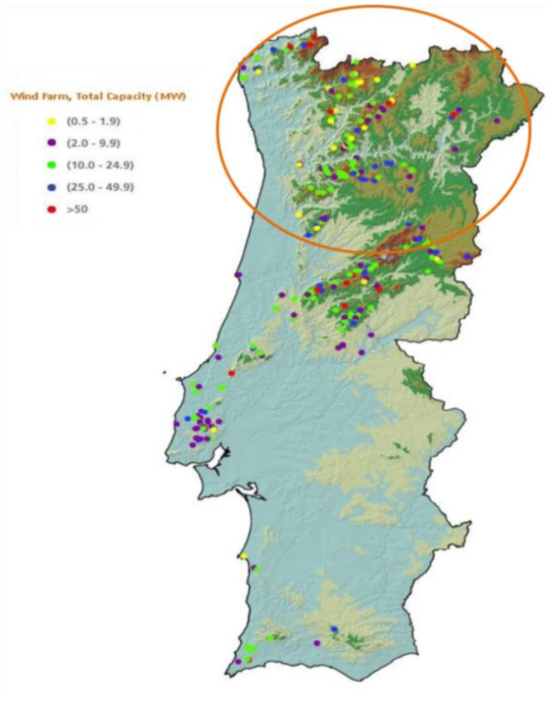

Figure 1 - Case Study location area. (Source: adapted from INEGI and APREN, 2011).

This has been an area associated to wind power deployment since the late 1990’s, and currently has a few projects in different stages of planning process, totalizing over 30 RES projects. Effectively Portugal has in recent years, invested in RES projects for a cleaner electricity production, backed up by national policies and legal framework.

In order to assess the potential socio-economic benefits at a regional and local scale, a case study was developed focusing a specific segment within stakeholder’s universe. Because wind turbines have been or will be installed in communal ground, which management is delineated by legal resolution nº 68/93, implying the institution of Communal Land Commission Councils, selected research participants were representatives from these same Commissions. This focal group was considered ideal for exploring local impact from RES projects because they have been present throughout the entire negotiation process and, represented a link between other key players, namely RES promoters and local population. This approach is expected to allow recognizing what both parties brought to the table, despite not being able to interview all focal stakeholders.

Although current legal framework established that 2,5% over total energy generation, income from a wind farm should be assigned to the local municipalities, other benefits derived from wind farm projects were also discussed with local community, namely with Communal Land Commission Council. Discussing with stakeholders this negotiation process directly contributes to answer proposed research questions, regarding what are the main impacts and how are they being perceived. Overall within stakeholders group, focused participants given their positions, and due to their responsibilities had a good knowledge of local reality, despite having different professional backgrounds. Most backgrounds ranged from three of the most preeminent local activities, such as construction workers, farmers or shepherds to engineers, accountants, bank account managers, contributing to diversified perceptions of wind energy deployment.

Further considering population characteristics, “target area” has an estimated average of 13.200 resident population, with focused villages having about 150 to 300 permanent local residents. Being a typical emigration area, population tends to increase during certain periods, especially during Summer time. This region could be described as having “disperse population” distribution, with a pronounced declining pattern due to above mentioned reason, as well as an increasing growth of elderly population. According to the latest statistic survey, Census 2011, National Statistics Institute (INE) (2012) the Portuguese aging population has increased circa 19% over the last decade, now reaching 2,023 million people. Of this universe the highest percentage (about 31%) of people over the age of 65 is currently concentrated in the northern region of Portugal (INE, 2012), coinciding with the selected study area. The cited characteristics, along with other factors such as the reliance on “agricultural subsidies” (Del Rio and Burguillo, 2009 and Munday et al., 2011), or the “high unemployment rate” make these areas ideal for RES project’s development.

Results

Regarding positive impacts stakeholder’s perceptions are till a certain extent, coincident with literature review undertaken. Most mentioned benefits are consistent with some of the identified categories for benefits schemes adopted by Sustainable Energy Authority of Ireland (SEAI) (2011: 60) and RenewableUK (2011) which included “community funds”, “benefits in kind”, “project ownership” or “local employment” (see Checklist 1). Allowing to establish a comparison and potential corroboration of obtained results versus other developed works.

Nonetheless, within stakeholder's statements, different perspectives regarding social issues were encountered distinguishing them from previous studies.

Despite such discrepancies, overall most participants viewed this investment as positive for local communities, registering both direct and indirect benefits (see Figure 2).

Regarding negative impacts, it is interesting to underline that all participants in the interview processes claim that none of the represented commissions ever received complaints regarding negative impacts from wind energy parks. Despite this, stakeholders did have many concerns regarding environmental, social and economic aspects (see Checklist 2), that were approached during negotiation process with project developers. Here similarly to what was verified with community benefits, there has been divergence in obtained answers.

Checklist 1 – Most mentioned impacts within categories of community benefits schemes (own elaboration).

Category	Most mentioned impact	Interview Subjects						
		1	2	3	4	5	6	7
Community Funds	- Regular payment (annual rent)	*	*	*	*	*	*	*
Benefits in kind	- Accessibilities provision or improvement	*	*	*	*	*	*	*
	- Social Equipments	*	*	*	*	*	*	*
	- Facility enhancements (repair local buildings)			*	*			
	- Environmental improvements (reforestation)		*	*		*	*	*
	- Wood supply to Commission members							*
	- Rental of local buildings	*						
	- Invest in other commercial activities (tourism)			*	*	*		
	- Donations			*		*		*
Project Ownership	-	-	-	-	-	-	-	-
Local Employment **Direct:**	- Local labor supply for construction phase						*	
	- Local labor supply for operational phase	*		*				
Indirect:	- Local labor supply for investment in social equipment	*	*	*	*	*	*	*
	- Local labor supply for investments in environmental improvement			*				

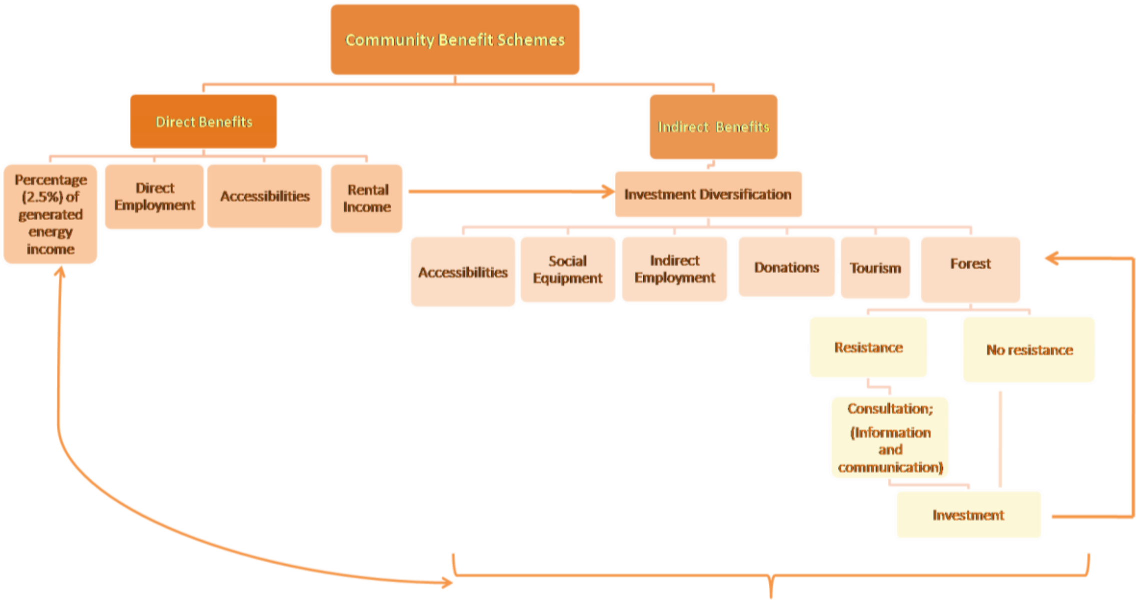

Figure 2 – Main direct and indirect benefits attained by wind power deployment (own elaboration).

Checklist 2 – Main referenced concerns with adverse impacts perceived by interviewees (own elaboration).

Category	Main Referenced Concerns						
	Interview Subjects						
	1	2	3	4	5	6	7
Landscape and visual impact	*	*	*	*	*	*	*
Noise emission impact	*	*	*	*	*	*	*
Wildlife impact	*	*	*	*	*	*	*
Land occupation and usage impact	*	*	*	*	*	*	*
Shadow flicker effect	*	*	*	*	*	*	*
Electromagnetic interferences	*	*	*	*	*	*	*
Socio-economic impacts:							
- Property value	*	*	*	*	*	*	*
- Cattle grazing	*	*	*	*	*	*	*
- Farming	*	*	*	*	*	*	*
- Tourism	*	*	*	*	*	*	*
Water resources impact	*	*	*	*	*	*	*
Air quality	*	*	*	*	*	*	*
Carbon footprint	-	-	-	-	-	-	-

*No impact
*Impact not negatively perceived
*Impact negatively perceived
- No information available

Discussion

Additional revenues have been mentioned by a large majority of interviewees as being the main advantage, when asked about main benefits, all interviewees reported community benefit funds as the first positive outcome for their villages, along with some benefits in kind, mainly providing or improving access roads. Checklist's 1 distribution of obtained answers accordingly to established criteria, reflects this tendency, being supported by Interviewee 2 quote: *"The main advantage for us is the financial benefit that is a compensation they give us resulting from the usage of land (baldios). Then we also have infrastructure improvement, since to access wind farm location, developers have to provide accessibilities, which is also reflected as a positive outcome for local community."*.

The main contradictions with existing literature (Munday et al., 2011 and Del Rio and Burgillo 2009) have been associated to other categories. Benefits in kind, for instance reforestation and indirect employment generation seem to prevail over other types of community benefit schemes more evident in previous studies (Munday et al., 2011; RenewableUK, 2011; SEAI, 2011 and Allan et al., 2011), such is the case of direct employment generation and project ownership.

Investments have been focused mainly towards day care centers for elderly people, reflecting a recurrent theme mentioned by research participants associated to increased aging of local communities. Interviewee 5 expressed it better when he said: *"(…) our biggest benefit was on a financial level, because it allowed to invest in new infrastructures and to improve others already existing. Before this would not be possible because we lacked income. These are remote areas, that do not have that sort of funds."*.

The extent of the potential impact of these projects in both social and economic dimension is adequately described by Interviewee 5: *"(…) here the little income we had was from the forest, there was no other source of income. We were talking about a yearly sum around 2 to 3 thousand euros, and now we are talking about 40 to 50 thousand. It is a very big difference."*.

For the most part of the stakeholders, employment generation has been associated to the way generated income is managed and redirected towards other investments, i.e. it has an indirect nature. These results reflected that indirectly generated employment should be emphasized, demonstrating a wide level of implementation contributing to local welfare, contradicting Del Rio and Burguillo (2009) findings, predicting enduring indirect jobs were probably very scarce. For example, Interviewee 2 gave an example of a nearby village that was very much undeveloped, and due to wind park implementation has now a retirement home that employed a total of about 18 people, making a substantial difference in an isolated rural area with social issues, namely aging and emigration of population as well as limited employment prospects.

Throughout the interviews certain underlying themes were identified, mainly related to information accessibility and communication of knowledge that ultimately influence in a positive or negative way the negotiation process, as well as the management process of attributed benefits. Relationships between local community's perceptions and acceptance of prospective investments were found. The complexity of such relationships was evidenced by obtained results regarding potential application of wind energy funds to forest resources, where respondents had conflicting views either willingly and consciously accepting this proposal or opposing it, preventing its application. Such resistance illustrated in Figure 2, is a consequence of a combination of socio-economic and cultural background allied to misinformation and miscommunication issues, implying negative aspects that cannot be dissociated from these benefits. Although the improvement of accessibilities reducing the risk of fires has been widely regarded as an asset, the initial foreseen prospect of a broader level of support and openness towards the idea of endorsing forest resources was bellow expected, due to registered divergences.

According to Interviewee 1 it has been quite challenging for some community members to accept reforestation, since grazing is a very ancient and typical activity. Within the group less supportive of projects that stimulate forest rehabilitation and its by-products, the abovementioned motivation was considered pivotal. However, another interesting fact for this attitude was given, suggesting a deeper reason for this lack of support and drive to revitalize this local resource. Still according to Interviewee 1, history played a major role in the current state of mind *"(…) we have a rural economy, and we have to make it profitable. But people are not aware of that. Before 1940's the management of this common land was directly made by local villages and everybody raised cattle, my family alone had a herd of about 400 animals (200 goats and 200 sheep), back then the government forced local population to sell their livestock and forested pasture areas. With implementation of democracy in 1974, there was a denial towards the forest, with people setting fire to previously forested areas. Regarding this issue, there is a negative rapport between local communities and communal land, and the sensation that there is still an injury that has not healed. People have to feel motivated to preserve and invest in this resource and only after that, they will have profit, meanwhile there is a lot of work to develop in order to raise awareness (…)."*.

In other cases, where communities were more aware and forest driven, acceptance and acknowledgment of forest investment was more prevalent. Respondents recognized that due to past activities, villagers were more alert to the importance and significance of the forest. This is the case of Interviewee 2*"(…) people in my village are highly conscious of forest related issues, since most of them worked precisely in the forest. Back then there was what they called the arboretum, a forest house, and about 80% of the village population worked there, from a very young age (14-15 years old) they had to leave school and work, also dedicating themselves to raising cattle. Therefore, for them a tree is like an asset."*.

Obtained statements have also underlined on one hand how crucial timely access to accurate information is to influence the outcome of contract negotiation, potentially contributing to beneficiate local communities, as well as the need to ensure stakeholders access to accurate information in order to make up their minds, and therefore deliberate about prospective opportunities. As admitted by interviewees 7 and 1: *"(…) our negotiation process was not very* *elaborate, we did not have negotiation skills for it. They arrived and offered a certain value per wind turbine, but we are not equipped to perceive if the amount is adequate or not (if it is very high or very low). (…) besides the promoters being very available during negotiation process, we did not have the knowledge to make that deal. (…)"* (Interviewee 7).

For Interviewee 1 *"(…) but it will be a difficult task to change mentalities. (…) currently people only think about short term investment, they don't have the perspective of long term investment, and I am referring to forest investment. People haven't seen yet the forest as an asset, or maybe as one of the biggest sources to generate profit and richness. Nowadays people view investment as applying revenues in local improvements (social equipment or accessibilities), that in my opinion will not have a return profit as interesting as the forest. I really think the secret here is to re-invest in the forest and people have not got that sensibility yet, so they do not see it as an objective, they do not make the proposal and do not vote for it. A lot of work needs to be done in order to raise awareness and motivate people to invest in the forest as a way to provide income, because this resource generates a lot of direct and indirect benefits. Besides biodiversity and other environmental issues, the forest creates many local jobs in several areas, such as tree resin, wood, mushrooms and honey. Therefore it's an asset that local population should take advantage of."*

On the other hand, Interviewee 3 mentioned *"(…) most of the population are aware of the value and need to make forest investments, but I am not saying all of them are, because that depends on the board of directors of the commission that changes from one locality to another." "(…) in my case, people are aware that we need the forest, and local population is so sensitive about this issue, that a local association was founded. At first there wasn't any income, but now that we have it, we are going to make business with all forests by-products (biomass, tree resin, wood, mushrooms and honey). We are currently studying the possibility of exploring the potential of biomass and analyzing proposals made to the local forest association. Consequently we are going to develop more, because the forest gives back in many ways and that is why I re-invest some of the money from wind farms in the forest."*.

Taking into consideration Interviewee 3's abovementioned statement, regarding future prospects and sustainability issues, comparatively to previous studies (Del Rio and Burguillo, 2009), largely due to the effort developed by commission councils, the tendency followed by benefit investments favoring diversification has been helpful to reconvert local rural economy, since indirectly opportunities are being developed to contribute to create attractive conditions to settle young population in the region. If this tendency is kept, a positive outcome could be perceived as far as wind farm potential contribution to mitigate desertification issues. However, as registered in other aspects focused in this case study, opinions seem to be divided, with other interviewees considering wind farms as being isolated investments, with needs regarding employment generation, considered essential to attract population to rural areas, as being very limited in time, associated to its construction phase. As mentioned by Interviewee 2: *"These investments require temporary construction work and then during operational phase they need maintenance. This maintenance will be made by a minimal number of qualified workers. Therefore I think that this is not a relevant contribution to decrease desertification."*.

According to Interviewee 7 point of view, in order to promote local socio-economic potential, it is necessary to ensure other types of benefits:*"(…) for me, this sort of investment would have a real benefit for the region, if benefits were in terms of local energy supply. For instance, if the energy is produced locally, why do not we have free energy supply, or cheaper energy bills? It could make a big difference. (…) or if it brought jobs to local economy (…) certainly even people that moved out to more urban areas, would come back to the village.".*

Regarding negative impacts, similarly to what was verified with community benefits, there has been divergence in obtained answers reflecting to some extent a problem with incomplete knowledge and also the recognition by research participants that benefits have a significant weight against potential negative impacts, which inevitably conditions its perceptions. Most of the negative impacts were either not verified or verified but not negatively perceived in this case study. For instance visual impact was according to some interviewees not verified due to wind farm location and substantial distance to residential areas or verified but not negatively perceived. Research participants also showed interest and concern over some aspects, namely impact on local economic activities; noise emissions and land occupation and usage (see Checklist 2).

According to Interviewee 1 *"(…) in our case, I do not think we will have visual impact because wind parks are located very far away from the village (about 3km). From residential areas it will not be even possible to see it. We (village) are located in the lower part of the mountain, and the wind park at a very long distance on top, therefore it will not be visible (…)"*.

Mostly interviewees claimed not having suffered of noise pollution, nonetheless measures were taken reduce its negative effects. For instance, Interviewee 3 claimed that special care has been taken to control noise emissions during certain periods of day, to avoid interference with highly ecologically sensitive areas. With a contrasting attitude to the rest of the interviewed group, Interviewee 7 stated that although no complaints by local community have ever been reported concerning this issue, he in particular considers his village is somewhat affected by noise emissions, being influenced by the prevalent wind direction.

Interviewee 1 highlighted that the development and maintenance of road accessibilities was a benefit that unveiled some disadvantages in terms of soil degradation and mobilization: *"Initial benefits such as development and maintenance of existing accessibilities were a positive addition, especially considering firefighting. But often these side roads end up having a negative effect on mobilization and soil degradation while having a positive effect as a barrier for fire propagation."*.

Although according to Interviewees 3 and 5 potential adverse effects on existing water lines used for agriculture, was one of the main concerns of local population during negotiation process. For Interviewee 1 most people regard land occupation as being confined to wind turbines space, when in fact this impact has a much more widespread effect than initially supposed by public opinion. This attitude is a response to the underlying lack of information that gives them a partial perception of reality, and not enough sensibility and awareness to identify *"one of the negative impacts resulting from development of accessibilities."*.

However the main drawback, according Interviewee 6, to has been associated to the gap within local community members. In this case study mistrust within stakeholders is promoted by economic interests associated to community benefit schemes attribution and the way they are being managed and re-invested. This conflicting behavior often leads to legal battles over who is entitled to manage and usufruct of the advantages of RES projects, defrauding a broader sense of community that has been patent in various interviewees answers, constantly focusing on community as a hole unit, and trying to suppress their needs instead of favoring individual parties: *"(…) it is one of the disadvantages, if not the biggest disadvantage from wind farms, it generates conflicts within local community, when ulterior economic interests are identified. (…) In our case, the old manuscripts describe this area as a common area destined to animal pasture, which was back then the main source of income connected to these mountain areas. One of the stakeholders (another village) did not see it that way, and went into negotiation process without consulting any of the other parts, which lead to the existing conflict (…)".*

These statements illustrate the fundamental need to incorporate local community members in all aspects of wind energy projects, in order to obtain public consent constituting an opportunity to incorporate suggestions made by them, further adjusting benefits to local needs, since proposed suggestions come from people with local knowledge.

Conclusions and Future Remarks

Although the relevance of wind energy's role towards a more sustainable energy system has been thoroughly recognized, with several case studies displaying impacts from its deployment, very few case studies have focused social dimension at a local scale, resorting to an exclusively qualitative methodology. This work aimed to develop such an approach and contributing to determine what were the main social impacts at local level from stakeholder's perspective.

To achieve the proposed research objectives a participative methodology supported on a case study selection and stakeholders interviews was designed and implemented. The intricate established research design allowed to, throughout its different phases refine and refocus the interviews towards crucial subjects, essentially based on focal stakeholder's perceptions. This aspect was extremely important, allowing to further establishing how those impacts were being perceived, ultimately leading to a logical understanding of obtained data.

The results heightened the relevance of local social and cultural aspects when addressing benefits or social costs ascribed to RES projects. The main social aspects of RES research were identified, as well as the nature of the issues that led to the obtained answers, while simultaneously establishing a comparison with other previous studies.

Most of the research participants declared themselves in favor of this type of investment. These opinions seem to be mainly driven by the perceived benefits resulting from wind farm deployment. The interviews outcomes denote a similarity between the main types of social benefits identified in literature review, yet with significant differences as for distribution within each type, emphasizing indirect employment, the use of benefits in kind, reinvestment of obtained revenues and non-applicability of project ownership. These discrepancies have illustrated how challenging can management of community benefit schemes be, being in this case mainly connected to an identified mix of cultural background, misconception and misinformation issues deeply rooted on local traditions. Denoting the need to adopt a widespread integrative solution involving various stakeholders within negotiation process, in order to achieve a more consensual, future length appropriate outcome, reinforcing the importance of local community perception’s to achieve local sustainability.

The presented case study revealed a consensual acceptance of the benefits of these projects but the validation of these results and their representativeness on National scale can only be achieved if the work proceeds with the analysis of other regions and even of other less consensual technologies. The implementation of the proposed participative methodology to other case studies would be a particular benefit providing new insights to both the scientific field of social impact assessment and to the sustainable energy decision making. The proposed future work should further help determining if local characteristics (considering both existing natural and social resources) bear some influence over the way community benefits are spent, implying a pattern in terms of its future investment; or if a different dynamic between focal stakeholder´s interaction would result in more innovative and diversified projects entailing a much more significant contribution towards sustainability of isolated rural communities.

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Economic, social, energy and environmental assessment of inter-municipality commuting

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Abstract

Commuting is one of the main contributors to the large energy consumption patterns in modern economies. Worldwide, trips between home and job locations are increasing and it is common to find commuters having to travel every day to a different city. The need to reduce the energy spent in commuting has attracted attention of academics and policy makers. This research main goal is to improve the knowledge on the economic, social, energy and environmental impacts of inter-municipality commuting. For this, it is assumed a hypothetical scenario based on the assumption that Portuguese households do not travel between different municipalities for commuting purposes coupled with the expected related changes in private final consumption. Accordingly, the direct, indirect and induced impacts of inter-municipality commuting are assessed using an Input-Output model. The significance of the estimated net benefits of commuting is analyzed according to their macroeconomic (employment, GVA, taxes, international imports), environmental and energy (primary energy consumption, CO_2 emissions) dimensions. The results obtained empirically support that inter-municipality commuting has significant opportunity costs in the GVA and GDP as well as in primary energy consumption (namely Oil and its derivatives) and CO_2 emissions.

Keywords: Commuting, Fuel Consumption, Input-Output Analysis, Impact Assessment

JEL Codes: O1 – Economic Development*;* Q4 – Energy; Q5 - Environmental Economics;

1. Introduction

Through the last century, urban population has consistently grown worldwide. Large metropolitan areas expanded in terms of population and dimension. Naturally, these processes did not occur homogeneously in the territories. Through the last decade, in most of the European and American cities, population in suburbs has largely increased while the population living in Central Business Districts has generally shrunk. Portugal was not an exception. From Census data, between 1980 and 2011, Lisbon and Oporto municipalities lost 33% and 27% of their population, respectively. On the other hand, population in Great Lisbon and Great Oporto metropolitan areas has increased more than 14% and 15%, respectively (INE, 2012). This phenomenon is often referred as urban sprawling and is associated with an increasing need of travelling larger distances between homes and job locations. This increase in commuting was sustained by economic conditions that allowed residents to buy fuel at relatively low prices. This has favoured increases in the consumption of primary energy and consequently CO_2 emissions. So, the lack of an Urban Policy and Planning concerned with the increase in the energy consumption has been contributing to an increasing dependence of fuel by urban commuters worldwide.

Analyzing the Portuguese consumption of Refined Petroleum Products in 2007 one can confirm that 21.5% is due to households private consumption, 23.2% is for Exportation and the rest is consumed as intermediate goods for industrial production. Additionally, 7.5% of total household income is spent in car buying and repairing and 1.4% is spent with road and rail passengers transportation services (INE, 2011). As with other products, consumption of these products affects the consumption of natural resources and the generation of pollutants as well as the corresponding levels of Gross Domestic Product (GDP), Gross Value Added (GVA), Employment, Imports and Tax collection. In the Portuguese economy (and other European economies), these goods are mainly imported or have a large amount of imported inputs in their production processes contributing to negative impacts in the balance of payments and the reduction of the multiplier effects in the economy.

This research intends to contribute to improving the knowledge on the economic, social, energy and environmental impacts of inter-municipality commuting. First, we assume a scenario in which no inter-municipality commuting occurs. Accordingly, people will be supposed to work in the same municipality in which they live or, alternatively, any possible commuting to other municipalities does not involve spending fossil energy or other expenses. Thus, the opportunity costs of commuting can be estimated as the differences between the current situation (in 2007, our base year) and the scenario. It is important to note that, in the scenario in which no inter-municipality commuting is assumed, the consumption of Portuguese households in cars, fuel and other products is reduced and, conversely, their spending in other products non-related with commuting is increased. To assess the economic, social, energy and environmental effects of this scenario we apply an Input-Output (I/O) model with a Supply and Use (SUT) format at basic prices and domestic flows, extended with an energy-environmental satellite account. The results will be offered considering different energy and environmental indicators (Oil, Natural Gas, Coal consumption and CO_2 emission) and economic and social ones (GDP, GVA, Imports, VAT, Other taxes on products and Employment).

The next section offers a concise literature review, highlighting the leading attempts to address the impacts of commuting on the economy, environment and energy consumption. The third section presents the methodology, considering three main phases, namely the procedures to estimate fuel consumption associated with inter-municipality commuting, the approach to assess the impact on the other products in the economy and, finally, a brief description of the I/O model adopted and the derivation of the satellite account. The fourth section presents the results obtained and suggests opportunities to explore the significance of the economic, social and environmental impacts associated with inter-municipality commuting.

2. Literature Review

In recent years, people have become increasingly aware of critical issues such as energy consumption and greenhouse gas (GHG) emissions. Accordingly, numerous contributions have focused their attention on the issue of passenger transportation, stressing its responsibility in 20% of the world primary energy use and in 13% of energy-related CO_2 emissions (IEA, 2006; Zhao et al., 2011). Regarding the Portuguese case, it is worth mention that, in 2010, the transportation sector total share of final energy consumption was 40.6%, while this sector direct 'responsibility' for GHG emissions reached a share of 26.8% (EUROSTAT, 2012). These figures, namely in what concerns to passenger transportation, have been into a large extent related with urban forms and cities densities, i.e., as the frictions to travel larger distances have been relaxed, cities have expanded and become less dense. These developments led to a fast increase in car ownership and use (Glaeser and Kahn, 2001; Zhao et al., 2011). For example, Camagni et al. (2002), regarding the Milan metropolitan area, confirmed that higher energy consumption and environmental impacts are associated with lower densities, sprawling development and urbanization processes. These studies, and other contributions more focused on energy consumption (Naess et al., 1995; Naess, 2010) or on their corresponding environmental consequences (Muñiz and Gallardo, 2005) had come to similar conclusions regarding the effects of extensive car use, the modal split and energy consumption. Fu et al. (2012) estimated the energy savings per commuter, in Ireland, resulting from the increase in home working. These authors argue that policies to restrain commuting should be of highest priority in terms of energy and emissions reduction. However, none of the contributions referred above had the scope of internalizing the interdependencies which characterize each economy within a certain geographical area. As an example, it is important to be aware that if a given economy reduces the consumption of a certain electricity-intensive product, the corresponding macroeconomic and the environmental shocks will depend of the type of inputs used in the electricity production or in the origin of the electricity (national or abroad).

The I/O models offer a method to properly integrate these economic interdependencies, namely if extended in order to deal with both energy and environmental issues (Cruz et al., 2005; Miller and Blair, 2009). These models have the capability of presenting the results in terms of direct impacts but also give the chance to discriminate the indirect and induced impacts of a shock. For instance, if the automobile industry increases its production the energy consumed is expected to increase, simultaneously this also leads to additional increases in the production of components of those cars (indirect effects). Moreover, as the production expands, the household's income also increases leading to a subsequent increase in the household's consumption (induced effects).

Cruz (2009), and Cruz and Barata (2011) developed satellite accounts in order to analyze the links between the different economic sectors, energy production and use, and the 'corresponding' production of CO_2 emissions. Regarding the focus on energy studies (Alcántara and Roca (1995), Labeaga and Labandeira (2002)) and Cardenete and Saguar (2011) have also employed an I/O model to estimate primary energy consumption and CO_2 emissions. The potential of applying these models at regional or national levels critically depends on the possibility of splitting the emissions generated by the branches of the economy into different effects depending on what demands their outputs have to satisfy. Alcántara (2011) also applied I/O techniques in order to analyse the different types of final demand and their importance in CO_2 emissions in Spain. These models which may include energy, waste or water together with economic data are mostly referred as hybrid or as extended I/O models.

In all these modelling approaches, the main idea is that the energy consumption is dependent on the domestic production and therefore on the consumption made by households, Government, either domestically or for exports. Indeed, the idea of simulating, in an I/O modelling framework, the changes in households' consumption patterns has been widely implemented. E.g., this methodology was used to estimate the economic impacts that could result of a change in the food diet of Flanders households (Dils et al., 2012) or the economic and environmental consequences of providing electricity to rural areas of India (Shimpo et al., 2009). More recently, Berglund (2012) analysed a time-series of CO_2 emissions from 1993 to 2005 in order to estimate the global climate impact of the different consumption levels by Sweden households. To summarize, the I/O models have the potential to estimate the direct, indirect and induced impacts which result from external shocks in the economy or simply from changes in consumption patterns. Simultaneously, when dealing with hybrid I/O, the results often include the impacts in terms of primary energy consumption and CO_2 emissions. In the next section we present firstly the methodology used to estimate the change in the household consumption pattern in Portugal associated with the scenario for no inter-municipality commuting. Secondly, our I/O hybrid model is presented as well as the estimation made in order to assess the direct, indirect and induced impacts in the Portuguese economy.

3. Methodology

In this section, the methodology used to estimate the economic, social, energy and environmental impacts of inter-municipality commuting is described. In this research, the household final consumption pattern is expected to change as inter-municipality commuting wipes out. Our approach is divided in three major steps. The first consists in the estimation of expenditures of fuel consumption associated with inter-municipality commuting. The second regards the estimation of the different consumption patterns among households which intensively commute and the others. Finally, these data are incorporated in an extended I/O model to assess the direct, indirect and induced impacts that the ceasing of inter-municipality commuting would generate in the Portuguese economic, social, energy and environmental dimensions.

3.1. Distance Travelled and Fuel Consumption

The first step consists on the estimation of fuel consumption by the Portuguese households due to inter-municipality commuting. For this, Census 2001 data on the number of commuters between municipalities is considered (INE, 2003). Accordingly, about 23.7% of the Portuguese individuals (which have stated to work or study) have to travel daily to a different municipality. Then, the information on the modal share in each municipality is considered. Our purpose is to estimate the number of daily inter-municipality commuters which use car. Then using a matrix representing the kilometric road distance between Portuguese municipalities (Ferreira et al., 2012) we calculate that Portuguese commuters make approximately $51x10^6$kilometers (Km) by car each day, being more than $24x10^6$Km in the region of Lisbon. This information highlights the evidence that people commute more intensively in the metropolitan areas.

To estimate the corresponding litters of fuel consumed we combined the methodology proposed by Carvalho *et al.* (2012) and data from the Portuguese Automobile Association (ACAP, 2009). The results indicate average consumptions of 7.1 and 6.7 l/100 Km for gasoline and diesel, respectively, in 2007. Accordingly, our estimates indicate that Portuguese inter-municipality car commuters spent more than $3x10^6$ litters of fuel per day. Finally, using the 2007 average annual price per litter of fuel type (DGEG, 2012b), the daily expenditure in fuel is estimated and, using the “Portuguese working days” of that year, we have calculated that in 2007 Portuguese households spent approximately $485x10^6$ Euros in gasoline and $362x10^6$ Euros in diesel with inter-municipality commuting. These values correspond to 25.2% and 24% of the accumulated expenditure in gasoline and diesel, respectively, by households below 65 years old.

3.2. Household Consumption Changes

Commuting practices have further impacts on household’s final consumption than the direct consumption of Refined Petroleum Products, i.e., one should not ignore that there are several other products that have their consumption affected by commuting. To study these phenomena we considered the Portuguese Household Budget Survey, disaggregated by 199 products (INE, 2008). This survey has not explicit information regarding commuting patterns of households. Thus, for analyzing the commuting behaviour we divided our sample and estimated two different household consumption structures: one corresponding to the consumption pattern of commuting-intensive households, and the other to the rest of the households. This was done using two criteria: the amount spent in fuel and the expenditure in public transportation services.

Comparing these two consumption structures, several differences could be identified in products related with transportation, insurance and expenditures in restaurants. Table 1 illustrates the changes considered for several products and that were taken into account in this modelling exercise.

Table 1 - Changes in households' final consumption (for the scenario with no inter-municipality commuting)

Product	**Change in final consumption (%)**
Manufacture of motor vehicles	-16.0
Wholesale, Retail Trade and Repair of motor vehicles and motorcycles	-25.1
Passenger interurban transport via railways	-9.5
Other Passenger Land Transport (urban)[1]	+21.2
Warehousing and Support Activities for Transportation	-24.8
Food and Beverage Service Activities (on restaurants)	-7.7
Non-Life Insurance	-9.6

The changes in these products' final consumption and the reduction in fuel consumption represented a total reduction of approximately 2.7% of household's final consumption. In order to 'compensate' this, the household's consumption of the remaining products was increased assuming a stable overall marginal propensity to consume (and consequently the marginal propensity to save).

3.3. Input-Output Model

Following the assessment of the differences in household's final consumption resulting from a change in the commuting patterns, our aim is to identify the direct, indirect and induced impacts that would occur according with the scenario of no inter-municipality commuting. Our approach is based in an I/O table, whose structure is presented in Figure 1. This I/O table, with 431 products and 125 sectors, at domestic flows and basic prices, takes as a starting point the Portuguese National Accounts Supply and Use Table (SUT), for the year 2007 (INE, 2011). An important feature of this I/O table is the consideration of two households groups: those headed by a person with more than 65 years old, and the ones headed by somebody less than 65 years old[2]. In the modelling procedure we considered that only those below 65 years old would be in conditions to commute to their school or workplace. In order to include the induced impacts, the I/O table was 'closed' to the consumption of this last household's group. The consumption of households over 65 years old was considered in the exogenous part of the matrix. More details on these modelling procedures may be found in Ramos *et al.* (2011). Additionally, using a satellite account approach regarding the primary energy consumption by industry (DGEG, 2012a) the changes in Oil, Natural Gas and Coal consumption are evaluated in

[1] This value is positive due to the increase in the use of urban public transportation inside metropolitan areas.
[2] This model was developed as part of the research project DEMOSPIN (FCT PTDC/CS-DEM/100530/2008), in which the authors participate.

terms of tones of oil equivalent (toe) and then estimated the corresponding CO_2 emissions using the conversion units for each type of fuel as suggested by the Intergovernmental Panel on Climate Change (IPCC, 2006; IA, 2011). The methodology used followed Cruz (2009).

Figure 1 – General framework of the I/O table

0	Intermediate consumption matrix (including < 65 household income and consumption) **Z**	Exogenous final demand matrix **Y**	Domestic Products Use (at basic prices - bp) $\mathbf{x}^{P}$
Production matrix **P**	0	0	Industries Total Output (at basic prices - bp) $\mathbf{x}^{I}$
	Imported (international) inputs ($\mathbf{m}_z$)	Imported (international) exog. final demand ($\mathbf{m}_y$)	
	Taxes less subsidies on inputs ($\mathbf{t}_z$)	Taxes less subs. on exog. final dem. ($\mathbf{t}_y$)	
	Gross oper. surplus (except h. mixed income) (**w**)		
Domestic Products Supply (bp) ($\mathbf{x}^{P'}$)	Industries Total Input (bp) ($\mathbf{x}^{I'}$)		

Let us call **A** to the great matrix of Figure 1, composed of **Z**, **P** and the 0 filled quadrants. Let us call **x** the vector comprising $\mathbf{x}^{P}$ and $\mathbf{x}^{I}$. From Figure 1 it is patent that:

(2) $\mathbf{A.i} + \mathbf{Y.i} = \mathbf{x}$

where **i** denote 1-filled column vectors, of proper size, whose mission is to add up the different columns of **A** and **Y**. We may compute as well input coefficients in matrix **A**, dividing each of its cells by the entries in $\mathbf{x}^{P'}$ and $\mathbf{x}^{I'}$ located in the bottom of Figure 1 (that are the totals of the corresponding columns).

$b_{ij} = \frac{z_{ij}}{x_j^I}$ and $q_{ij} = \frac{p_{ij}}{x_j^P}$ are the two different sets of input coefficients representing the locally produced inputs (at basic prices) used in the production processes of industries and the shares of each industry in the production of each product (as principal or secondary products), respectively. **C**, the input coefficients matrix, may be defined as:

$$\mathbf{C} = \left[\begin{array}{c|c} \mathbf{0} & \mathbf{B} \\ \hline \mathbf{Q} & \mathbf{0} \end{array}\right]$$

we then it may be re-written (2) as:

(3) $\mathbf{C.x} + \mathbf{y} = \mathbf{x}$ (**y** is the vector **Y.i**)

so

(4) $\mathbf{x} = (\mathbf{I} - \mathbf{C})^{-1} . \mathbf{y}$

The multipliers matrix $\mathbf{D} = (\mathbf{I} - \mathbf{C})^{-1}$ has in fact four different parts:

$$\mathbf{D} = \left[\begin{array}{c|c} \mathbf{D}^1 & \mathbf{D}^2 \\ \hline \mathbf{D}^3 & \mathbf{D}^4 \end{array}\right]$$

$\mathbf{D}^1$ and $\mathbf{D}^3$ represent the impacts respectively on product outputs and industry outputs of changes in exogenous final demand condensed in **y**. $\mathbf{D}^2$. $\mathbf{D}^4$ refer to multipliers, measuring effects on $\mathbf{x}^P$ and $\mathbf{x}^I$ as well, of a reallocation of the final demand to the industries that fill it. In fact, the most important sub-matrix of **D** is $\mathbf{D}^3$, as the final demand consists of products but the GVAs as well as the employment impacts are generated by the industries.

In this contribution, we do not proceed in the most common way, analyzing the impact of a change in **y** on the output $\mathbf{x}^I$ provided by $\mathbf{D}^3$. Otherwise, our approach consisted in modifying matrix **C**, namely the sub-matrix **B**, in the part corresponding to the consumption of households with less than 65 years old. As the total consumption is kept stable, the consumption change of products associated with commuting is compensated by a proportional change in the consumption of products which are non-related with commuting (and therefore the sum of the total direct effects is null). In this sense, we assumed that the marginal propensity to consume (and to save) is stable. $\mathbf{D}^3$ was then recalculated with the modified **B** and **C** matrices, which allow one to estimate the new output **x**, for the same total final exogenous demand **y**.

With the new output **x** and the energy-environmental satellite account, we estimated the new primary energy requirements by industry and by households, as well as the corresponding CO_2 emissions. In economic terms, the new output will also prompt changes in other macroeconomic indicators as GDP, GVA, VAT, other Taxes on products less Subsidies, Imports and Employment.

4. Results and Discussion

In this section we present some of the most significant opportunity costs regarding the expected economic, social, energy and environmental impacts associated with inter-municipality commuting. The results presented in Table 2, regarding primary energy consumption and CO_2 emissions[3], remark the negative impacts of commuting in the environment.

Table 2 – Environmental Impacts of Commuting

	Initial value (with commuting)	Scenario (without inter-municipality commuting)	Change	%
Oil and Derivatives (toe)	15.652.935	15.034.648	- 618.287	-4.0
Natural Gas (toe)	3.773.160	3.819.255	46.095	1.2
Coal (toe)	2.909.866	2.957.636	47.770	1.6
TOTAL	22.335.961	21.811.539	- 524.422	- 2.4
CO_2 emissions (10^3 tonnes)	61.521	60.161	-1.360	-2.2

A reduction in the consumption of Oil and its Derivatives is expected as a result of ceasing inter-municipality commuting (direct effect). However, as the economy grows (as a consequence of the increase in the consumption of other products) the indirect and induced effects are responsible both by a total impact which is lower than the initial reduction as well as the increase in the consumption of Natural Gas and Coal. The substitution from products imported by the domestically produced ones leads to a subsequent increase in the consumption of primary energy or Electricity. As an example, the increase in the output of the industry "Production, Transport and Distribution of Electricity" implies an increase of 1.7% in the consumption of Oil and its Derivatives. The CO_2 emissions would also decrease significantly mainly as a result of the decreasing consumption of fuels and refined petroleum products.

Table 3 presents the impacts associated with inter-municipality commuting in the main socioeconomic aggregates.

[3] Values in Table 2 differ from the ones provided by the IPCC data on National GHG Inventories as they exclude the primary energy consumption associated with exports.

Table 3 – Economic and Social Impacts of Commuting

	Initial value (with commuting)	**Scenario (without inter-municipality commuting)**	**Change**	**%**
GVA (10^6 Euros)	145.698	147.004	1.307	0.9
Imports (10^6 Euros)	66.867	66.771	- 96	- 0.1
Taxes on Products less Subsidies excluding VAT (10^6 Euros)	8.549	8.192	- 357	- 4.2
VAT (10^6 Euros)	14.333	14.241	- 92	- 0.6
GDP (10^6 Euros)	167.714	168.570	856	0.5
Employment (Full-time equivalent)	4.986.499	5.018.661	32.162	0.7

The indirect and induced estimated effects are positive, leading to an increase of the GDP, GVA and the Employment. Further, for the scenario with no inter-municipality commuting 116 (of the 125) industries would increase their Output and globally the Portuguese GVA would increase approximately 0.9%. The estimation revealed that the industries that increase more in terms of GVA are the Other Passenger Land Transport, Telecommunications, Real Estate Activities and Retail Trade, except of motor vehicles and motorcycles. Among the most negatively affected industries are the Manufacture of Refined Petroleum Products, the Food and Beverage Service Activities, Wholesale, Retail Trade and Repair of Motor Vehicles and Motorcycles and Warehousing and Support Activities for Transportation.

The overall impact on Imports is mitigated (-0.1%) because the initial shock is compensated mainly by the effect of the increase in household's income and consequently in private consumption (induced effect). Another interesting result is the estimated reduction in Other Taxes on Products and VAT. The increase in the consumption of the majority of the products and consequently on the associated Other Taxes on Products and VAT, does not compensate the reduction in the consumption of products with relatively high rates of Other Taxes and VAT, as it is the case of motor vehicles and petroleum products.

Finally, in terms of Net Employment effects, the changes in the household consumption would result in a positive impact. In terms of industries, the majority of the employment generated would be associated with the Agriculture and Farming of Animals, the Retail Trade (except of motor vehicles and motorcycles) and the Other Passenger Land Transport industries.

Summing up, if households' consumption is reallocated from products associated with commuting to the other products it is expected that the economy grows and the consumption of primary energy inputs decreases. So, according with the results obtained, the Portuguese GDP would increase 0.5% and Employment 0.7%. Additionally, savings in terms of the use of

Oil and Derivatives would be more than 3% and the reduction in CO_2 emissions could surpass 2%.

5. Conclusion

The main aim of this research is to assess the relative magnitude of the economic, social, energy and environmental opportunity costs from commuting in order to assist policy making.

The results show that, in Portugal, the responsibility of inter-municipality commuting, as a consequence of the need of travelling between different municipalities and mostly in the area of Lisbon, is very significant regarding the global consumption of Oil and Derivatives and of the correspondent CO_2 emissions. The results also suggest that the absence of urban and energy policies counteracting the growing increase of the distances travelled by commuters (e.g., by controlling the urban sprawling), besides the negative impacts in terms of primary energy consumption and CO_2 emissions, contributes to a contractionary impact in the economy. Further, cities and regions' development grounded in the use of private transport imposes a significant supplementary macroeconomic burden in economies where oil (and/or its derivatives) and cars are mainly imported.

Accordingly, the results empirically support policy-oriented measures capable of reducing car use, restraining commuting intensity and the amount of kilometres travelled every day by metropolitan residents, as they are potentially beneficial to macroeconomic indicators such as GDP, GVA and Employment. These conclusions have the additional significance that for economies where oil and its derivatives are predominantly imported such policy suggestions positively contribute to socio-economic growth and simultaneously contribute for improvements in three pillars of energy policy: security of energy supply, competitiveness and environmental protection.

Acknowledgements

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Evaluation of Post-2012 carbon policies

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Abstract

A dynamic-recursive general equilibrium model ICES was employed to evaluate the alternative post-2012 targets and policies of CO2 reduction in Annex I and non-Annex I countries. The special focus of this study is to investigate the implications of hot air trading and to evaluate its impact on post-2012 climate regime.In the model the carbon abatement targets of all regions reflect the low end of pledges confirmed at COP-16th negotiations on climate change. Countries' commitments were evaluated for the alternative policy settings that include international carbon trading, domestic actions, and linking of the EU ETS with Russian and Ukrainian carbon markets. The results of computer simulations reveal that by 2020 global carbon emissions will exceed their levels in 1990 by 71– 96% depending on the model scenario. The multilateral implementation of COP-16th pledges result in the lowest emission levels among the model scenarios, but still by 5 Gt of CO2 overshoots the levels sufficient to stabilize atmospheric GHGs concentrations at 450 ppm by 2100. Attainment of COP-16th commitments would cost 0.4% − 0.6% of baseline GDP, depending on the size of carbon market. Only the possibility to trade permits with other countries incentivises Russia and Ukraine to abate emissions below the baseline. Such trade is also profitable for the EU, as it halves the carbon price comparing with the case when EU implements its emission policy domestically. The important findings are that due to spillover effects, domestic price on carbon does not necessary correlate with welfare implications of carbon policies; countries with loose abatement targets could be affected by the terms of trade effects that result from emission reduction in other countries. The study concludes that ambitious abatement targets along with large emission market could make the climate policy effective.

Keywords: carbon abatement, emission trading, general equilibrium model.

JEL codes: C68, Q54, Q53.

DAY 10 - 9:30		
Room 626 - Energy System Analysis 2		
Energy planning with electricity storage and sustainable mobility: the study of São Miguel island	Miguel Moreira da Silva[1]; Manuel António Matos[2]; João Abel Peças Lopes[2]	[1]Faculdade de Engenharia, Universidade do Porto; [2]Faculdade de Engenharia, Universidade do Porto / INESC Porto
Useful work transitions for Portugal from 1856 to 2009. Intensities and European patterns.	André Cabrera Serrenho[1]; Benjamin Warr[2]; Tânia Sousa[1]; Robert U. Ayres[2]; Tiago Domingos[1]	[1]Instituto Superior Técnico, Technical University of Lisbon; [2]INSEAD
The systems of data acquisition in bioreactor for modeling of biowaste composting	Damian Janczak; Jacek Dach; Krzysztof Pilarski; Piotr Boniecki; Jacek Przyby; Andrzej Lewicki; Wojciech Czekała; Kamil Witaszek; Pablo César Rodríguez Carmona; Marta Cieślik	Institute of Biosystems Engineering, Poznan University of Life Sciences, POLAND
Selection of portfolios of electricity generation projects: an exploratory study	Eduardo Matos, Paula Ferreira, Jorge Cunha	Center for Industrial and Technology Management, Universidade do Minho
Potential Role of Stationary Urban Distributed Storage on the Management of Power Systems	José Gonçalves[1,3], António Martins[1,3], Luís Neves[1,2,3]	[1]University of Coimbra, [2] Polytechnic Institute of Leiria, [3] INESC Coimbra

Energy planning with electricity storage and sustainable mobility: the study of São Miguel Island

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Abstract

This paper describes an energy planning methodology for enhancing the sustainability of a given isolated system, through a multicriteria evaluation of strategies for renewable energy sources integration, electricity storage, sustainable mobility and the adoption of energy efficiency measures. This methodology consists in a process of systematic building of energy planning alternatives, which are analyzed through a detailed modelling of meaningful criteria, i.e.: environmental impact (carbon emissions from the transport sector and power system); economic and financial costs (power generation costs, costs of centralized storage, costs of electric mobility and costs of energy efficiency measures); and adequacy of the generation system (loss of load expectation). In addition, this work develops an algorithm for unit commitment and economic dispatch, including renewable energy sources, centralized electricity storage, and electric vehicles charging and vehicle-to-grid. The developed energy planning approach is applied to the São Miguel Island (Azores, Portugal), bearing in mind its power system characteristics and expected investments. This work, besides identifying energy planning alternatives and computing the selected attributes (associated to the criteria) for the year 2030, presents a multi-attribute and multi-scenario analysis that takes into account multiple points of view and the uncertainty of future fuel and electricity prices.

Keywords: Energy Planning; Electricity Storage; Sustainable Mobility; Multi-attribute Analysis; São Miguel Island

Nomenclature

f	number of fuel types for ICVs	ACC_{PS}	equivalent annual capital cost for additional power generation units (€)	P_k^{max}	maximum power output of the fossil-fired unit k
i	type of internal combustion fuel	OMC_{PS}	annual operation and maintenance cost for power generation units (€)	P_k^{min}	minimum power output of the fossil-fired unit k
N_v	total number of light vehicles	NRC	annual operation and maintenance cost for non-renewable energy sources (€)	SR_i	spinning reserve at period i
sh_i	share of light vehicles with fuel i	RC	annual operation and maintenance cost for renewable energy sources (€)	MUT_k	minimum up-time of unit k
m_d	daily mileage of light vehicles (km)	$u_{i,k}$	status (1-on; 0-off) of unit k, at period i	MDT_k	minimum down-time of unit k;
et_i	well-to-wheel emissions factor of light vehicles with fuel i (gCO_2/km)	F	fuel and fixed costs in period i, of unit k with $P_{i,k}$ of power output	i_{su}	hour at which the unit k is started up
sh_{EV}	share of EVs among the light vehicles of the system	$P_{i,k}$	power output from unit k at period i	i_{sd}	hour at which the unit k is shut down
H	total hours of a day	n	number of units (non-renewable generators)	$RG_{i,k}^{I}$	renewable generation of energy type k, at period i, in the base year (MWh)
h	hour	C_k^u	costs of starting-up unit k	RP_k^{I}	already installed power of renewable generation of energy type k, in the base year (MW)
N	number of non-renewable electricity generators per fuel type	C_k^d	costs of shutting-down unit k	RP_k^{II}	new installed power of the renewable generation of energy type k, in the target year (MW)
j	fuel type of non-renewable electricity generation	P_i^L	electricity load at period i, including the additional load from EVs' charging	C_k^R	Feed-in-tariff for renewable generation, energy type k, that includes Capex and Opex (€/MWh)
$G_{h,j}$	hourly electricity generation of j type generation (kWh)	P_i^R	total renewable power output at period i (including wind, hydro, geothermal, biomass, etc.)	E^i_{tot}	annual electricity demand of the target year (MWh)
eg_j	emissions factor (including processing and extraction, transport of raw material, and electricity generation) owing to j type of electricity generation (gCO_2/kWh)	P_i^S	power output from centralized storage at period i (which electricity comes from surplus renewable energy sources), according to a strategy for daily generation profile, tuned to supply electricity at off-valley periods (assuming a constant power output)	F_{tot}	annual electricity generated by the centralized storage facility (CSF), resulting from a strategy for daily generation profile, and calculated as follows (MWh)
D	number of days of the target year	P_i^V	power output from EVs V2G at period i, according to a strategy for daily V2G profile with a constant power output	F_{stor}	annual electricity stored by the CSF, due to RES surplus (MWh)

η_{ss}	energy transformation (round-trip) efficiency of the CSF (%)	C_{e2}^{EV}	cost of electricity generation through EV Vehicle-to-Grid (€/MWh)	L_c	lifetime in cycles
d_o	typical hours of energy autonomy in a day	P_{e2}^{EV}	local electricity selling price at off-valley hours, for EVs (€/MWh)	DoD	depth of discharge for the corresponding L_c (%)
DOD_L	maximum depth of discharge (%)	E_{disp}	annual electricity dispatched from the EVs, according to a strategy for daily V2G profile, tuned to provide energy at off-valley periods (MWh)	C_{EffPS}	energy efficiency cost applied to the power system (expressed in €/GWh), which increases linearly over time.
P_p^S	CSF power output, at the peak power period p (MW)	EV_i^{ch}	EVs power demand, at period i, according to a strategy for daily charging profile (MW)	E_{ICVs}^{i-1}	annual ICVs' emissions in year $i-1$ ($tonCO_2$)
η_p	power generation efficiency of the CSF (%)	EV_{EC}	energy consumed per EV for mobility purposes (MWh/km)	EE	annual abatement potential owing for efficient ICVs (%)
C_c	specific energy cost (€/MWh)	m_d	daily mileage of each EV (km)	TF	annual abatement potential by improving the traffic flow (%)
C_p	specific power cost (€/MW)	N_{EV}	number of EVs in the system	DB	annual abatement potential owing to improved driving behavior (%)
C_{co}	additional cost for corrosion prevention measures, in case of a seawater storage facility (% of capital cost increase)	EV_{ES}	total energy storage of the EV battery (MWh)	DD	annual abatement potential by reducing the distance driven (%)
C_e^{SS}	local electricity purchase cost for valley-hour rate, for CSF (€/MWh)	r^d	rate of the EVs' daily available energy for V2G, according to a strategy for daily V2G profile (%)	BF	annual abatement potential by blending low carbon biofuel (%)
P_e^{SS}	local electricity selling price for off-valley-hour rate, for CSF (€/MWh)	η_{conv}	efficiency of the EV conversion of the stored energy back to electricity (%)	Con	conversion factor from $tonCO_2$ to GWh of energy consumption from the ICVs
C_{e1}^{EV}	local electricity purchase cost for valley-hour rate, for EVs (€/MWh)	ACC_{EV}	annualized capital cost for EM	C_{ET}	cost of abatement measures in the transport sector (expressed in €/GWh), which increases linearly over time
P_{e1}^{EV}	local electricity selling price for valley-hour rate, for EVs (€/MWh)	C_d	extra degradation cost owing to V2G functionalities (€/MWh)		
E_{ch}	annual electricity consumed for EVs charging, which results from a strategy for daily charging profile, tuned to maximize the RES integration (expectedly at valley periods) and taking into account energy demand for daily mobility and, if it is the case, the additional energy required to perform V2G at off-valley periods (MWh)	C_{bat}	battery capital cost, including replacement labour (€)		

1. INTRODUCTION

The future power systems will have to ensure flexibility, stability and reliability, as a result of the large integration of variable renewable energy sources (RES). Electricity storage is one of the means to provide flexibility to the system, being even more relevant for the islands case. Besides the challenges presented to power systems, a holistic energy planning requires addressing the transport sector, by studying the impact of efficient internal combustion vehicles (ICVs), as well as electric vehicles (EVs). In view of this research motivation, this paper presents a methodology for multicriteria energy planning, for an isolated system (São Miguel Island, Azores), consisting in a process of systematic building of energy planning alternatives, from a set of basis options, namely the integration of RES, strategies for sustainable mobility (ICV-based or electric mobility), electricity storage options (centralized storage facility and/or electric vehicles charging), and adoption of energy efficiency measures.

2. METHODOLOGY FOR MULTICRITERIA ENERGY PLANNING

2.1 Problem Formulation

The decision situation of the energy planning problem should be characterized, by identifying a set of decision variables and alternatives, a set of criteria, and a set of attributes. The alternatives identification reproduces a range of potential hypotheses for a given energy system. Accordingly, each alternative is a strategy, enclosing a set of decision variables, namely: adoption (yes/no) of energy efficiency measures; installed capacity RES (business-as-usual, mid-range RES increase, or high-range RES increase); sustainable mobility options (efficient ICVs, biofuels and behavioural change, or strategies based in EVs introduction); electricity storage strategies (storage through a centralized storage facility and/or EVs charging, including the vehicle-to-grid concept). The alternatives evaluation is carried out by defining key criteria, which are assessed by associating an attribute to each criterion. Each criterion, C_i, gathers a set of attributes, X_i, and sub-attributes, which are presented as follows:

- C_1: Environmental impact (minimize)
  $\Rightarrow X_1$: CO_2 emissions from transport sector and power system
- C_2: Economic and Financial costs (minimize)
  $\Rightarrow X_2$: Overall alternative costs
    - Power generation costs (renewable and non-renewable generation)
    - Costs of Centralized Storage Facility
    - Costs of Electric Mobility
    - Costs of Energy Efficiency Measures (power system and transport sector)
- C_3: Adequacy of the generation system in terms of reliability (maximize)
  $\Rightarrow X_3$: Loss of Load Expectation index (minimize).

2.2 Mathematical Modelling

The attributes relevant for the decision procedure are calculated for a certain year in the future, as described next.

Environmental Impact

The equation which gives the annual CO_2 emissions from both the power system and transport sector, *TE,* is the following (obtained from a typical daily pattern).

$$\boldsymbol{TE = \left(\sum_i^f (N_v \times sh_i \times m_d \times et_i) \times (1 - sh_{EV}) + \sum_h^H \sum_j^N G_{h,j} \times eg_j\right) \times D} \tag{1}$$

Economic and Financial Costs

The attribute for the overall alternative costs should gather the Operation Expenditures (Opex) and the additional Capital Expenditures (Capex) from a set of sub-attributes: Power Generation costs (TAC_{PS}); Costs of Centralized Storage Facility (TAC_{ss}); Costs of Electric Mobility (TAC_{EV}); Costs of Energy Efficiency Measures (TAC_{Eff}).

Thus, the total annual costs, *TAC*, are obtained from the next equation.

$$\boldsymbol{TAC = TAC_{PS} + TAC_{ss} + TAC_{EV} + TAC_{Eff}} \tag{2}$$

To simplify the costs accountability, all the referred costs are assumed to be handled by the local utility, yet the costs for energy efficiency measures and electric mobility may be indirectly financed by the regional authorities.

A. Power Generation Costs

The annual costs related to power generation, ACC_{PS}, gather capital and operation costs.

$$\boldsymbol{TAC_{PS} = ACC_{PS} + OMC_{PS} = ACC_{PS} + NRC + RC} \tag{3}$$

To make financial decisions, calculations are typically made on a yearly basis and capital cost is annualized. One way to annualize a single capital cost is to multiply it by the capital recovery factor (CRF). That is to say, the equivalent annual capital cost, ACC_{PS}, is the amount of money to be paid at the end of each year, to amortize the present value for the capital cost, CC_{PS}, at a rate *d* and during *n* years [1], [2].

$$\boldsymbol{ACC_{PS} = CC_{PS} \times CRF = CC_{PS} \times \frac{1}{\frac{1}{d} - \frac{1}{d \times (1+d)^n}}} \tag{4}$$

Capital costs for renewable energy sources are assumed to be included in the corresponding feed-in-tariff (FIT), as a common cost-based incentive [2].

Concerning the operation and maintenance costs of non-renewable energy generation, a specific algorithm is developed for the unit commitment and economic dispatch (UCED) of thermal power units, including renewable energy sources, centralized electricity storage, and electric vehicles charging, addressing as well the V2G concept. The UCED problem has the following formulation and corresponds to the minimization of power generation operation costs in a 24h period.

$$min\ NRC = \sum_{i=1}^{H}\left\{\sum_{k=1}^{n}\left[u_{i,k} \times (F(P_{i,k}) + C_k^u \times (1 - u_{i-1,k})) + (1 - u_{i,k}) \times u_{i-1,k} \times C_k^d\right]\right\} \times D \tag{5}$$

Subject to:

$$\sum_{k=1}^{n} \boldsymbol{u_{i,k}} \times \boldsymbol{P_{i,k}} = \boldsymbol{P_i^L} - \boldsymbol{P_i^R} - \boldsymbol{P_i^S} - \boldsymbol{P_i^V},\ \forall \boldsymbol{i} \tag{6}$$

$$\sum_{k=1}^{n} \boldsymbol{u_{i,k}} \times \boldsymbol{P_k^{max}} \geq \boldsymbol{SR_i} + \boldsymbol{P_i^L} - \boldsymbol{P_i^R} - \boldsymbol{P_i^S} - \boldsymbol{P_i^V}, \forall \boldsymbol{i} \tag{7}$$

$$\boldsymbol{u_{i,k}} \times \boldsymbol{P_k^{min}} \leq \boldsymbol{P_{i,k}} \leq \boldsymbol{u_{i,k}} \times \boldsymbol{P_k^{max}}, \forall \boldsymbol{i}, \boldsymbol{k} \tag{8}$$

$$\boldsymbol{u_{i,k}} = \boldsymbol{1}\ \boldsymbol{for}\ \sum_{i=i_{su}}^{i-1} \boldsymbol{u_{i,k}} < \boldsymbol{MUT_k}\ , \forall \boldsymbol{k} \tag{9}$$

$$\boldsymbol{u_{i,k}} = \boldsymbol{0}\ \boldsymbol{for}\ \sum_{i=i_{du}}^{i-1} (\boldsymbol{1} - \boldsymbol{u_{i,k}}) < \boldsymbol{MDT_k}\ , \forall \boldsymbol{k} \tag{10}$$

Taking into account the characteristics and purpose of the present research, a merit order scheme, using a priority list, is developed. This algorithm is applied to a typical daily load profile.

Besides the non-renewable energy units, it is also worth evaluating the costs of the renewable energy sources, which are typically accounted by specific feed-in-tariffs. The annual renewable generation costs, RC, are then obtained from the next equation.

$$\mathrm{RC} = \left(\sum_{\mathrm{i=1}}^{\mathrm{h}} \left(\sum_{\mathrm{k=1}}^{\mathrm{n}} \mathrm{RG}_{\mathrm{i,k}}^{\mathrm{I}} \times \left(\frac{\mathrm{RP}_{\mathrm{k}}^{\mathrm{I}} + \mathrm{RP}_{\mathrm{k}}^{\mathrm{II}}}{\mathrm{RP}_{\mathrm{k}}^{\mathrm{I}}}\right) \times \mathrm{C}_{\mathrm{k}}^{\mathrm{R}}\right)\right) \times \mathrm{D} \tag{11}$$

B. Costs of Centralized Storage Facility

The total equivalent annual costs, TAC_{ss}, for a pumped hydro centralized storage facility (CSF) are described as follows [3], [4].

$$\boldsymbol{TAC_{ss}} = \boldsymbol{ACC_{ss}} + \boldsymbol{OMC_{ss}} = \boldsymbol{ACC_{ss}} + \boldsymbol{EC_{ss}} + \boldsymbol{FC_{ss}} \tag{12}$$

Where, ACC_{ss} stands for annualized capital cost (€); OMC_{ss} refers to operation and maintenance cost (€); EC_{ss} is the annual energy cost (€); FC_{ss} is the annual fixed maintenance cost (€).

The details of the previous equation are hereafter explained, based on the premise that the local utility is the CSF investor and operator, and following similar approaches presented in [4] and [5]. Concerning the equivalent annual costs calculation, firstly, it is necessary to find out a parameter to describe the contribution of the storage system to the overall energy demand, ε.

$$\boldsymbol{\varepsilon = F_{tot}/E_{tot}^{i}} \tag{13}$$

$$\boldsymbol{F_{tot} = \left(\sum_{i=1}^{h} P_i^S\right) \times D = F_{stor} \times \eta_{SS}} \tag{14}$$

When a part or all the stored electricity is not allowed to be injected into the grid (owing to the power system operation rules), the previous equality is not applicable.

For making an economic evaluation of CSF its main characteristics should be defined, i.e. the energy storage capacity, E_{ss}, and nominal power, N_{ss}.

$$\boldsymbol{E_{ss} = d_o \cdot \left(\frac{F_{tot}}{8760}\right) \cdot \frac{1}{\eta_{ss}} \cdot \frac{1}{DOD_L}} \tag{15}$$

While the CSF nominal power is given by,

$$\boldsymbol{N_{ss} = \frac{P_p^S}{\eta_p}} \tag{16}$$

Now it is possible to find the capital cost, CC_{ss}, of the storage system.

$$\boldsymbol{CC_{ss} = (C_c.E_{ss} + C_p.N_{ss}) \times (1 + C_{co})} \tag{17}$$

Finally, the equivalent annual capital cost, ACC_{ss}, is found by the next equation.

$$\boldsymbol{ACC_{ss} = CC_{ss} \times CRF = CC_{ss} \times \frac{1}{\frac{1}{d} - \frac{1}{d \times (1+d)^n}}} \tag{18}$$

Concerning the energy cost, EC_{ss}, it is drawn by the next equation, assuming storage/pumping operation during valley hours and power generation at off-valley periods.

$$\boldsymbol{EC_{ss} = F_{stor} \cdot C_e^{SS} - F_{tot} \cdot P_e^{SS}} \tag{19}$$

The annual fixed maintenance cost, FC_{ss}, is found by multiplying the CSF's capital cost, CC_{ss}, by a parameter, m, which stands for the fraction of the initial capital invested.

$$\boldsymbol{FC_{ss} = CC_{ss} \cdot m} \tag{20}$$

C. Costs of Electric Mobility

The total annual costs of the electric mobility, TAC_{EV}, gather the following strands: annual operation and maintenance cost, OM_{EV}, and annualized capital cost, ACC_{EV}.

$$\boldsymbol{TAC_{EV} = OMC_{EV} + ACC_{EV}} \tag{21}$$

The next formulation is based on the assumption that the local utility is the investor and operator of the electric mobility (EM), and provides all the EM and electricity operations. Then, the EM operation cost is described by the next equation.

$$\boldsymbol{OMC_{EV} = \left(C_{e1}^{EV} - P_{e1}^{EV}\right) \times E_{ch} + (C_{e2}^{EV} - P_{e2}^{EV}) \times E_{disp}} \tag{22}$$

While,

$$\boldsymbol{E_{ch}} = \left(\sum_{i=1}^{h} \boldsymbol{EV_i^{ch}}\right) \times \boldsymbol{D} = \left(\boldsymbol{EV_{EC}} \times \boldsymbol{m_d} \times \boldsymbol{N_{EV}} + \boldsymbol{EV_{ES}} \times \boldsymbol{r^d} \times \boldsymbol{N_{EV}}\right) \times \boldsymbol{D} \qquad (23)$$

$$E_{disp} = \left(\sum_{i=1}^{h} P_i{}^V\right) \times D = EV_{ES} \times r^d \times \eta_{conv} \times N_{EV} \times D \qquad (24)$$

The equality presented in equation (24) assumes the technical feasibility of performing energy shift of the whole stored electricity, for (vehicle-to-grid) V2G purposes. However, when a part or all the stored electricity is not allowed to be injected into the grid (owing to the power system operation rules), the referred equality is not applicable.

When it comes to the cost of electricity generation through EV Vehicle-to-Grid, $C_{e2}{}^{EV}$, one proposes the next formulation, adapted from [6], [7] and [8].

$$\boldsymbol{C_{e2}^{EV}} = \frac{\boldsymbol{ACC_{EV}}}{\boldsymbol{E_{disp}}} + \boldsymbol{C_d} \qquad (25)$$

The C_d is found by the next equation.

$$\boldsymbol{C_d} = \frac{\boldsymbol{C_{bat}}}{\boldsymbol{L_{ET}}} \qquad (26)$$

The battery lifetime throughput energy for the cycling regime, L_{ET} (MWh), is obtained as follows.

$$\boldsymbol{L_{ET}} = \boldsymbol{L_c} \times \boldsymbol{EV_{ES}} \times \boldsymbol{DoD} \qquad (27)$$

Concerning the formulation for the equivalent annual capital cost, the capital recovery factor is multiplied to the capital cost of EM, CC_{EV}, as follows.

$$\boldsymbol{ACC_{EV}} = \boldsymbol{CC_{EV}} \times \boldsymbol{CRF} = \boldsymbol{CC_{EV}} \times \frac{\boldsymbol{1}}{\frac{\boldsymbol{1}}{\boldsymbol{d}} - \frac{\boldsymbol{1}}{\boldsymbol{d} \times (\boldsymbol{1}+\boldsymbol{d})^{\boldsymbol{n}}}} \qquad (28)$$

D. Costs of Energy Efficiency Measures

The annual costs for energy efficiency measures, TAC_{Eff}, gather power system and transport sector costs, as follows.

$$\boldsymbol{TAC_{Eff}} = \boldsymbol{TAC_{EffPS}} + \boldsymbol{TAC_{EffICVs}} \qquad (29)$$

Where, TAC_{EffPS}, is the annual costs for measures applied on the demand-side of the power system (€); and $TAC_{EffICVs}$, is the annual costs for measures applied on the transport sector (€). As stated previously, some alternatives follow an energy efficiency pathway in terms of the power system demand. The search out of the concerned energy efficiency costs is carried out right through the next tiers.

The annual electricity consumption in the target year *i*, $E_{tot}{}^{i}$, and the annual electricity demand variation, $E_{EffPS}{}^{i}$, are given by the following equations.

$$E_{tot}^{i} = E_{tot}^{i-1} \times (1 + E_{\Delta}) \quad (30)$$

$$E_{EffPS}^{i} = E_{tot}^{i-1} - E_{tot}^{i} \quad (31)$$

Where, E_{Δ} is the percentage of annual load variation from year *i-1* to year *i*; and E_{tot}^{i-1} is the annual electricity demand in year *i-1* (GWh).

The energy efficiency depends, consequently, on the E_{Δ} and occurs only when this variable is negative. Hence, the total annual costs of energy efficiency applied to the power system, TAC_{EffPS}, are calculated as follows.

$$TAC_{EffPS} = E_{EffPS}^{i} \times C_{EffPS} \quad (32)$$

When it comes to the transport sector, the annual ICVs' emissions for the energy efficiency alternatives, in the target year *i*, E_{ICVs}^{i} ($tonCO_2$), are calculated by the next equation [9].

$$E_{ICVs}^{i} = E_{ICVs}^{i-1} \times (1 - EE - TF - DB - DD - BF) \quad (33)$$

Now, the total annual costs of energy efficiency measures applied to the ICVs, $TAC_{EffICVs}$, are determined as follows.

$$TAC_{EffICVs} = C_{ET} \times ({E_{ICVs}}^{i-1} - E_{ICVs}^{i})/Con \quad (34)$$

Adequacy of the Power System

The adequacy of the electric power system is evaluated through a reliability analysis where loss of load expectation (LOLE) provides the key information.

$$LOLE = \sum_{k=1}^{n} p_k \cdot t_k \quad \text{time units} \quad (35)$$

Where, n is the number of capacity outage states; p_k is the probability of the k^{th} capacity outage state with magnitude O_k; t_k is the number of time units in the study interval that an outage magnitude, O_k, would result in a loss of load.

To calculate the LOLE, the capacity outage probability table is built by applying a recursive algorithm described in [10], and considering wind and hydro power historical performance, in order to assess the impact on the reliability.

3. THE SÃO MIGUEL ISLAND CASE STUDY

In 2008 the generation system of São Miguel Island had roughly 130 MW of installed capacity with the following breakdown: one thermal power plant (Caldeirão) with eight fuel oil units; two geothermal power plants (Ribeira Grande and Pico Vermelho); and seven small hydro power plants [11]. As stated previously, the alternatives are defined by considering the investments and policies that are being studied by the decision maker, who is represented by the regional authorities of the analysed energy system. Hence, the alternatives identification reproduces a range of potential hypotheses for a given energy system, gathering a set of decision variables: adoption of energy efficiency measures; installed capacity RES (BAU – business as usual, mid-range RES increase, or high-range RES increase); sustainable mobility options (efficient ICVs, biofuels and behavioural change, or strategies based in EVs introduction); electricity storage strategies (storage through a centralized storage facility and/or EVs charging, including the V2G concept). The potential alternatives for energy planning are sketched out in Table 1 (Annex). The described attributes are computed for the year 2030, for two scenarios, i.e.: "high prices" scenario; and "low prices" scenario.

Through the results presented in Table 2, the LOLE is found reasonable for most of the alternatives (for both scenarios), except for alternatives 14, 15 and 16. Therefore, these alternatives will be disregarded in this study. The analysis of the Table 2 allows identifying the next group of non-dominated alternatives: 20, 21, 22, 26, 27, 28, 29, 30, 32, 33, 34, 35 and 36. Yet alternative 21 won't be included in this study, since it is represented by 22 (owing to lack of V2G opportunity). Aggregation of the two remaining attributes is made through the trade-off between cost and emissions, which should be provided by the decision maker. In the paper, a sensitivity study on the trade-offs is developed that shows the influence of the decision maker preferences in the final decision. In each case, the trade-off is used to compute the Equivalent Costs in "high prices" scenario, Z_H, and in "low prices" scenario, Z_L, as presented in Table 3. In terms of uncertainty modeling, the minimax regret approach is adopted. Fig. 1 depicts the variation of maximum regret with the trade-off, for the three preferred alternatives. It is observed that alternative 33 would be preferred only if $\alpha < 16$ €/tonCO_2 (low valorization of emissions) and alternative 20 would be preferred only if $\alpha > 53$ €/ tonCO_2 (very high valorization of emissions). For intermediate values ($16 < \alpha < 53$ €/ tonCO_2), alternative 26 should be selected. The final choice belongs to decision maker.

4. CONCLUSIONS

The methodology presented in this paper provides a structured analysis of the relevant economical and technical aspects associated to the joint planning of an isolated power system and a transport system, when cost, security of supply and CO_2 emissions are the main points of view to be taken into consideration. The multi-attribute and multi-scenario analysis took into account multiple points of view and the uncertainty of future fuel and electricity prices.

The analysis carried out for São Miguel Island confirmed a set of expected findings (environmental benefits of RES and energy efficiency), but also revealed the economic benefits of EVs V2G for energy shift, the cost competitiveness of RES, in the "high prices" scenario, the economic benefits of energy efficiency measures on the load, and the important contribution of efficient ICVs, biofuels and behavioural change for lowering carbon emissions. It must be pointed out, however, that the main purpose of this paper is presenting and illustrating the application of the methodology, rather than deriving final conclusions for the case study.

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1 Annex

Table 1 – Alternatives for energy planning of São Miguel Island

Energy Efficiency Measures on the Load	Renewable Energy Increase	Efficient ICVs, biofuels and behavioural change	Electric Mobility (Number of EVs)	Centralized Storage (Installed Capacity of Pumped Hydro Storage)	Vehicle-to-Grid	Alternative Number
No	High-range	Yes	No (0 EVs)	Yes (20 MW)	No	1
				No (0 MW)		2
		No	Yes (10 000 EVs)	No (0 MW)	Yes	3
					No	4
			Yes (5 000 EVs)	Yes (20 MW)	Yes	5
					No	6
	Mid-range	Yes	No (0 EVs)	Yes (20 MW)	No	7
				No (0 MW)		8
		No	Yes (10 000 EVs)	No (0 MW)	Yes	9
					No	10
			Yes (5 000 EVs)	Yes (20 MW)	Yes	11
					No	12
	BAU	Yes	No (0 EVs)	Yes (20 MW)	No	13
				No (0 MW)		14
		No	Yes (10 000 EVs)	No (0 MW)	Yes	15
					No	16
			Yes (5 000 EVs)	Yes (20 MW)	Yes	17
					No	18
Yes	High-range	Yes	No (0 EVs)	Yes (20 MW)	No	19
				No (0 MW)		20
		No	Yes (10 000 EVs)	No (0 MW)	Yes	21
					No	22
			Yes (5 000 EVs)	Yes (20 MW)	Yes	23
					No	24
	Mid-range	Yes	No (0 EVs)	Yes (20 MW)	No	25
				No (0 MW)		26
		No	Yes (10 000 EVs)	No (0 MW)	Yes	27
					No	28
			Yes (5 000 EVs)	Yes (20 MW)	Yes	29
					No	30
	BAU	Yes	No (0 EVs)	Yes (20 MW)	No	31
				No (0 MW)		32
		No	Yes (10 000 EVs)	No (0 MW)	Yes	33
					No	34
			Yes (5 000 EVs)	Yes (20 MW)	Yes	35
					No	36

Table 2 – Total annual carbon emissions, costs and LOLE in 2030

Alternative	Annual CO_2 emissions from power system plus transport sector (kton)	Total Annual Costs (million Euros) - 2030		LOLE (days/year)
		“High” prices scenario	“Low” prices scenario	
1	262,98	55,57	50,37	0,004
2	287,11	58,81	49,90	0,065
3	278,69	56,42	53,10	0,065
4	285,21	59,47	51,37	0,065
5	278,30	56,78	52,27	0,004
6	278,96	57,56	51,25	0,004
7	390,35	63,17	46,91	0,130
8	390,35	62,05	45,79	0,846
9	412,09	60,70	47,94	0,846
10	409,41	62,32	45,99	0,846
11	409,83	60,21	46,68	0,130
12	408,49	63,29	46,84	0,130
13	494,44	71,40	46,09	1,057
14	494,44	70,28	44,96	9,308
15	516,18	68,47	46,90	9,308
16	513,51	72,30	46,07	9,308
17	513,92	70,01	46,67	1,057
18	512,58	72,51	46,54	1,057
19	166,58	80,37	59,92	4E-08
20	166,58	31,39	30,17	1E-06
21	162,85	32,36	31,88	1E-06
22	162,85	32,36	31,88	1E-06
23	173,32	57,07	49,21	4E-08
24	173,32	57,07	49,21	4E-08
25	182,37	35,39	32,52	2E-06
26	200,14	29,60	27,00	2E-05
27	183,98	28,78	31,30	2E-05
28	196,41	30,57	28,71	2E-05
29	183,74	28,96	30,51	2E-06
30	186,98	30,69	30,24	2E-06
31	261,26	34,95	27,40	7E-06
32	262,86	34,47	26,49	2E-04
33	282,61	28,29	26,34	2E-04
34	279,93	32,79	25,85	2E-04
35	280,35	30,56	26,47	7E-06
36	279,01	33,96	26,85	7E-06

Table 3 – Equivalent Costs of alternatives, in 2030, for a set of trade-offs

Alternative	**X_H (kton)**	**Y_H (million €)**	**Z_H (million €) for α=0€/ton**	**Z_H (million €) for α=10€/ton**	**Z_H (million €) for α=20€/ton**	**Z_H (million €) for α=30€/ton**	**Z_H (million €) for α=40€/ton**	**Z_H (million €) for α=50€/ton**	**Z_H (million €) for α=60€/ton**	**X_L (kton)**	**Y_L (million €)**	**Z_L (million €) for α=0€/ton**	**Z_L (million €) for α=10€/ton**	**Z_L (million €) for α=20€/ton**	**Z_L (million €) for α=30€/ton**	**Z_L (million €) for α=40€/ton**	**Z_L (million €) for α=50€/ton**	**Z_L (million €) for α=60€/ton**
20	166,58	31,39	**31,39**	**33,05**	**34,72**	**36,38**	**38,05**	**39,72**	**41,38**	166,58	30,17	**30,17**	**31,84**	**33,50**	**35,17**	**36,83**	**38,50**	**40,17**
22	162,85	32,36	**32,36**	**33,99**	**35,61**	**37,24**	**38,87**	**40,50**	**42,13**	162,85	31,88	**31,88**	**33,51**	**35,14**	**36,77**	**38,39**	**40,02**	**41,65**
26	200,14	29,60	**29,60**	**31,60**	**33,60**	**35,60**	**37,60**	**39,60**	**41,61**	200,14	27,00	**27,00**	**29,00**	**31,00**	**33,00**	**35,00**	**37,00**	**39,00**
27	183,98	28,78	**28,78**	**30,62**	**32,46**	**34,30**	**36,14**	**37,98**	**39,82**	183,98	31,30	**31,30**	**33,14**	**34,98**	**36,82**	**38,66**	**40,50**	**42,34**
28	196,41	30,57	**30,57**	**32,53**	**34,49**	**36,46**	**38,42**	**40,39**	**42,35**	196,41	28,71	**28,71**	**30,67**	**32,63**	**34,60**	**36,56**	**38,53**	**40,49**
29	183,74	28,96	**28,96**	**30,79**	**32,63**	**34,47**	**36,30**	**38,14**	**39,98**	183,74	30,51	**30,51**	**32,35**	**34,18**	**36,02**	**37,86**	**39,70**	**41,53**
30	186,98	30,69	**30,69**	**32,56**	**34,43**	**36,30**	**38,17**	**40,04**	**41,91**	186,98	30,24	**30,24**	**32,11**	**33,98**	**35,85**	**37,71**	**39,58**	**41,45**
32	262,86	34,47	**34,47**	**37,10**	**39,73**	**42,36**	**44,99**	**47,62**	**50,24**	262,86	26,49	**26,49**	**29,12**	**31,75**	**34,38**	**37,00**	**39,63**	**42,26**
33	282,61	28,29	**28,29**	**31,11**	**33,94**	**36,77**	**39,59**	**42,42**	**45,24**	282,61	26,34	**26,34**	**29,17**	**32,00**	**34,82**	**37,65**	**40,47**	**43,30**
34	279,93	32,79	**32,79**	**35,59**	**38,39**	**41,19**	**43,99**	**46,79**	**49,59**	279,93	25,85	**25,85**	**28,65**	**31,45**	**34,25**	**37,05**	**39,85**	**42,65**
35	280,35	30,56	**30,56**	**33,36**	**36,16**	**38,97**	**41,77**	**44,57**	**47,38**	280,35	26,47	**26,47**	**29,28**	**32,08**	**34,88**	**37,69**	**40,49**	**43,30**
36	279,01	33,96	**33,96**	**36,75**	**39,54**	**42,33**	**45,12**	**47,91**	**50,70**	279,01	26,85	**26,85**	**29,64**	**32,43**	**35,22**	**38,01**	**40,80**	**43,59**

Legend
Y_H - total annual costs of an alternative, in the "high prices" scenario
X_H - total annual carbon emissions of an alternative, in the "high prices" scenario
α - trade-off costs/carbon emissions
Y_L - total annual costs of an alternative, in the "low prices" scenario
X_L - total annual carbon emissions of an alternative, in the "low prices" scenario

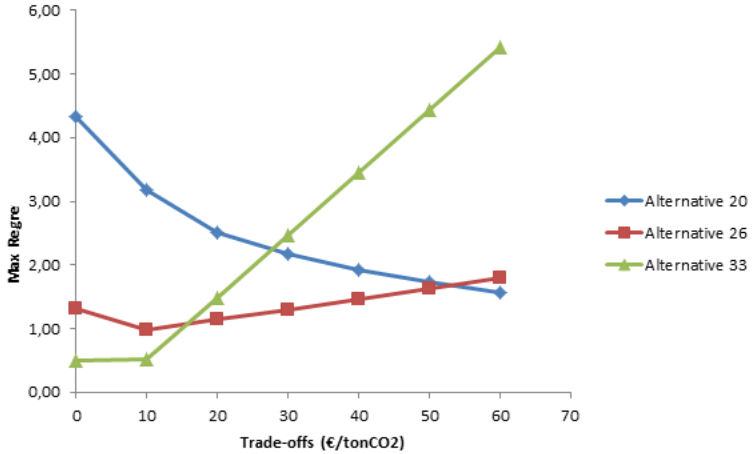

Fig. 1: Sensitivity study of trade-offs effect on the maximum regret

Useful work transitions for Portugal from 1856 to 2009. Intensities and European patterns.

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Conference topic: Energy system analysis.

Abstract

This paper applies a methodology for useful work accounting to Portugal from 1856 to 2009 and for the EU-15 countries from 1960 to 2009, considering five different useful work categories: heat, mechanical drive, light, other electric uses and muscle work. From historic energy records, final exergy was estimated, as well as its allocations to useful work categories and final-to-useful efficiencies for the entire economies. The overall transitions in terms of energy carriers and uses are identified for Portugal in this timespan.

Regarding Portuguese energy intensities, in spite of GDP and useful work having grown nearly by a factor of 30 from 1856 to 2009, we show that useful work economic intensity (useful work / GDP) varied by no more than 20% above and below its 154-year average, in contrast to the final energy and exergy intensities that decreased by a factor of 4 in the same timespan. This result reinforces the argument for a close relationship between economic growth and useful work and suggests that a reduction in the intensity of the use of energy resources can only be achieved by increasing energy efficiencies. This result is confirmed when assessing the EU-15 countries in the post-war period.

1. Introduction

A vast bibliography explores these changes in the patterns of energy use. However most studies focus on primary energy or final energy (e.g. Apergis and Payne, 2010; Chontanawat et al., 2008; Kümmel et al., 1985; Miketa and Mulder, 2005; Mulder and Groot, 2007; Stern, 1993). Therefore, these approaches tend to focus on energy supplies (where the energy comes from) and not on how energy is used productively within the economic system.

Several exergy analyses (primary and final) have also been done for different countries, both single year exergy studies (e.g. Wall, 1987, 1990; Wall et al., 1994) and historical analyses of patterns of exergy consumption (e.g. Ayres et al., 2003; Chen and Chen, 2007a, b, c; Chen and Chen, 2007d; Chen and Qi, 2007; Warr and Ayres, 2010; Warr et al., 2010; Warr et al., 2008; Williams et al., 2008). These works provide relevant economy-wide results, characterizing exergy flows, and exergy sources and consumers, but neither capture long-term trends nor explore the relations between exergy use and economic growth.

Here, we briefly present a methodology for useful work accounting at a country-level. Useful work is the exergy equivalent of useful energy and is formally defined as the minimum amount of work (or exergy) required to produce a given end use. Useful work encloses the quality and productivity of the energy used in an economy, providing better insights on the relation between economic growth and energy use (Ayres, 2008; Ayres et al., 2003; Ayres and Warr, 2005; Stern, 2010; Warr and Ayres, 2006, 2010; Warr et al., 2010; Warr et al., 2008). Useful work is much closer to productive energy uses within an economy, measuring the actual amount of exergy (and not energy) delivered to a final function, e.g. the mechanical work actually used by a car from its fuel, the exergy of the heat actually provided to a blast furnace, or the light emitted by an electric lamp.

Recent decoupling literature (e.g. UNEP, 2011) acknowledges the need for reducing the level of resource utilization per unit of GDP, which, regarding energy, represents a reduction of the primary energy (or exergy) intensity. Such economic intensity may be achieved by increasing primary-to-final efficiency, final-to-useful efficiency and/or useful work intensity, as expressed by eq. (1). In this work we explore useful work intensity trends, which is the only one out of three intensities in that is not subject to thermodynamic limits.

$$\frac{\text{Primary exergy}}{\text{GDP}} = \frac{\text{Primary exergy}}{\text{Final exergy}} \frac{\text{Final exergy}}{\text{Useful work}} \frac{\text{Useful work}}{\text{GDP}}$$

(1)

We apply the presented methodology to Portugal from 1856 to 2009 and to the EU-15 countries from 1960 to 2009, considering five different useful work categories: heat, mechanical drive, light, other electric uses, and muscle work. From historic energy records, final exergy figures were estimated, as well as its allocations to useful work categories and final-to-useful efficiencies for the assessed economies. We obtain final exergy and useful work series for these countries and periods.

Useful work accounting methodology is briefly described in section 0. Historical data series and exergy breakdown in terms of useful work categories is presented. An automated accounting methodology used for the EU-15 countries is also explained in this section. The results of the extended timespan analysis for Portugal and shorter timespan analysis for the EU-15 countries are presented and discussed in section 0. Also, useful work intensity is compared to traditional intensity measures for all assessed countries and its meaning and consequences are discussed. We conclude by summarizing the main conclusions (section 0).

2. Methodology

Useful work accounting comprises a five-step methodology for each energy carrier (Ayres et al., 2003):

1. Conversion of existing final energy data[1] to final exergy values;
2. Allocation of each final exergy consumption to one useful work category;
3. Computation of final exergy consumption by useful work category;
4. Definition of an aggregated second-law final-to-useful efficiency for each useful work category;
5. Calculation of an aggregated useful work value for each useful work category.

2.1. Useful work in Portugal

This methodology was applied to Portuguese energy data from 1856 to 2009. Energy data from 1960 to 2009 was collected from International Energy Agency (IEA) Energy Statistics and Energy Balances (IEA, 2011a, b). Historical estimates of previous energy data were assembled from Henriques, 2011.

Referred energy statistics were converted to exergy units applying the respective exergy factors as in Table 1.

Table 1. Exergy factors. Source: Chen and Chen, 2006; Ertesvåg and Mielnik, 2000; Nakicenovic et al., 1996; Wall et al., 1994.

Energy carriers	Exergy factors
Coal and coal products	1.06
Oil and oil products	1.06
Natural gas	1.04
Combustible renewables	1.11
Electricity and CHP heat	1
Food and feed	1
Other non-conventional	1

[1] We define final energy consumption as the total effective consumption, i.e. standard final energy consumption as commonly defined in official energy statistics plus energy sector own energy uses (Fouquet et al., 2009; IEA, 2011a, c; Sorman and Giampietro, 2011).

In order to estimate the muscle work done from food and feed, we used raw data on food and feed final energy consumption from FAO, 2011; Henriques, 2011 and we considered the assumptions for end-use and efficiencies as in Wirsenius, 2000.

A straightforward allocation of final energy uses to useful work categories was made for the period 1960 to 2009 from IEA energy balances. However, for former years the allocation process was less intuitive. This allocation was based on existing records of national and international official entities for trade and customs and previous works on the history of energy use in Portugal (DGSE, 1929-1984; Henriques, 2011; INE, 1941-1960, 1970, 1976, 1983, 1987-1997, 1992, 1997, 2002, 2008, 2010; Madureira, 2005).

Regarding second-law efficiencies, several estimations were made for each useful work category. The major references used were the following: Ayres et al., 2005; Ford et al., 1975; Fouquet and Peaeson, 2006; Heywood, 1988; Joyce, 1991; Ross, 1997; Smil, 2001. Detailed information on these procedures can be found in other publications from the authors of this paper.

2.2. Useful work in the EU-15 countries

The methodology described for Portugal was applied to the EU-15 countries from 1960 to 2009: Austria, Belgium, Denmark, France, Finland, Germany, Greece, Italy, Ireland, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the UK. For these countries and timespan, we have used energy data from the IEA Energy Balances and form FAOSTAT (FAO, 2011; IEA, 2011a).

Useful work results were obtain using a general automated calculation, based on a straightforward general allocation of each pair final energy carrier – activity sector to a given useful work category. A general matrix of second-law efficiencies was estimated from detailed information on efficiencies for Portugal and the UK. Therefore useful work (U) is obtained as

$$U = \boldsymbol{\epsilon} \cdot \boldsymbol{B} \, ,$$

where $\boldsymbol{B}$ stands for a final exergy vector (each component for the final exergy by each useful work category) and $\boldsymbol{\epsilon}$ is the second-law final-to-useful efficiency vector (each component for each useful work category efficiency).

3. Results and discussion

3.1. Portugal from 1856 to 2009

During this timespan, the Portuguese final exergy consumption and useful work increased by a factor of 9 and 27, respectively. In global terms we can see the transition from poorer to nobler uses, such as medium and high temperature heat, mechanical drive and other electric uses instead of low temperature heat and food & feed (Figure 1).

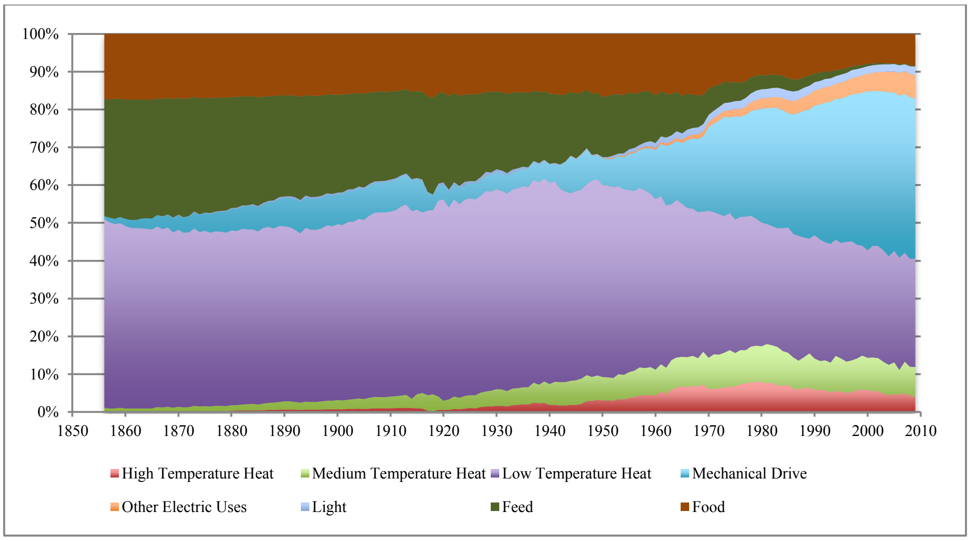

Figure 1. Share of useful work by type of use in Portugal from 1856 to 2009.

To understand the importance of each useful work category it is adequate to analyze its share. The structure of useful work categories changed in the analyzed period in Portugal (Figure 1), showing a slow transformation of useful work needs. The economy evolved to a higher dependency on mechanical drive services than in the past. Also, as referred, other electric uses and higher temperature heat uses gained importance. These changes happened as a consequence of the industrialization of the country and mobility needs that led to increases in transport sector energy uses. Notwithstanding, these changes occur slowly and in well-defined historical periods.

Relevant increases in the final-to-useful aggregated efficiency are visible, starting in the beginning of the 20th century but in a more pronounced way since World War II (Figure 2). This shows technological progress at the energy use level, but is also a consequence of changes in the type of energy uses and energy carriers to a more efficient setup. Technological changes implied more efficient devices and enabled more efficient and valuable uses of energy. An evolution in mechanical drive devices' efficiencies and a shift from low temperature heat uses to higher temperature heat explains this result until the 1970's. A significant part of this transformation is also explained by an increase in the use of electricity, which has generally higher final-to-useful efficiencies whatever the use.

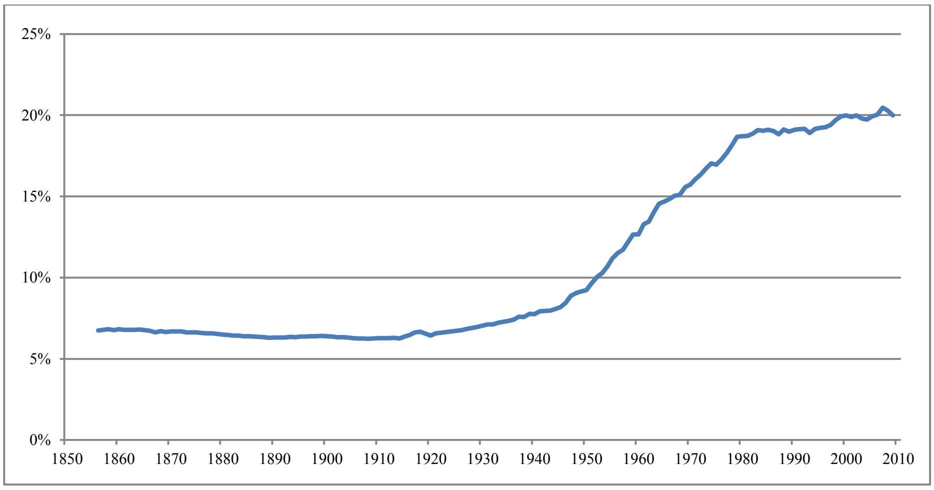

Figure 2. Final-to-useful second law efficiency in Portugal from 1856 to 2009.

One of the more surprising and distinctive results of this useful work methodology is shown in Figure 3. When compared with final exergy intensity[2], useful work intensity is almost constant since 1856 with a variation of about 20% below and above the 154-year average value. Such result does not contradict recent decoupling literature, but suggests that a reduction in primary energy (or exergy) economic intensity may only be achieved by increasing primary-to-final efficiency and/or final-to-useful efficiency. According to eq. (1), thermodynamic limits impose a maximum boundary for primary-to-final and final-to-useful efficiencies, and a reduction in primary energy (or exergy) efficiency may only go further with structural changes that reduce the useful work intensity.

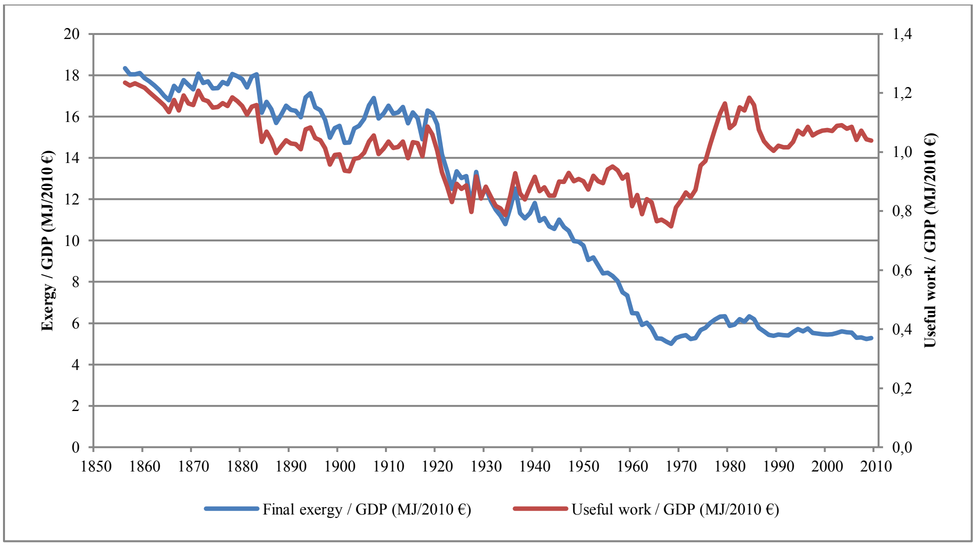

Figure 3. Final exergy and useful work intensity for Portugal from 1856 to 2009.

[2] Defined as final exergy over GDP. It has a decreasing trend similar to primary energy intensity.

3.2. EU-15 countries from 1960 to 2009

After the result obtained for Portugal, it is convenient to confirm whether such result is representative or just a particularity of Portugal.

From the automated calculation procedure described above, and just for the period from 1960 to 2009 (the timespan for which systematic statistic are known for these countries), we obtained the results of useful work intensity for the EU-15 countries, except for Luxembourg[3] (Figure 5).

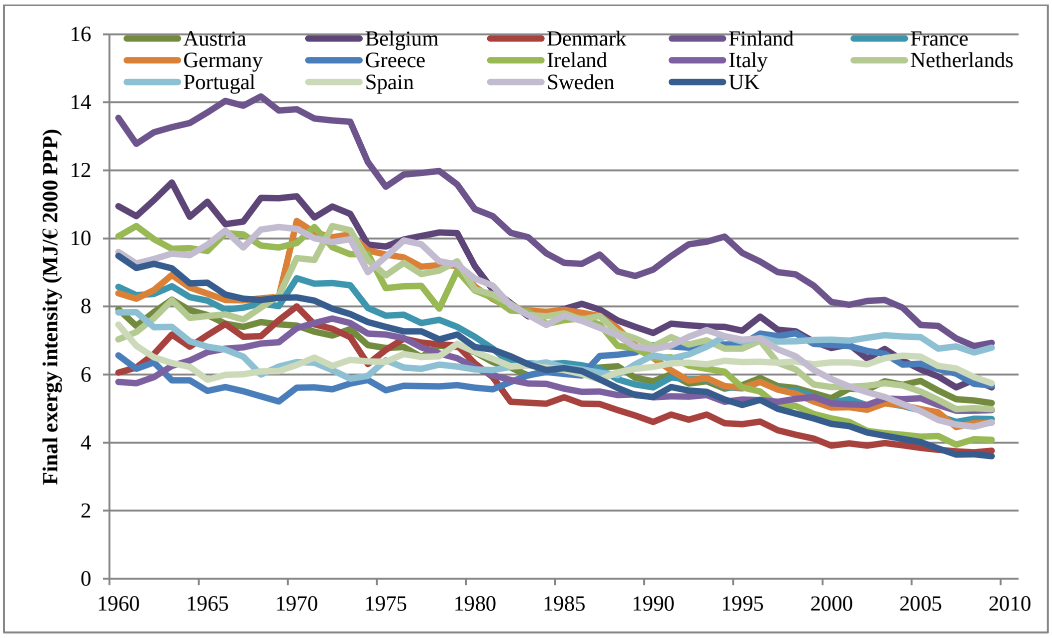

Figure 4. Final exergy intensities for the EU-15 countries (except Luxembourg) from 1960 to 2009.

3 Luxembourg was excluded from this analysis. Its significant differences, namely concerning country size and GDP per capita, could lead to spurious comparisons with the other EU-15 countries.

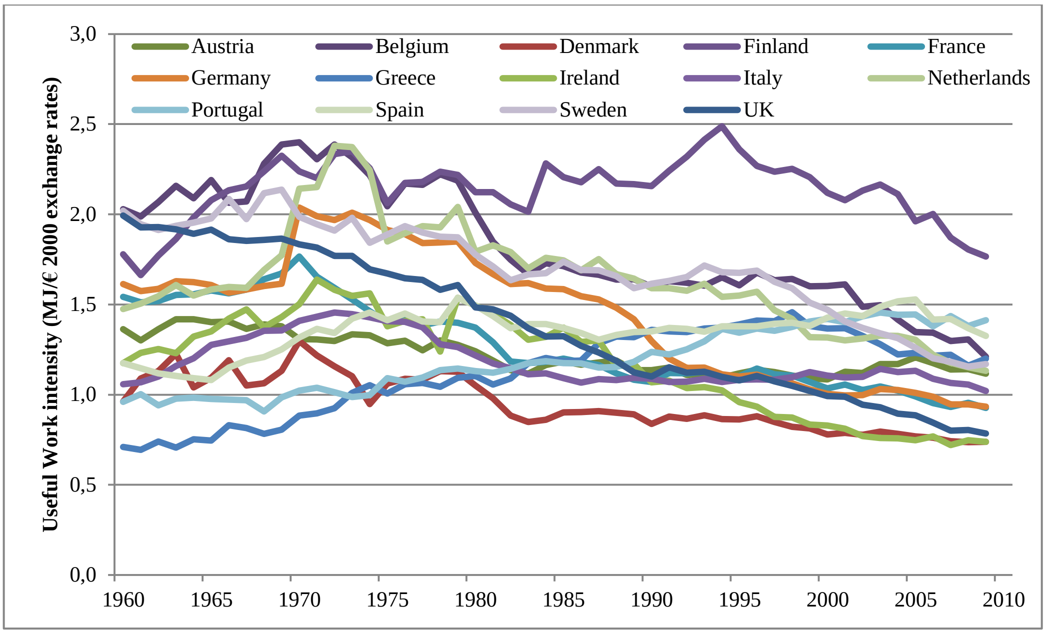

Figure 5. Useful work intensities for the EU-15 countries (except Luxembourg) from 1960 to 2009.

Similarly to what is observed in a long-term analysis for Portugal, we see a decrease in final exergy intensities for all countries and most of them exhibit a very stable useful work intensity path since 1960 (Figure 4 and Figure 5). It is visible that, unlike other countries, this intensity decreases in the UK, Germany and Sweden.

Given the diversity of the results above, we need to test which intensity is closely connected to economic growth. To answer that, we tested the following model using the entire panel data of the EU-15 countries from 1960 to 2009 (Table 2). We used growth rates of the variables in order to pull out the effect of time and excepted autocorrelations of the independent variables.

*Table 2. Results of the regression based on data for the EU-15 countries from 1960 to 2009. *** stands for significant at 1%, UW stands for useful work, and FEx stands for final exergy.*

$$\frac{\widehat{G\dot{D}P}}{GDP} = 0.4013^{***}\frac{U\dot{W}}{UW} + 0.0633\frac{F\dot{E}x}{FEx}$$

$$R^2 = 0.3501$$
$$AdjR^2 = 0.3490$$
$$P(F < c) = 0$$

Regression results (Table 2) suggest a stronger relation between useful work growth rates and economic growth rates, and consequently suggest a stability of useful work intensity at level of 1%. It is worth noting that the final exergy growth rate coefficient is not statistically significant at 10%, so we cannot exclude the hypothesis that this coefficient is zero.

4. Conclusions

In Portugal, the final exergy mix has significantly changed since 1856. A transition from biomass products to fossil fuels and electricity took place. When assessing the evolution of useful work by types of use, each useful work category changes slowly from 1856 to 2009, accompanying the major structural changes in the demand for energy services. Such structural changes were promoted by the introduction of new energy carriers used in Portugal and the consequent changes in the final exergy mix. Such transition and technological progress fostered the improvements in final-to-useful conversion efficiencies.

Economic useful work intensity exhibits a nearly constant path in Portugal during this 154-year period. The consistency of such result seems to be confirmed by running the presented methodology for the EU-15 countries, at least for the assessed timespan (1960-2009). Previous results relating the strong relation between useful work and economic growth (Warr et al., 2010) seem to be confirmed. However, a deeper analysis involving more variables and an extended timespan should be carried out in order to obtain new insights on growth theory. Also, the meaning and relevance of energy intensity measures should be discussed taking into account the useful work intensity (Sorman and Giampietro, 2011).

Acknowledgements

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The systems of data acquisition in bioreactor for modeling of biowaste composting

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Abstract
Working in field-scale demand lots of resources and work in order to obtain representative results. Even with perfect methodology and field experiment conducting there commonly appear factors (mostly weather conditions) which can disrupt the course or destroy the experiment. Therefore it is gainful to support the fieldworks with laboratory research. At the Institute of Biosystems Engineering of Poznan University of Life Sciences scientist find out the outset and constructed the reactor to research the composting process. The solutions use in bioreactor (especially thermal isolation and complex analytical sensors) allow to approximate very high its use to lead the research and outcomes reliability with reference to data got from fieldworks.

Key Words. biowaste, bioreactor, composting, modeling, data acquisition.

1. Introduction
Since the 90's of the last century it has been observed the dynamic development of research on the utilization and reuse of organic waste of agricultural, municipal and industrial origin [Boniecki et al. 2009, Dach et al. 2004, Gómez 2008, Marcinkowska et al. 2011]. This phenomenon was caused by general trends towards the protection of natural environment and then accelerated with the necessity of implementation of relevant legal regulations in this field in accordance with the strict ecological standards introduced in European Union after 1992 [Harrison et al. 2006, Petersen et al. 2007, Wolna-Maruwka et al. 2009].

Research over the course of composting process of different materials usually were conducted in pot experiments, or – using higher financial support – in field experiments. The pot experiments usually carried out in small volume containers did not provide the course of organic matter decomposition process congenial to the one occurring in nature. It was caused, most of all, by the small mass of tested samples (usually less than few pounds), a thus also completely different surface area to volume ratio of stored or composted material than in real field conditions. This fact influence on faster heat loss comparing to real-scale heaps and considerable shortening of termophilic phase [Dach et al. 2003, Dach et al. 2004]. Therefore, the oxygen supply in pot experiments – the basic factor determining the composting process course – was much more facilitated than in field experiments with piles of few or several tons.

However, on the other hand, small mass of samples in the laboratory and their inadequate proportion of surface to volume caused faster heat loss resulted from intense process of decomposition of energy compounds contained in waste, thus leading to a drastic shortening of the thermophilic phase. It is worth to underline that thermophilic phase lasting minimum 10-15 days is a condition ensuring a proper course of the composting process. At this stage there is an intense decomposition of hard degradable compounds (such as cellulose, hemicellulose and lignin) which dominate in the content of some materials like wooden chips, sawdust, and waste from greenery or containing the straw.

In contrary to the laboratory research, the field experiments require higher labor effort and resources, without any guarantee of replications because of weather conditions variability. Moreover in filed experiments it is much harder or even impossible to use extended equipment to measure the changes of particular parameters of material composting process like in case of laboratory experiments. This situation is the reason why pot experiments are widely used despite the fact that usually they do not give a description of the phenomena course in accordance with the real conditions.

The experiments conducted within last 15 years at Institute of Agricultural Engineering primarily were focused on decay processes study and working out of the utilization technology of a very wide species of biowaste (there is over 110 mln tons of biowaste yearly produced in Poland). From beginning, the experiments based on the real-scale windrows of composted wastes. Already at the beginning it has been stated that vessel experiments do not give an accurate picture of run of organic matter decomposition during composting [Dach et al. 2003, Boniecki et al. 2009].

The research activity of past years showed the necessity of possession of a supporting tool for fieldworks which can help to create some models, also modeling with usage of neural networks [Boniecki et al. 2009, Boniecki et al. 2009, Slosarz et al. 2011]. The tool which will at least allow to follow and define basic changes running in composted waste [Wolna-Maruwka and Dach. 2009].

In 2002 scientific team from Institute of Agricultural Engineering (Poznan University of Life Sciences) worked out the idea and built two sections of isolated 2-chamber bioreactor for model research on the processes of organic matter decay (in the frame of Ministry of Science and Higher Education grant concerning the study of gaseous emissions from different technologies of manure management) [Dach et al. 2003]. On the basis of many investigations it has been stated that during the experiments bioreactor ensures the run of decomposition similar like in real conditions during heap composting with usage of tractor aerator. Simultaneously allow to control very precisely changes running during the process [Dach et al. 2004, Raghavarao et al. 2003, Xiang-hua et al. 1999].

Numerous experiments explored with usage of bioreactor resulted in new conceptions of solutions [Wolna-Maruwka et al. 2009, Wolna-Maruwka and Dach. 2009, Piotrowska-Cyplik et al. 2009]. In 2006 (under the CleanCompost 6 FP UE project) 4-chamber bioreactor was designed (Fig. 1). Completely new idea of gaseous measurement was introduced, the tightness level and thermal isolation were raised, and control and measurement of aeration level were improved.

2. Aim of the study

The aim of this paper was to describe the research tool development that would allow to conduct the laboratory research at maximum rapprochement to the conditions in real field scale.

For this reason in 2002 at the Institute of Biosystems Engineering - (Poznan University of Life Sciences) it was developed the concept and built the bioreactor to study the course of organic waste decomposition processes. Research realized in Institute since 1995 in cooperation with Ecole Nationale Superieure Agronomique de Rennes (ENSAR) and Institute Nationale de la Recherche Agronomique (INRA) in Rennes, France, mostly were focused on the filed experiments because at the beginning it has been stated that pot experiments do not provide a complete picture of the course of organic matter decomposition during composting process.

This work has been funded by the Polish Ministry of Science. This study presents initial work started in the framework of governmental project No N N313 271338 and N N313 271338.

3. Description of construction of bioreactor chambers

In 2002 scientific team from Institute of Agricultural Engineering (Poznan University of Life Sciences) worked out the idea and built two sections of isolated 2-chamber bioreactor (125 dm^3 of each chamber) for modeling the processes of organic matter biodegradation [Dach et al. 2003]. On the basis of many investigations it has been stated that during the experiments bioreactor ensures the run of decomposition similar like in real conditions during heap composting with usage of tractor aerator. Simultaneously allow to control very precisely changes running during the process [Dach et al. 2004, Raghavarao et al. 2003, Xiang-hua et al. 1999]. However, the research development and growth of mass of the samples taking for different, wide analysis, let us to increase the volume of chambers from 125 to 165 dm^3.

The bioreactor schematic diagram is presented on Fig.1. The capacity of one bioreactor chamber amounts 165 dm^3. All chambers are made from High Density PoliEthylene (which has better resistance against the big temperature fluctuations). It is indispensable regard highly aggressive environment occurring during composting (NH_3, H_2S, and temperature reaching 80^oC), in particular sewage sludge composting process [Dach et al. 2003]. However, there are the steel squares on the top of chambers in order to reinforce this upper part with the cover. All covers are attracted to the chambers using the screw. This needs to use the elements stronger that plastic material, but guaranty the very well and strong connection between chamber walls and cover, and in consequence lack of escaped gases. Thermal isolation consists of hermetic 10 cm tight polystyrene layer. It ensures the run of composting process under exact control without any disturbances from the outside.

The air pressed by the membrane air pumps flows through the biomass placed in bioreactor chamber. Chambers have second bottom with openings of ϕ 2.5 mm placed every 50 mm on the whole surface. It allows to distribute evenly the delivered air in the entire mass volume, as well as to obtain wholeness of drains leaking out from the biomass while composting. Inside the chamber, on the top cover there is an eaves connected with half pipe. The goal of this system is to collect and evacuate outside the water vaporized during composting process. Between the chamber and the cover specialistic seals were used. In connection with 60 kg charge it is a hermetic set-up empowering the chemical analysis of the air leaving the chamber.

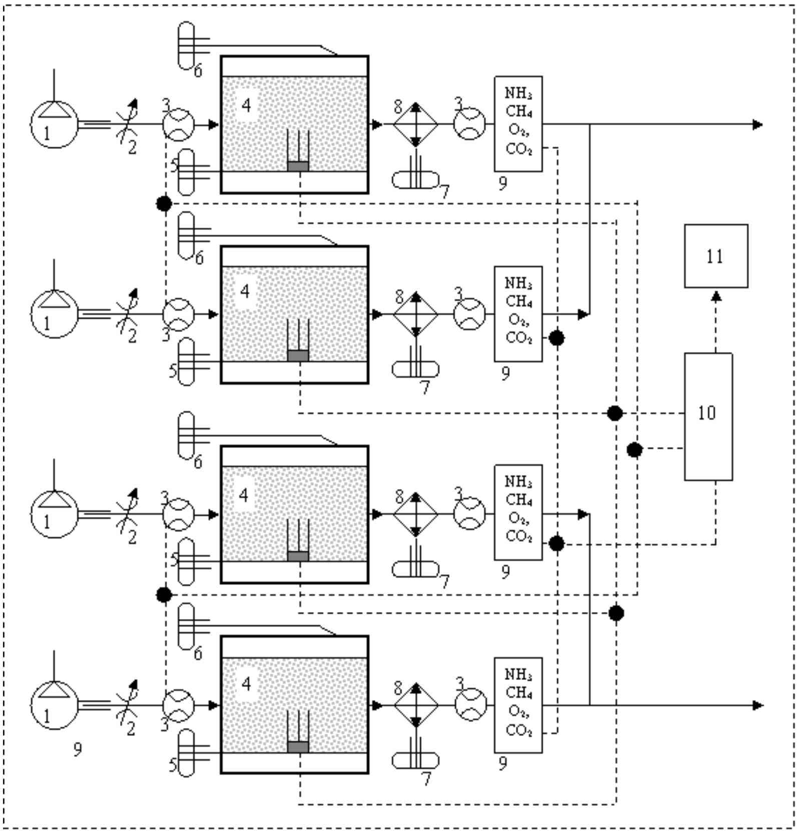

Fig.1. Bioreactor scheme:

1. Air pomp,
2. Flow regulator,
3. Flow meter,
4. Isolated chamber,
5. Drained liquids container,
6. Container for condensate steam from chamber lid,
7. Container for condensate steam from cooling set-up,
8. Air cooling set-up,
9. Multiple gas sensor array,
10. Data logger set-up,
11. PC computer.

4. Control systems and measured parameters

One of the idea of bioreactor concept development was to have possibilities to measure the maximum amount of parameters in order to receive large spectrum of analyzed parameters. That is why the bioreactor received several sensors and systems.

Selected parameters of bioreactor measuring system are shown in Tab. 1. Parent part of this measuring system are simultaneously working two microprocessor recorders of measuring signals. Main parameters are presented in Tab. 2. In case of a breakdown of one of the recorders the data continuity is ensured by working of the second one. In case of voltage fading of feed net system automatically passes on a battery power supply. It allows to save the data already recorded in the memory and to register further measurements. The system is constantly connected with a computer. In any moment the measurements results can be forward to the computer with usage of standard output RS 232C.

Between the air pomp and chamber inlet there is an air flow regulator integrated with a flow sensor, processed according to the individual solution. This system allows to precise control and constant registry of the air amount delivered into the chamber (in the range 0.5-20 l/min)

Table 1. Selected parameters of bioreactor measuring system

Measured parameter	Sensor type	Measuring range	Output signal
Temperature	KYORITSU	0-100^{o}C	0-600 V
Air flow	GT 1355/D	0,81 ln/min to 8,1 ln/min	0-5 V
NH_3	MG-72	0-100 ppm[2)] 0-1000 ppm	4-20 mA
O_2	MG-72	0-25 %	20-4 mA
CH_4	MG-71	0-4,8 %[2)] 0-100%	4-20 mA
CO_2	MG-73	0-100 %	4-20 mA

[1)] *independently to electronic sensor, the mechanical flow-meter are also used*

[2)] *depending on the gas content, there are the sensors with narrow and wide range which can be used by simple switch*

Apart from automatically saved data, the personnel can take some data by manual measurement. This concerns the usage of classical analyzers and meters. The list of "manually" measurements is presented below:

- mass of composted material – electronic balance (METTLER ID5 Multi Range) range 0-600 kg (made only before put material do chamber or after its pull out with accuracy of 0,01 kg)
- amount of air passed by each chamber – INTERGAZ DE-07-M1002-PTB005 (made during each gas and temperature analyzing with accuracy of 1 dm^3)
- volume of mass inside each chamber – by steel ruler measured with each 0,5 cm of accuracy
- amount of leakage from each chamber – measured with usage of balance (accuracy of 1 g)
- amount of condensate from each chamber – measured with usage of balance (accuracy of 1 g)
- temperature measured by sensors PT-100 – measured while gas analysis (1-3 times per day, depending of intensity of composting process)

Part of data taken manually is the same like obtained by automatic colleting. However, the classical way of measurement let to check the quality and propriety of automatic system work. In case of breakdown of automatic systems, the data taking manually let to guaranty the continuity of the experiment.

Table 2. Basic parameters of microprocessor recorders of measuring signals

Parameter	Type 1	Type 2
Maximum amount of measurement	168	2011
Measurement frequency	1 measur./h	≤ 4 measur./s
Supply voltage	12 V DC	12 V DC
Amount of measuring channels	16	32

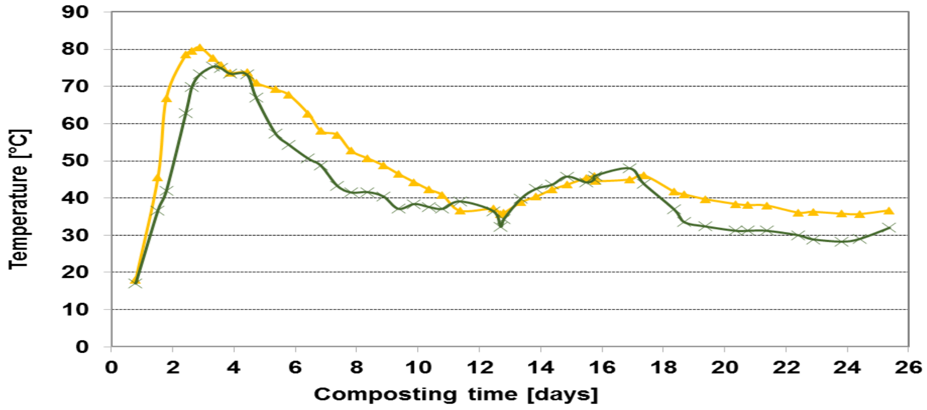

Fig.2. Exemplary run of temperatures while composting in two bioreactors

In every bioreactor chamber there are at least 2 temperature sensors in special acid-resistant covers. Fig. 2. shows an exemplary run of temperatures. Additionally is placed one control sensor measuring the surrounding temperature. The air leaving the chamber at first gets to the cooler cooperating with condensers system. The cooler target is to chill the air to the temperature below 40°C. From one hand it is forced by the technical parameters of gaseous heads (Tab.2) and from the other cooling down of the air allows to condense the air humidity and its chemical analysis.

Next the air flow again is measured and recorded. It allows to estimate the level of lost air during the experiment and to control if it was ensured that the gaseous heads had sufficient flow empowering reliably concentration measurement. The efficiency of gaseous measurement depends on an optimal flow obtained in the chamber outlet 0.7 l/min.

Applied measurement heads MG-72 of Alter S.A. firm are designed to measure the gasses concentration and to forward this information to the central measuring unit. Tab.3 shows the basic technical parameters of gaseous heads. Electro-chemical sensor is the main part of this head. It turns the changes of concentration magnitude of measured gas onto adequate changes of electric parameters. Output signal is the most essential information from the recorder point of view. Gasses measuring system consist of the following heads: NH_3 (0-100 and 0-1000 ppm), CH_4 (0-5% and 0-100%), O_2 (0-25%), CO_2 (0-25%) and H_2S (0-2000 ppm). It cooperates with an original system of electro valves which empower to use one set of heads for 4 bioreactor chambers. An exemplary run of ammonia emission measured for the chambers filled in by different sewage sludge and straw mixtures is shown on Fig.3.

Table 3. Basic technical parameters of gaseous heads MG-72

Delivery time of meteorological ability	≤ 20 sec.
Nominal supply parameters	5.6V DC/30 mA
Maximum termination resistance of current loop	50Ω
Temperature working range	- 20 to +40ºC
Humidity working range	10 – 90% Rh (without condensation)

5. Data storage and processing

All collected data are stored in the specific Excel sweet. The data measured by electronic systems are stored automatically. However, data taken manually (as well as results from physical or chemical analysis) have to be put in the sheet by personnel working within experiment.

The formulas created in excel sheet let to use obtained data in order to calculated new results. The good example of it is to use the basic data about air flowed through chambers, ammonia content in the exhausted gases and in consequence – calculation of cumulative losses ammonia emitted during composting (Fig 3).

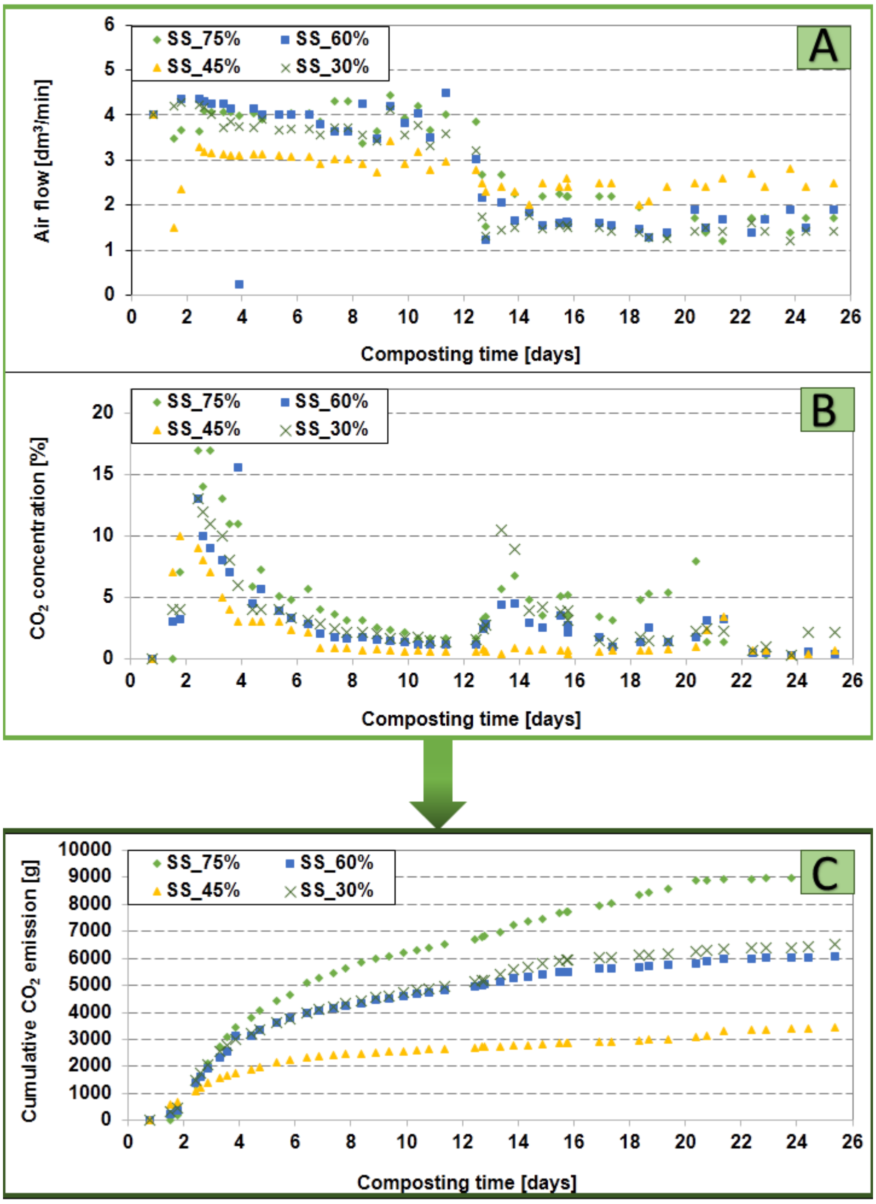

Fig.3. The example of schema of basic data used for calculation other parameters: data concern air flow and CO_2 concentration were used for calculation of CO_2 cumulative emission

The other possibilities of data usage is to collect the experimental data not only to describe the processes run but also for modeling, including neural modeling. The data gathered in laboratory tests are placed in a single file α, which served as a starting point for creating the learning set needed to create Artificial Neural Networks. The examples of data collecting for learning files are shown on Fig. 4.

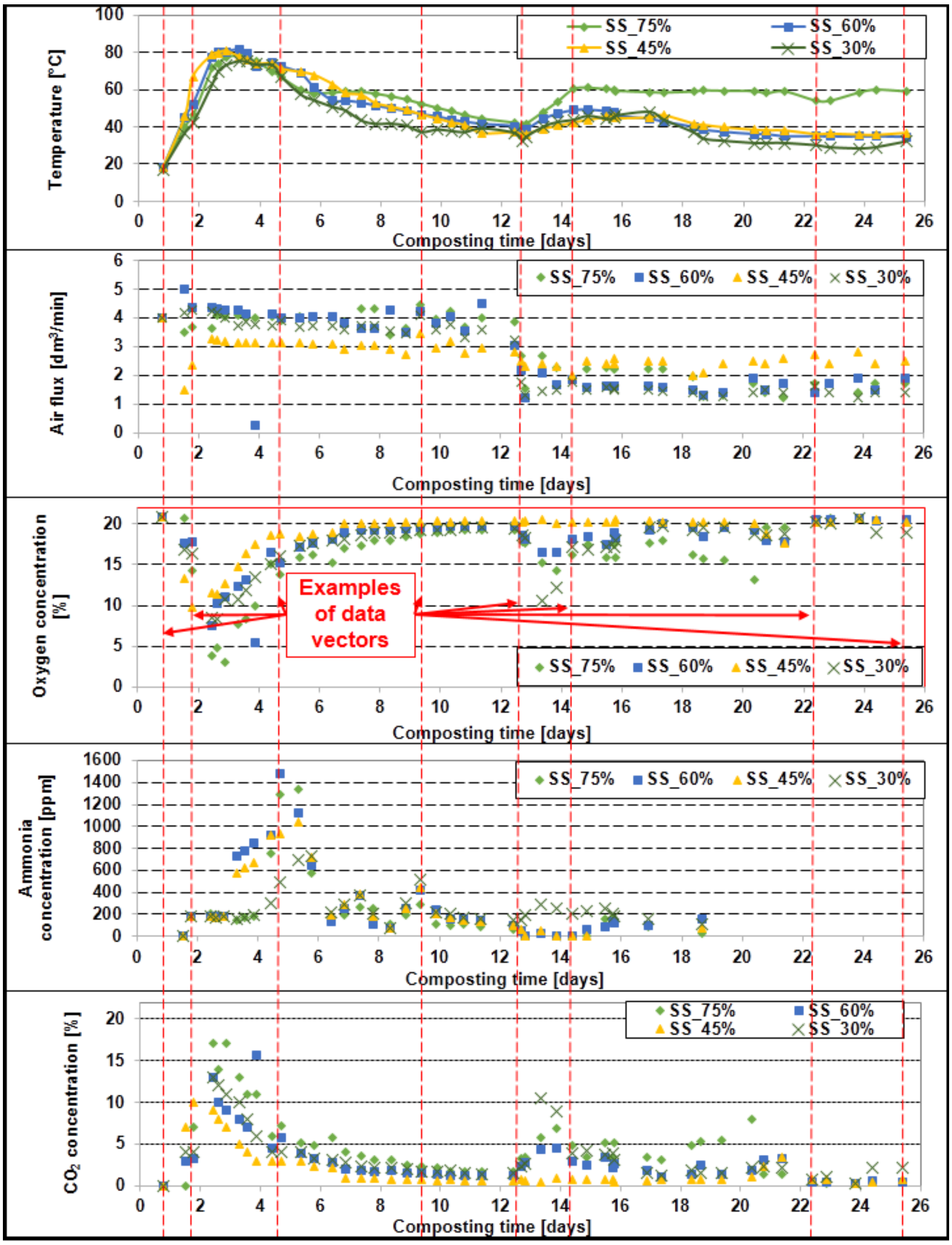

Fig. 4. The examples of learning vectors with data prepared for neural modeling; example for composting mixtures with sewage sludge contenct from 75% (SS_75%) to 30% (SS_30%), completed by straw and sawdust

The modeling with large spectrum of data can be very useful to predict the changes of many process parameters ie. ammonia emissions [Boniecki et al. 2012].

4. Conclusion

The specific solutions use in bioreactor i.e. thermal isolation. air flow with controlled oxygen level and complex analytical sensors allow to approximate very high its use to lead the research and outcomes reliability with reference to data got from fieldworks. Measuring systems used in bioreactor are the source of wide amount of data. Large measuring frequency reflects the real dynamics of physical and chemical changes of composted mass. Moreover, it is very helpful in gaining the representative data indispensable in modeling of occurring processes. This is an essential for usage of bioreactor as a tool for prediction of aerobic and anaerobic decomposition process with traditional modeling as well as usage of artificial neural network.

It has to be underlined that sage of bioreactor eliminates some part of fieldworks, considerably decreasing costs and accelerates the obtainment of final results. Laboratory conditions give an opportunity of usage of more developed measuring apparatus in comparison with fieldworks ones.

Constant control of oxygen content allow to avoid the presence of anaerobic conditions, unfavorably influencing on the quality of compost. The obtained results are very complex and with data from traditionally made physical and chemical analysis give to the researcher very powerful experimental tool with high potential of biochemical processes modeling.

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Selection of portfolios of electricity generation projects: an exploratory study

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Abstract

The electricity planning traditionally relies on optimization models with the objective of minimizing system costs. However, the liberalization trend of the market and development of renewable energy increased the complexity of this planning exercise. It becomes then necessary to study other methodologies in order to include in the planning process the risk variables and potential correlation between technologies and fuels. The main guidelines of current energy policy in Portugal should meet the goals of energy efficiency, reduce energy dependence without compromising security of supply, minimizing the environmental impact and promoting renewable energy development. In a scenario of high growth of renewable energy sources (RES), it is pertinent to study the seasonality of electricity production by the various RES (biomass, hydro, wind, solar ...) evaluating the potential complementarily between these sources as a mitigation or increase risk factor. As for thermal power plants, the existence or not of correlation between fossil fuel prices must also be considered. The risk-return approach is often used in the selection of financial assets, however, several studies have revealed its potential when applied to electricity planning, especially with regard to the inclusion of RES projects. This study will test the possible application this model for the Portuguese electricity system, resulting in the proposal of future scenarios for the electricity generation sector taking into account the increasing importance of RES.

Keywords: Electricity planning; Renewable Energy; Risk; System Optimization.

1. INTRODUCTION

According to DGEG (Direcção Geral de Energia e Geologia), Portugal is heavily dependent on foreign sources of energy, particularly oil. However, this trend has been declining due to increasing installed capacity of renewable energy. At the same time, due to successive increases in the price of primary energy, the costs with energy imports increased between 2009 and 2010. In Portugal, hydro and wind are the main natural resources used for electricity generation. Currently, these two RES represent more than 60% of the total installed power of the Portuguese electricity system. The development of RES based technologies to generate electricity can represent a key strategy for reducing dependence on foreign energy, contributing also to increased security of supply of electricity to consumers (DGEG, 2012).

The electricity and heat production activities are responsible for almost 20% of total primary energy consumption in 2011. Also, 55% of electricity consumption in Portugal has origin in importations, namely imported fossil fuel and imported electricity from Spain. The production of electricity is, then, the largest consumer of primary energy in Portugal (DGEG, 2011).

Table 1 shows the evolution, in the last three years, of the installed capacity of each technology for electricity generation in Portugal, based on data collected from REN (the Portuguese electricity grid operator).

Table1: Installed capacity evolution, Source: REN

INSTALLED CAPACITY (MW)			
	2009	**2010**	**2011**
Gas	2992	3829	3829
Coal	1756	1756	1756
Large hydro	2160	2397	2397
Run of river	2023	2583	2583
Small hydro	395	410	412
Onshore wind	3357	3705	4081
Solar PV	95	122	155

According to Table 1, wind power role has been increasing during the last years and in 2011 the installed power overpassed 4 GW. From the table, one can see, also, that there is also a slight expansion in solar technology. Table 1 also shows that the three hydro technologies sum up currently an installed capacity of nearly 5.5 GW, representing more than 30% of the total electricity power installed in Portugal. Therefore, hydropower has a key role in the National Electricity System (NES) management. As so, an extremely dry year can cause a significant increase in the production of electricity resourcing to fossil fuels and consequently impacting importation levels of these products. Moreover, a rainy year should result in lower importations of fossil fuel products to be used for electricity production.

Figure 1 shows the contribution of each technology to supply the electricity demand between 2009 and 2011 in Portugal. In 2009, the total consumption of electricity in Portugal was 49.9 TWh. The hydroelectricity production supplied 14% of consumption, whereas thermal energy sources supplied 47% of the total electricity consumption in Portugal. Special Regime Production (SRP) includes renewable power producers (excluding large hydro) and cogeneration. These SRP supplied 29% of consumption, of which 15% was due to wind-power. The import/export balance stood at 9%.

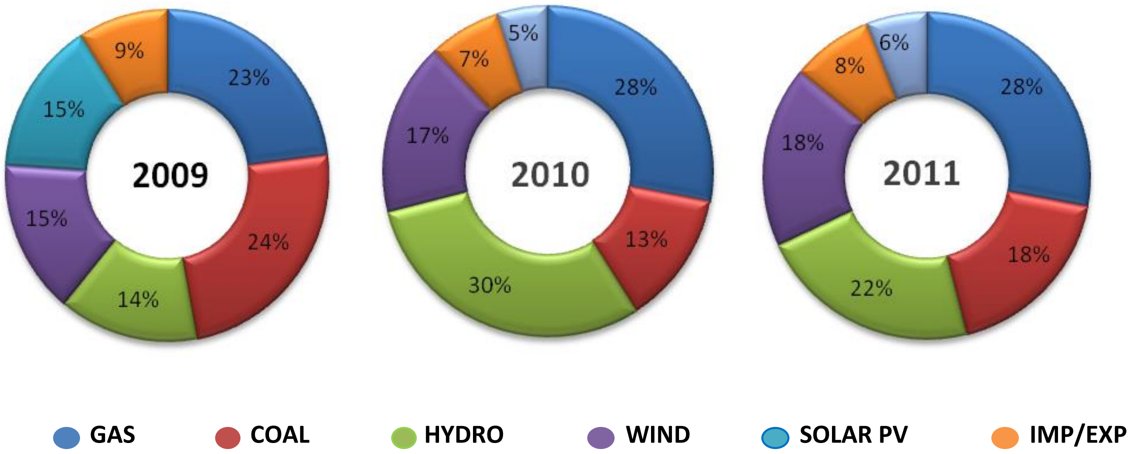

Figure 1: Sources of electricity supply over the last 3 years (Source: REN)

In 2010, electricity consumption increased to 52.5 TWh. The hydroelectricity sector supplied 28% of total consumption due to an higher than average hydroelectricity productivity index (HPI), which was 1.31 according to REN. The SRP supplied 34% of the consumption of which 17% were due to the wind power, which increased 20% over 2009 due to the construction of new parks and a higher than average wind production index (WPI) was 1.08. Thermal power plants supplied 33% of the electricity demand, the lowest share in 30 years. The import/export balance was the lowest since 2002, registering a supply of only 5% of total consumption (REN, 2010). These numbers show that this was a year extremely favorable to the production of electricity through renewable energy, mainly due to the higher HPI, compared to the other years of the study. For this reason, several stops from coal plants happened this year and there was, also, a decrease in electricity production through gas, especially during winter periods.

Finally, in 2011, electricity consumption was 50.5 TWh. The RES production supplied 46% of the total electricity consumption (wind 18%, hydro 22%, and other RES 6%) lower than the 52% share of the previous year. The HPI and WPI were below the average, 0.92 and 0.97, respectively. Moreover, the wind production decreased compared to the previous year, despite the increase in installed capacity of 375 MW. The thermal power production increased

12% and supplied 38% of total electricity demand (gas 20% and coal 18%). The import/export balance, in turn, increased, and represented 6% of total demand (REN, 2011).

The environmental pollution and energy dependence are major concerns of the European Union (EU), driving measures to reduce CO_2 emissions to satisfactory levels. The challenge is to generate "clean" and efficient energy within European borders in order to reduce environmental pollution and energy dependency. Development of renewable energy in Portugal was driven by a favorable environment, namely the stated Portuguese government goal of a sharp increase of electricity generation from RES sources and to enhance energy efficiency. This objective was accomplished through economic incentives for the installation of electricity generators from renewable sources coupled with technological developments. Finally, according to Deloitte (2009) report the Portuguese weather conditions are clearly favorable to the production of electricity through renewable energy sources, particularly hydro, solar, wind and even wave power.

2. THE MEAN-VARIANCE APPROACH (MVA) FOR ELECTRICITY PLANNING

2.1 Brief History of MVA

The MVA approach has its roots on the seminal paper of Markowitz (1952). The major objective of this approach is the selection of investment portfolios based on maximizing the value of future expected return within a certain level of risk the investor is willing to assume for its investment (Ferreira, Cunha 2011). With this approach it is possible to identify minimum variance portfolios for any level of expected return.). According to Markowitz (1952), the portfolio selection process can be divided into two stages. The first starts with observation and experience and ends with a perspective on the future performance of available securities. The second stage begins with the perspective on the future and ends with the selection of a portfolio of assets. Any investor in securities should maximize the return on its investment within acceptable risk levels. Risk and return, typically, have a positive correlation with each other. When the former increases the latter also increases. Therefore, the greater the risk, the greater the return of investment. However, Markowitz (1952) emphasized that diversification can reduce portfolio risk to lower levels, and this will depend on the correlation between assets within a given portfolio. Therefore, when deciding on their investments, investors should consider, in addition to the expected return, the dispersion of returns around the mean, i.e. the variance. Thus, the characteristics of an investment can be measured using the variables expected return and variance (Ferreira, Cunha 2011), and this is due to the fact that the distribution of expected returns follows a normal distribution. Therefore, assuming that a particular investor is risk averse, with a choice between two investments with the same standard deviation but different expected returns, it will always decide who is at higher expected return. So, instead of investing in a single financial asset, the investor should choose to invest in portfolios consisting of various assets. There are two main reasons why diversification reduces investment risk. On the one hand, as each asset included in a given portfolio represents only a small part of the capital invested, any event that affects one or some of these assets has a much more limited impact on the total value of the investment. Moreover, the effect of specific events on the value of each asset within the portfolio can be positive or negative. In large and diversified portfolios, these effects tend to offset each other without affecting the overall value (Ferreira, Cunha 2011).

2.2 MVA applied to electricity planning

In this paper, the intuition underlying the MVA approach is applied to the selection of portfolios of electricity generation technologies. By including as a decision variable the risk of portfolio (in this case the production costs of electricity), this approach allows policy makers or private investor integrating the three main objectives of energy policy in a quantifiable manner (McLoughlin, Basilian 2006): Energy at competitive prices; security of energy supply; mitigation of environmental impacts.

In recent years there has been an increasing application of the MVA approach to electricity planning in many countries such as Ireland (McLoughlin, Basilian 2006), Italy (Arnesano et al 2012) and Japan (Bhattacharya, 2010). In fact, the mean-variance model can be used to estimate optimal portfolios of electricity generation both for a company and for a country (Ferreira, Cunha 2011). As emphasized by Awerbuch (2003), energy planning is no different than investing in financial securities, where efficient portfolios are widely used by investors to manage risk and improve performance. Thus, energy planning should be focused to develop portfolios with efficient production than on finding alternatives with lower cost of production, because, at any given time, certain alternatives may have high costs and others may have lower costs. However, over time, a favorable combination of alternatives may facilitate minimizing the overall cost of production compared to the risk (Awerbuch, 2003).

Apart from the fact that it can find the optimal portfolio, the application of MVA allows analyzing the impact of the inclusion of renewable technologies (RES) in the scenario of generating sources of electricity. In particular, the MVATP allows a better assessment of the risk associated with the different technologies. Moreover, it allows, also, to illustrate the trade-off between production costs and risk, which means that it is not possible to achieve a lower cost of production of electricity, without assuming higher levels of risk (Ferreira, Cunha 2011).

Awerbuch (2003), in the analysis of power (or energy) systems, was able to model a combination of political, environmental and technological aspects. The inclusion of this aspects and, particularly, environmental concerns, has demonstrated that producing electricity through renewables is a strategy conducive to positive effects on the environment. In fact, Awerbuch (2003) demonstrated that the introduction of RES technologies (as wind, solar and hydro) in the energy portfolio, significantly reduces the total cost of energy and the production risk, since solar and photovoltaic technologies are risk-free, since its operation is not correlated with the change in the price of fuel (Arnesano et al 2012).

2.3 MVA applied to the Portuguese case

Electricity production investments in Portugal have been focused, mainly, in renewable energy sources. This focus, beyond the issue of economic and energy self-sufficiency, follows the guidelines of the EU towards reducing CO_2 emissions into the atmosphere, which justifies the decline of production of electricity through coal, despite the stability of its price in recent years. The frequent indexation of the price of non-renewable energy to oil prices and the concerns about fuel diversification and security of supply, led to the adoption of new technological solutions in the supply of electricity throughout the country.

The cost production of electricity depends on the technology and primary energy source used. In the case of thermal or non-renewable energy sources, the most relevant factor in calculating the cost associated with the production of electricity is the price of fuel that is subject to market fluctuations. In the case of renewable sources, the critical component for calculating the associated cost is the capacity factor (CF) – the ratio of actual power produced and the power the generation plant could produce. The reason is that the initial investment is high and the marginal cost is very low. Therefore, the return on investment comes only within a reasonable period of time if the natural resources permit (Arnesano et al 2012).

Thus, for each technology, the respective levelised cost of electricity (LCOE) was calculated, which represents the total cost per MWh produced throughout the life of a plant and which can be obtained from the following expressions:

$$LCOE = \frac{\sum I_t + (M_t + F_t + X_t)\frac{(1+r)^t - 1}{r(1+r)^t}}{E_t . n} \qquad (1)$$

Where,
I_t = Investment cost
M_t = Operation and Maintenance costs
F_t = Fuel costs
X_t = Environmental costs
n = Lifetime of the plant
E_t = Power output
t = time period under study

The investment cost was estimated from values related to constructions of various electricity generation plants, published by the International Energy Agency (IEA, 2010).

The operation and maintenance costs are all expenses inherent in the process of producing electricity and maintenance of equipment such as labor or material costs and, like the investment costs, in this study, were obtained from the publication of the IEA (2010). These costs may be fixed, as is the case of labor costs, and, if appropriate, maintenance contracts, or variables, namely costs which usually vary with the production, usually coupled with fatigue equipment or any necessary modifications in the equipment according production. The cost of fuel, naturally, only applies to thermal production technologies (coal and gas). The price of natural gas was obtained through the database "Datastream, Thomson Reuters" and is expressed in €/MWh. For this work we used the daily values. In the case of coal, the price of this raw material was obtained through the source "EUROPEAN COAL: CIF ARA". The environmental costs refer to the amount paid by the operator of the power plant relative to the amount of CO_2 released into the atmosphere and, as the price of coal, was obtained by database "Datastream, Thomson," coal price column. The lifetime of the plant corresponds to the average life time (in years) estimated for all power plants corresponding to each technology. In this study, we used values published by IEA (2010) and Moot MacDonald (2010).

Figure 2 shows the mean values of the power output for each technology over the last 3 years, computed from REN data.

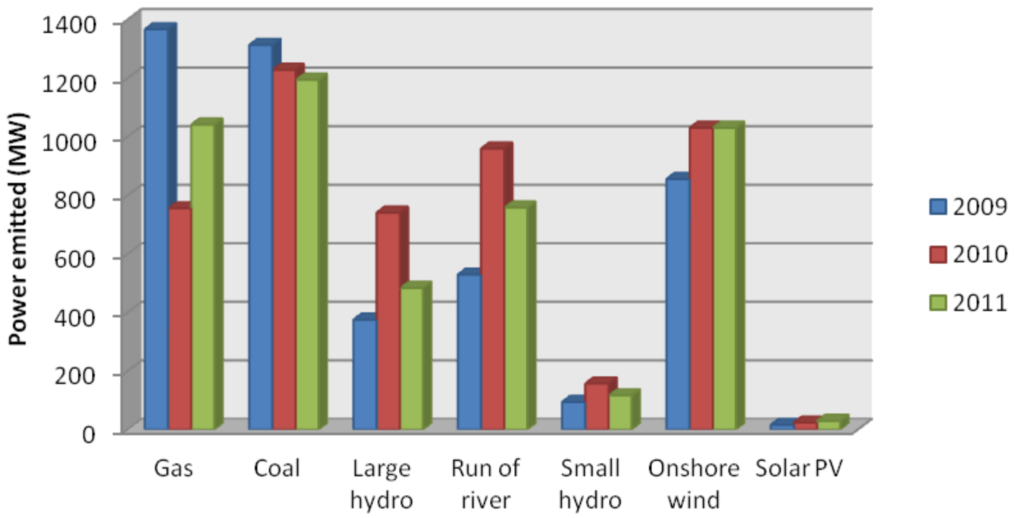

Figure 2: Mean power output for each technology 2009-2011. Source: REN.

Table 2 shows the evolution of the LCOE over the three years for all technologies included in this study. These values were by applying the equation (1) using the data from the sources described above.

Table2: Levelised Cost of Electricity over the three years (average values)

Levelised Cost of Eletricity (€/MWh)			
	2009	**2010**	**2011**
Gas	69,30	131,97	115,37
Coal	57,90	75,29	85,24
Large hydro	88,49	64,87	79,17
Run-of.river	108,71	76,66	88,94
Small hydro	120,61	91,48	107,07
Onshore wind	68,31	62,43	65,42
Solar PV	218,19	173,55	174,88

2.4 Simulation of Optimization Model

Markowitz (1952) showed that in order to maximize the expected return on any investment, and at the same time minimizing the associated risk, the investment should be diversified into more financial assets. Therefore, all assets considered in portfolio analysis should be characterized not only by the expected return but also by their variability, measured as the variance (or standard deviation) of expected returns. Investment diversification is effective in maximizing expected return while minimizing risk since the evolution of assets' prices are not perfectly correlated. One can say that a portfolio is efficient if there is no other portfolio with the same variance and higher expected return, or if there is no other portfolio with the same expected return and lower variance. Therefore, the efficient frontier is the set of efficient portfolios (Arnesano et al 2012).

Although, the MVA approach has been extensively applied in a financial context, in order to estimate the portfolio risk and expected return , it is also possible to use it for the selection of portfolios of electricity generation technologies (Bhattacharya, 2010). In this context, costs are quantified as generation costs and the return is measured by the inverse of those costs (Awerbuch, 2003).

The expected return of the portfolio is expressed by the weight of each technology's return in the portfolio and can be calculated by equation (2).

$$E(R_p) = \sum_{i=1}^{N} W_i E_{(Ri)} \qquad (2)$$

Where $E_{(Ri)}$ represents the value of the expected return from the i_{th} technology (R_i), and W_i is the share of the ith technology in the portfolio.

The inverse of the LCOE for each technology serve as a proxy measure of return of a physical output per monetary unit as input (Awerbuch, 2003). In other words, lower cost means higher outcomes associated to the production of electricity using the same technology (Arnesano et al 2012).

$$R_t = \frac{1}{LCOE_t} \qquad (3)$$

Where (R_t) is the return in period t, and ($LCOE_t$) is the cost in period t for a given technology.

The risk of the portfolio, E (σ_p), is represented by the standard deviation of the portfolio (σ_p) measured by variations on the LCOE. The risk associated with the portfolio is calculated by equation 4.

$$E_{(\sigma p)} = \sqrt{\sum_{i=1}^{N} w_i^2 \sigma_i^2 + \sum_{j=1}^{N} w_i w_j cov_{ij}} \qquad (4)$$

Where,

$i \neq j$; i=1,2,3,…,n; j=1,2,3,…,n; w_i and w_j are the variables which represent the corresponding weight technologies i and j respectively, in the portfolio; σ_i represent the standard deviation of the rate of change of cost and COV_{ij} is the covariance of two technologies as can be seen in equation 5.

$$cov_{ij} = \rho_{ij}\sigma_i\sigma_j \qquad (5)$$

ρ_{ij} is the correlation between technologies i and j, which characterizes the diversity within the portfolio. The lower the value of ρ_{ij} between portfolio's technologies the higher the portfolio's diversity and, consequently, contributes to a reduction in portfolio's risk, $E_{(\sigma p)}$. In other words, increasing the diversity of the portfolio, by adding technologies uncorrelated or correlated negatively, reduces the risk of the portfolio, which can be observed by the tendency of correlation to zero (Bhattacharya, Kojima 2010).

For the calculations REN data was used, representing the power output for each technology measured for each quarter of an hour for the period 2009-2011. This level of data detail is particularly important as is it allows capturing de variability and seasonality of RES. Table 3 describes the correlation between different technologies obtained from these time series.

Table 3: Correlation between different technologies

	Coal	**Large hídro**	**Run of river**	**Small hydro**	**Onshore wind**	**Solar PV**
Gas	0,0631	0,0378	0,0490	0,0399	-0,0541	0,0101
Coal		0,0600	0,0427	0,0198	-0,0975	-0,0034
Large hídro			0,1641	0,0750	-0,0652	0,0107
Fio-de-agua				0,0834	-0,0388	0,0099
Small hídro					-0,0174	0,0339
Onshore wind						-0,0440

Once the covariance between different technologies is determined, the first objective function of this model is to minimize the investment risk of a given portfolio of electricity generation technologies, as given in equation 4. Assuming that a particular portfolio is comprised of *n* different technologies, the optimization problem can be solved by equation 6.

$$\text{Minimize}\left(\mathrm{E}(\sigma_p)\right)Min = \sqrt{\sum W_i^{\,2}\sigma_i^2 + \sum(w_i w_j cov_{ij})} \qquad (6)$$

Subject to

$\sum w_i = 1$;

$Wi \geq 0$;

After calculating the lowest risk portfolio, to be increased the risk, the efficient portfolio will be found. The second objective function (Equation 7) is used in order to maximize the expected return without exceeding risk assumed, ie:

$$Maximize\ E_{(r_p)}\ Max = \sum_{i=1}^{N} w_i E_{(r_i)} \qquad (7)$$

Subject to,

$$\sigma_p^2 = \sum_{i=1}^{N} \sum_{j=1}^{N} w_i w_j \sigma_{ij} \leq \sigma^2$$

$$\sum_{i=1}^{N} w_i = 1$$

$$w_i \geq 0$$

Solving equation 7 for different levels of expected return, different portfolios of technologies are obtained. Table 4 shows some examples of these portfolios.

Table 4: Energy solutions portfolios with different risk levels

Portfolio	**A**	**B**	**C**	**D**
RISK	**0,015**	**0,030**	**0,060**	**0,120**
W (coal)	25,5%	9,2%	0,0%	0,0%
W (gas)	16,0%	12,9%	0,0%	0,0%
W (Large hídro)	1,8%	16,4%	38,2%	100,0%
W (fio d'água)	3,0%	15,4%	26,5%	0,0%
W (Small-hídro)	21,0%	8,6%	0,0%	0,0%
W (Wind)	29,2%	19,4%	0,0%	0,0%
W (Solar)	3,4%	18,1%	35,4%	0,0%
E(rp)	**0,00076**	**0,00235**	**0,00435**	**0,00585**

Table 4 shows the convergence to a solution composed of 100% electricity production through large hydro. From Table 4 it becomes evident that lower risk solutions are the ones with a more diversified portfolio. The return of the portfolio can increase for less diversified solutions relying mainly on RES technologies but the risk increases, which can be justified by the variability and seasonality of the renewable resources.

The set of portfolios that result from this process and that forms the efficient frontier is shown in Figure 3.

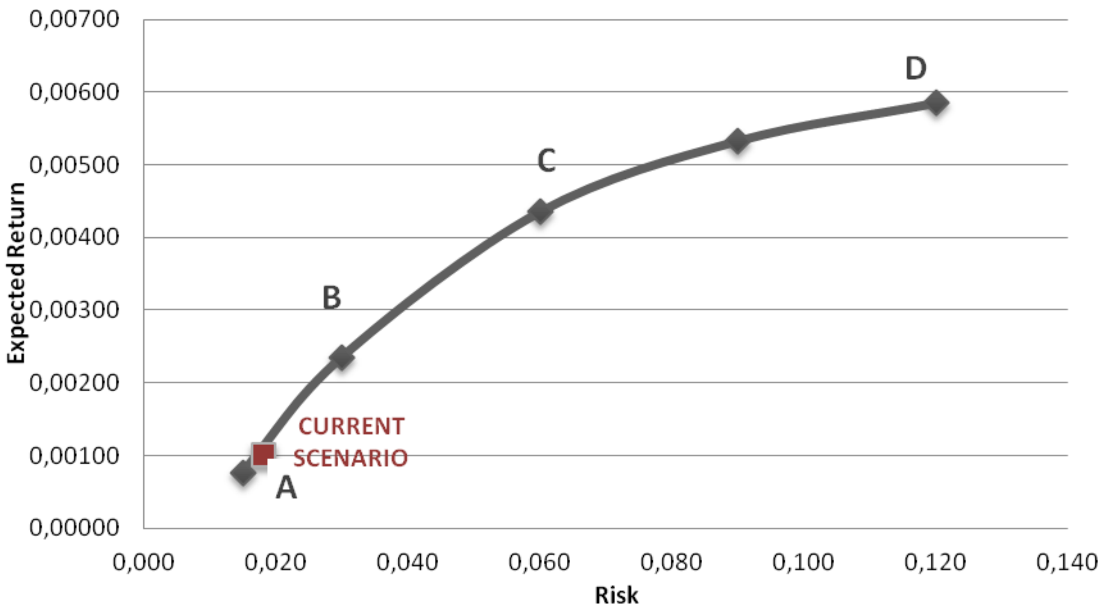

Figura 3: Comparison between the solutions presented by the MTP and the current scenario of REN

Each point on the efficient frontier represents a portfolio with maximum expected return for a given level of risk or minimum risk for a given level of return. The Portfolio A: Portfolio with lower risk, but lower expected return. Normally there is more diversity in their assets; Portfolio B: Portfolio with expected value higher than the A, however, increases the risk associated. Typically, there is less diversity in their assets. Portfolio B presents a very small proportion of thermal energy, the result of increased weight of hydropower, which is only possible in rainy periods, and by photovoltaic that in this solution has 18% (table 4) of the total electric power issued for NES. The portfolio C, is composed only by the photovoltaic and hydropower, so this scenario is considered very hard to implement, since, currently. Finally, the portfolio D, presents a scenario composed of 100% large hydro, allowing to obtaining the maximum expected return utilizing the large hydro to produce all electricity in Portugal. It should be underlined that this MVA approach does not take into account the technical feasibility of the proposed portfolios, as no constraints were imposed for these matters.

Figure 2 also shows at what point of the efficient frontier is located the combination of current technologies for producing electricity, in terms of risk and expected return, respectively. The current scenario presents a very low risk and of course, an expected low return. Therefore, the current Portuguese portfolio of technologies to generate electricity is on the efficient frontier and near Portfolio A.

3. CONCLUSIONS

This paper presents an approach to electricity power planning in a system with strong RES influence and, as so, highly dependent on the seasonality and variability of the renewable resources. If from one side, RES based technologies are recognized to have low marginal costs, their high capital costs and the uncertainty of their output are major drawbacks to their effective implementation. The MVA use on the definition of electricity portfolio was tested and revealed to be a valuable tool for energy decision makers. It allows to explicitly dealing with the cost aspects, by resourcing to the LCOE for the return computation, and with the variability of the system, by including the risk element in the analysis.

MVA presents itself as a very powerful tool in the decision making of financial investors, taking into account the risk that each is subject to assume a given investment in the stock market. However, the results of this model have several limitations when applied to electricity generation that should not be overlooked.

The stock market's financial sector is constantly marked by the rise and fall of their respective values and what makes them more or less risky an investment in the stock market is the dispersion of possible outcomes, a value that is measured by the standard deviation. What happens in the stock market is that their greater profitability happens when they value increases; the same is not true in situations stagnant stock price. The model applied in this work translates exactly this variability and presents the results in terms of maximum expected return and minimum variation. However on the NES, greater stability is not always an advantageous if the output values are very low. For NES the return will be much higher in a situation with high output values, even with a decreasing trend, than in a situation of low output values with an increasing trend. That is to say, the objective should be to ensure the high outputs for the longest possible period. Also, the technical feasibility of the portfolios and the RES potential must be also include in the model in order to ensure that the solutions can in fact be implemented. This means that future work must focus on the development of a modified MVA model where new return and risk variables are to be defined and additional restrictions are to be included, according to the technical characteristics of the electricity problem under analysis.

Nevertheless, this exploratory exercise allowed to clearly demonstrate the need to include the risk variable on the electricity planning and to take into account the existence of correlations between RES underlying resources and consequently on their output.

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Potential Role of Stationary Urban Distributed Storage on the Management of Power Systems

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Abstract

Electric energy storage (EES) systems applied to the electricity grid were presented in a recent past as a utopia due to lack of technological options and the low price of energy, which precluded the adoption of alternative management systems. (Barton and Infield, 2004), (Ribeiro *et al.*, 2001) This paper aims to provide a general understanding of energy storage applications in order to draw important insights for the development of a methodology that assesses the feasibility of a distributed EES solution integrated in urban infrastructures, making use of possible idle states, designed to provide energy services to the grid. An overview is made of ESS operation requirements, possible applications and services that can be delivered to the network, barriers and an ESS assessment for quantification of net benefits. After this review an orientation can be obtained regarding the best approach for the development of a new methodology that enables decision makers to assess the best distribution matrix of ESS related total revenues and costs, mitigating the risk of decisions.

Keywords: Energy Storage, Urban Infrastructures, Electric Grid, Power Quality, Energy Services, Smart Grids, DSM – Demand Side Management.

JEL: Q42 - Alternative Energy Sources;

Introduction

Although in the recent past energy storage for daily periods seemed economically unfeasible (Barton and Infield, 2004), taking into account the rising cost of oil coupled with the need to rethink the management of the electricity grid to meet the demands of current loads, the concept of energy storage, centralized or decentralized, is presented today as an opportunity to consider, facilitating the solution of many problems of capacity and reliability of the network (Ribeiro *et al.*, 2001), (Divya and Østergaard, 2009) .

The European Technology Platform SmartGrids (2012) presents storage as a key solution in order to achieve the EU 20-20-20 goals, and to obtain the envisioned CO2 reduction of 80% by 2050, even considering the high acquisition and maintenance costs. The integration of storage technologies, addressing different needs (e.g. quick response, high grid security, long term energy storage, lowering peak demand, among others) will help tackling these challenges.

Continuous load growth, increasing power quality requirements of electronic loads and higher regional power transfers in a largely interconnected network, can lead to complex and less secure power system operation, especially because power plants are not able to follow new demands as a result of economic, environmental, technical, and governmental regulation constraints (Ribeiro *et al.*, 2001) (Ali Ipakchi, 2009).

EES Operation

By the year 2035 it is expected that a large fraction of the generation capacity in Europe will have stochastic and/or intermittent availability. Due to technological improvements, it is expected that EES in Europe and USA will grow by 10 to 15 %, and even higher in Japan, in a near future, motivating a major change in the electricity industry (C. Haisheng et al., 2008).

The development of energy storage systems is essential to the achievement of a more flexible and controllable electric grid, e.g. smart grids, enabling higher levels of demand side management, an increased proximity of generation to the loads, the integration of intermittent generation from renewable sources, and other forms of decentralized production (Ali Ipakchi, 2009), (Beer et al., 2012).

Lassila et al. (2012) claim that the use of intelligent charging/discharging schemes will release network capacity, enabling a more efficient operation. According to these authors this will postpone grid reinforcements by the utility company, decrease network losses, avoid short interruptions and some voltage quality problems, shave power peaks and smooth load curves.

However, it is important to notice that the operation of battery based EES is constrained both in capacity and storage balances, for batteries and grid connections. For instance: battery capacity constraints, related to nominal capacity; unintended end effects, which can be minimized by fixing a percentage battery level working set point; battery wear costs, related to the life cycle of each technology, and, capacity limits for the grid connections, which are related to existing physical electric infrastructure interfaces, such as wires and other circuitry connection and/or the rated maximum power of the interface's power electronics (Kristoffersen et al., 2011), (Kempton and Tomic', 2005).

According to Divya and Østergaard (2009), instantaneous, short-term and mid-term applications seem to be commercially feasible at present. Currently, the battery energy storage systems (BESS) seem to be cost effective when designed for less than 5 h storage. Although the storage of large amounts of energy would be desirable, even batteries of modest power and able to deliver only during seconds or minutes seem to be cost-effective.

Nevertheless batteries appear as important equipment, capable of storing energy for a large number of requests, and easily integrated in a city environment (Baker et al., 1999), (EPRI, 2010).

EES Possible Applications and Services

The adoption of distributed energy storage allows an optimization of resources by providing the capability to effectively balance supply and demand (Kintner-Meyer et al., 2007), (EPRI, 2010).

Barton and Infield (2004) state that and increased storage capacity, spanning a few hours, allows the distribution network to respond to higher demands without causing too much load flow in the transmission network, compared to a system without storage, as well as it would allow an increased consumption of inductive reactive power.

According to C. Haisheng et al., (2009) and to Rahman et al., (2011), EES technologies provide three primary functions of energy management, bridging power, power quality and reliability. However, there are other definitions for more specific applications. It is important to note that no single storage system based on commercially available technologies meets currently all the requirements for an ideal EES - being mature, having a long lifetime, low cost, high density and high efficiency, and being environmentally benign. Each storage system has a suitable application range. For utility applications, cost is the most important factor and storage facilities need to be sized in tens or hundreds of megawatts with a few hours duration. On the other hand, automotive applications have small footprints and high power outputs (Rahman et al., 2011).

According to C. Haisheng et al., (2009), each service presented above can be performed as one of the options in Table 1:

Table 1 - Application Category Specifications (C. Haisheng et al., 2009)

Service	Power rating	Application
Medium-scale energy management	10 - 100MW	Load leveling, ramping/load following, and spinning reserve;
Bridging power	0.1 -10MW	Assure continuity of service when switching from one

		source of energy generation to another
Power quality	Lower than 1 MW	Voltage drop, flicker mitigation and short duration uninterruptible power supply (UPS)

Schoenung and Hassenzahl (2003) defined an application category specification table regarding the power level and discharge time requirements, based in published studies, as presented in Table 2.

Table 2 - Application Category Specifications (Schoenung and Hassenzahl, 2003)

Representative Applications	**Discharge Power Range**	**Discharge Time Range**	**Stored Energy Range**
Load leveling, spinning reserve	10-1000 MW	1-8 hrs	10-8000 MWh
Peak shaving, transmission deferral	100-2000 kW	0.5-4 hrs	50-8000 kWh
End-use power quality and reliability	0.1-2 MW	1-30 sec	0.1-60 MJ (0.028-16.67 kWh)

We can observe that the capacity range for each application is not well defined in tables 1 and 2, varying among authors. Moreover, energy storage capacity is specifically determined by the time duration required for delivery or discharge. Applications tend to fall into time categories of very short, short, long, and very long duration, as shown in Table 3, according to the time category applications recognized by utilities and customers.

Table 3 – Types of applications as a function of time span duration (S. M. Schoenung, 2001)

Very short duration	**Short duration**	**Long duration**	**Very long duration**
• End-use ride through, power quality, motor starting; • Transit; • T&D stabilization.	• Distributed generation (peaking); • End-use peak shaving (to avoid demand charges); • Spinning reserve – rapid response within 3 sec to avoid automatic shift; • Spinning reserve – conventional (respond within 10 min); • Telecommunications back-up; • Renewable matching (intermittent);	• Generation, load leveling; • Ramping, load following.	• Emergency back-up; • Seasonal storage; • Renewables back-up.

By analyzing Portuguese supply failures presented in (EDP Distribuição, 2011) we can conclude, using the previous table information, that EES seems suited for distributed generation and power quality applications of short and very short duration.

The ideal ESS solution, in urban environments, should have means of rapidly damp oscillations, respond to sudden changes in load, supply load during transmission or distribution interruptions, provide spinning reserve, correct load voltage profiles with rapid reactive power control, and still allow the generators to balance with the system load at their normal speed

(Sutanto and Lachs, 1997), (Ribeiro et al., 2001), (Peças Lopes et al., 2010), (P. Rocha Almeida et al., 2011).

Moreover, the increase of storage capacity besides solving network problems will enable the integration of vehicle-to-grid (V2G), Plug-in Hybrid Vehicles (PHEV) or PEV and electric vehicles (EV) that will have an important role in mitigating some requests from the network (Benjamin K.Sovacool, 2009), (Ali Ipakchi, 2009).

As small distributed generation systems are expected to spread in urban environments, the assessment of the value of small scale storage against supply interruptions will be very important. In order to understand the technical and economic viability of each type of system, it is however important to assess all the associated costs and benefits in order to find out whether there is overall economic justification.

The profitability of an ESS to provide a specific energy service depends on the technology used. Some authors argue that ESS should perform all the possible services in order to obtain the highest possible profit (Hittinger et al., 2012).

However, due to energy density limitations of most of ESS, especially the small ones, it seems consensual that the frequency regulation is one of the most profitable services suited for supercapacitors or lithium-ion batteries (Hittinger et al., 2012), (S. M. Schoenung, 2001), (Schoenung and Hassenzahl, 2003).

The benefits of using ESS applications are: Increased income from higher integration of wind power generation into the network; Income from generation capacity stability(firming); Income from higher network voltage stability; Income from higher network reliability; Income related to environmental benefits such as reduced GHG emission among others (Le and Nguyen, 2008), (Ali Ipakchi, 2009), (Fairley, 2011), (Rahman et al., 2011).

The European Technology Platform SmartGrids (2012) consider the possible exchange of ancillary services between the TSO and DSO using a storage system in the distribution chain to be a possible solution to perform ancillary services in a more cost-effective way. It is also shown that, according to discharge time, different technologies may be used for different applications: long discharge time technologies will be used to secure the capacity of RES, while short ones will be adopted to perform frequency regulation or voltage control.

Although some researchers understand that capital costs are important for economic viability, confidence in technological innovation research, support the belief that capital costs will naturally decrease. However, the perception of the technologies with greater potential for reductions in capital costs is essential to the future of ESS (Hittinger et al., 2012).

ESS Barriers

The electric vehicles (PEV) charging infrastructure is presented as one possible storage solution. However, it still remains under development, with several limitations regarding the unpredictability of vehicle (batteries) connection to the network, of their willingness to present themselves as potential power providers, or the increase of harmonic and voltage problems and line losses, leading to a power quality degradation. (Ali Ipakchi, 2009), (Gerkensmeyer et al., 2010), (Peças Lopes et al., 2010)

The use of EV without a proper management infrastructure will lead to negative consequences (Hadley and Tsvetkova, 2009). Some authors try to solve that issue introducing different management structures to work within the smart grid concept. (Peças Lopes et al., 2010), (P. M. Rocha Almeida et al., 2010)

Divya and Østergaard (2009) outline some of the reasons for a small deployment of storage systems, such as the existence of a large number of conventional generators that can be adjusted to match the load demand, and the interconnection of areas which can help to balance the load demand. However this scenario is changing due to the present high rate of deployment of renewable energy sources and the existing limits in the interconnections.

Additionally, the lack of practical experience and of the availability of tools which could be used for: (i) operational cost optimization and (ii) assessing the benefits of storage technology (considering the market models) during planning.

However, Benjamin K. Sovacool (2009) also claims that a major issue to the adoption of a distributed storage infrastructure is the existence of some resistance by network operators to integrate resources (e.g. batteries) not managed by them.

Moreover the use of stationary systems will solve the unpredictability problems enabling the grid manager to choose the more effective location of ESS in the network.

This justifies the motivation to develop a methodology tool that assesses the storage benefits to decision makers. This tool will provide support to decision makers also about distribution grid reinforcements.

Assessment of ESS

Previous research to study and quantify the impact of batteries energy storage systems (BESS) on the power system operation and economics were focused in economic/optimal sizing, modeling the BESS from the point of view of cost (BESS economic models) or the assessment of operational benefits, modeling the BESS response to power system disturbances at appropriate time scales (BESS operational model) (Divya and Østergaard, 2009).

Table 4 – BESS models for economics and power systems studies (Divya and Østergaard, 2009)

BESS models used for economic analysis	BESS models for power system studies
▪ Utility side applications; ▪ Demand side applications.	▪ BESSpower system reliability analysis; ▪ BESSpower system stability analysis.

All the studies in economic analysis consider vertically integrated utilities and do not incorporate the market models to assess the benefits of BESS in the present day deregulated market. On the other side, the majority of the studies concerning power systems analyses usually do not refer to any particular battery type, neither to any limitation to the performance of BESS (Divya and Østergaard, 2009).

Schoenung and Hassenzahl (2003) argue that the real benefit should be assessed considering the distribution of ESS in the network, given a specific technology and considering market parameters such as electricity costs and interest rates.

Lassila et al., (2012) presents one methodology framework, considering the economic perspective, to assess the benefits and costs of a distributed storage system. According to these authors, most of the previous publications have neglected the economic effects on the network. They also present one possible way to assess the benefit for peak power services, considering them at least equal to avoided grid reinforcements, using EV daily available capacity based on daily driving patterns and forecasted grid connected EV.

$$\text{ESS Benefit} \geq Reinforcement = C_{inv}\Delta P_{peak} \quad (1)$$

In (1) ΔP_{peak} is the power capacity decreased on the feeder [kW] and C_{inv} the average marginal cost on the feeder [€/kW].

Table 5 presents two different ways to quantify benefits.

Table 5 – Revenue and cost for peak power service presented by

Energy Service	**Peak power** (Lassila *et al.,* 2012)	**Peak power** (Kempton and Tomic', 2005)
Revenue	$r = \Delta P_{peak} C_{inv}$	$r = p_{el} E_{disp}$
Cost	$c = \frac{C_{en} E_{charge}}{\eta} + (1-\eta) E_{peak} C_{grid\_en}$	$c = c_{en} E_{disp} + c_{ac}$

In the Table 5 p_{el} is the market rate (tariff) of electricity [€/kWh], E_{disp}, the total energy dispatched over the contract period [kWh], c_{ac} the annualized capital costs [€/year], c_{en} the cost per energy unit produced(delivered to network) [€/kWh], E_{charge} the energy charged cost [€/kWh], and C_{grid_en} the cost of delivered energy depending on the technology[€/kWh].

Kempton and Tomic' (2005) present other formulas to quantify the net benefits for different services based on the same general approach.

Table 6 – Revenues and costs presented by (Kempton and Tomic', 2005)

Energy Service	**Spinning reserve**	**Regulation services**
Revenue	$r = p_{el} E_{disp} + p_{cap} P_{disp} t_{disp}$	$r = p_{el} R_{d-c} P_{disp} t_{disp} + p_{cap} P_{disp} t_{disp}$
Cost	$c = c_{en} \left(\sum_{i=1}^{N_{disp}} P_{disp} t_{disp} \right) + c_{ac}$	$c = c_{en} R_{d-c} P_{disp} t_{disp} + c_{ac}$

In Table 6 R_{d-c} is the dispatch to contract ratio (dimensionless) and t_{disp} , the total time the power is dispatched [h].

Le and Nguyen (2008) developed an analytical approach, based on a cost-benefit analysis, to find a rating of the most-profitable energy storage systems with the aim of increasing wind farms power dispatchability (power firming). Some of the benefits considered were the revenue from higher renewable integration into the network (higher capacity), the revenue from generation capacity firming, the revenue from improved grid voltage stability, the revenue from improved grid reliability and the revenue related to environmental benefits such as reduced green-house gas emissions among others. It should be noticed that the quality of results depends on the measurement and verification methods and of the accuracy of the calculation methods that should be established within the research community and the power industry.

In order to quantify the saved energy or impact of each solution on the load diagram Le, Santoso and Nguyen (2012) present a method for calculating a reference output profile, using a charge-discharge scheme for guiding the ESS operation, as well as an economic assessment for regulating wind power variation, and an optimization-based method for determining the ESS optimal rating. These authors use an optimum power flow analysis (OPF) program to define the suited power output for a given network. The ESS will fill the gaps between the real profile and the desired one. The rate of the ESS is determined by an optimization-based method that maximizes the net benefit, taking into account five possible benefit factors determined on the basis of the ESS rate.

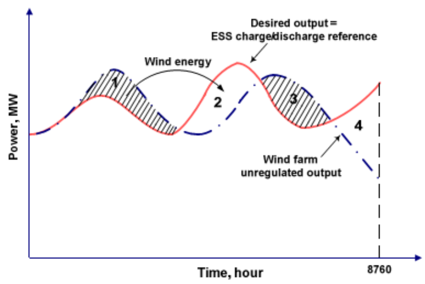

Figure 1 –Illustration of simplified wind output profile and desired output (Le and Nguyen, 2008)

Modified profiles to assess impacts on the network are commonly used in order to study the impact of charging/discharging EV in the power grid, evaluating impacts on load diagrams. (Rahman and Shrestha, 1993), (Qian et al., 2011), (Rong-Ceng, 2011), (Chen et al., 2012)

In order to assess the best location, avoiding on the use of pre-defined scenarios, the use of techniques that can combine grid characteristics, load diagrams, supply diagrams and charging/discharging diagrams of ESS will be important to obtain the maximum benefit from storage.

Rong-Ceng (2011) and Chen et al., (2012) used genetic algorithms (GA) to obtain results only diverging in the fitness function factors. The use of GA enables a multiobjective approach, very useful to problems that do not have a unique optimal result but a result set depending on the relative importance of each objective to the decision maker.

The environmental assessment of different technologies also requires a specific methodology. This process is not straightforward as different impacts with different units cannot be added directly. The last update in 2005 to the ExternE-methodology provided a good framework that enabled the transformation of different impacts into a common unit, however it should be used in judgmental form for all the specified factors (European Commission, 2005), (Commission, 1999), (Neves, 2004).

The concept presented in this paper regards decentralized energy storage, through the use of infrastructures owned by a network operator with predictable and reliable availability. This option will not require the introduction of the aggregator presented in (Peças Lopes et al., 2010), (P. M. Rocha Almeida et al., 2010) avoiding the adoption of a new management structure. (Divya and Østergaard, 2009), (European Technology Platform SmartGrids, 2012). Nevertheless, the analysis of the real economic and technical impacts on the network, by quantifying revenues and benefits, and the global impacts on environment and society for each service to be provided, is required.

Conclusion

Considering the above review, a new methodology, to be developed, will help potential promoters to assess the feasibility of urban distributed energy storage systems, given specific energy services, technology limitations, and an existing infrastructure, namely with long idle periods or long periods of reduced load. Such a methodology should include power flow analysis to evaluate, in a technical way, each possible solution, also considering the market value for each service, as well as the environmental and societal benefits.

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DAY 10 - 9:30		
Room 639 - Energy Markets 1		
Drivers for household electricity prices in the EU: a system-GMM panel data approach	Patrícia Pereira da Silva[1]; Pedro Cerqueira[2]	[1]Faculty of Economics - Univ. Coimbra, INESCCoimbra and Energy for Sustainability Initiative; [2]Faculty of Economics - Univ. Coimbra and GEMF
Causes of the volatility of electricity spot price in Brazil	Nivalde José de Castro[1]; André Luis da Silva Leite[2]; Guilherme de Azevedo Dantas[1]; Roberto Brandão[1]	[1]Federal University of Rio de Janeiro UFRJ Brazil; [2]Federal University of Santa Catarina UFSC Brazil
The welfare cost of energy insecurity	Baltasar Manzano[1]; Luis Rey[2]	[1]Universidade de Vigo and Economics for Energy; [2]Economics for Energy
Explanatory variables on South-west spot electricity markets integration	Nuno Figueiredo[1]; P. Pereira da Silva[2]	[1]MIT-Portugal - Universidade de Coimbra; [2]Faculty of Economics, University of Coimbra

Drivers for household electricity prices in the EU: a system-GMM panel data approach

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Abstract

Electricity as well as gas or refined petroleum products exemplify a significant part of the consumer basket of European households and companies. As energy products are important inputs of nearly all final goods and services, any change of energy prices has a direct impact of the general price level. In this context, the main purpose study is to assess the main drivers of household electricity prices in the European Union (EU), relying on Eurostat up to date data. Not only we analyze the long-term evolution of household electricity prices across the EU, but also essentially we provide latest empirical evidence on their chief determinants while confronting the results with the EU energy policy path.

For this purpose a new approach is herein developed based on a dynamic model with panel data through GMM proposal method by Blundell and Bond (1998) with a Windermeijer correction (2005).

Key words: household electricity prices, market reform, system-GMM panel data model

JEL Codes: Q28, Q48, C33

1. Introduction

Generally, microeconomic theory suggests that competition and the profit drive result in internal (production) and external (market) efficiency and that the benefits are passed on to customers and the economy in the form of lower prices and costs.

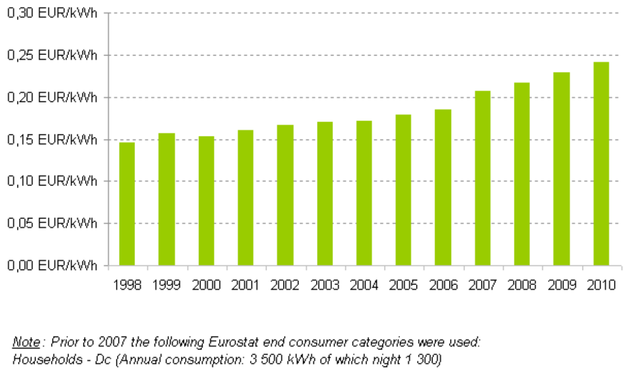
Recently, however, in the context of electricity markets, the overall wisdom of the European Union (EU) ambition towards more competition and more open energy markets and what concrete benefits were brought to end consumers by this policy have been questioned (Cruciani, 2011).

According to Jasmab and Pollitt (2005) European electricity market liberalization represents the world's most extensive cross-jurisdiction reform of the electricity sector involving integration of distinct state-level or national electricity markets. Electricity sector liberalization is part of the wider trend toward liberalization and wishes on the withdrawal of the state from involvement in infrastructure industries. Given the strategic position of the electricity industry in national politics, in the absence of policy at the level of the European Union (EU), the pace of reform in many member states would have been considerably slower, in spite of several criticism concerning the long process behind the building of the internal energy market.

Although the performance of liberalization can be measured in a number ways, the effect on electricity prices is, perhaps, the single most important performance indicator. A desirable outcome of the single European market was to achieve a lower average EU price and a degree of price convergence through wholesale and retail competition. (Jasmab and Pollit, 2005)

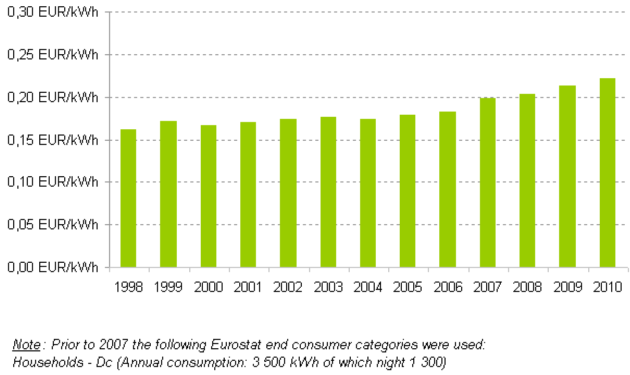
In this context, a more recent study by Cruciani (2011) is to mention. His argument starts with the observation that electricity prices for domestic and industrial users have increased significantly since 1998, the year that marks the opening of the EU electricity markets. The charts in Figure 1 and 2 illustrate this by presenting the case of the German median domestic consumers who saw their electricity bills increase by more than 60% in the observed period (EC, 2012).

Figure 1 – German retail electricity prices for domestic consumers (nominal prices, all taxes included)



Source: Eurostat

Figure 2 – German retail electricity prices for domestic consumers (prices in 2005 EUR, all taxes included)



Source: Eurostat

European Commission documents also state that the aim of the EU energy policy was "*to ensure that EU consumers receive the full benefits of market opening in terms of lower domestic bills for electricity and gas*", but Cruciani (2011) concludes that, more than 10 years after the opening of the markets, the liberalization has not delivered tangible benefits to consumers.

An additional set of issues raised by electricity deregulation (or re-regulation, as some might prefer), could influence the final outcome. The foremost problems are related to the unusual characteristics of "electricity" as a product, which make the industry very different from other network industries: electricity is not storable, demand and supply must be constantly balanced, and demand is both volatile and inelastic (Silva and Soares, 2008, Joskow, 2008).

Jamasb et al. (2004), using a three broad category to classify approaches to analyze electricity reforms (econometric methods, efficiency and productivity analysis methods, and individual or comparative case studies), argue that econometric studies are best suited to the analysis of well-defined issues and the testing of hypotheses through statistical analysis of reform determinants and performance. Within this classification, the present study suits the first category.

As underlined by the same authors, there is a lack of generally accepted and measured indicators for monitoring the progress, performance of electricity sector reforms, and, namely, impacts on electricity prices, the main purpose of our article. To our best knowledge, no applied study has been done so far using a system-GMM panel data proposal method by Blundell and Bond (1998) with Windermeijer correction (2005) as we herein provide.

The remainder of this study is organized as follows: in section 2 a brief overview of the evolution of the EU electricity market is provides; section 3 summarizes previous studies on electricity prices; section 4 presents the empirical method and data; and section 5 concludes.

2. The evolution of the EU electricity market

Electricity sectors either being European or elsewhere evolved with (primarily) vertically integrated geographic monopolies that were either state-owned or privately- owned and subject to price and entry regulation as natural monopolies. The primary components of electricity supply - generation, transmission, distribution, and retail supply - were integrated within individual electric utilities.

The prevailing reform goal has been to create new institutional arrangements for the electricity sector that provide long-term benefits to society and to ensure that an appropriate share of these benefits are conveyed to consumers through prices that reflect the efficient economic cost of supplying electricity and service quality attributes that reflect consumer valuations.

The European Electricity Supply Industry (ESI) reform was pursued at two parallel levels. First, under EU Electricity Market Directives, member countries were required to take at least a minimum set of steps by certain key dates toward the liberalization of their national markets. Second, the European Commission promoted efforts to improve the interfaces between national markets by improving cross-border trading rules, and to expand cross-border transmission links. The underlying aim of both of these policies was to extend the principles of the European Single Market to the energy market by Directives that would enable companies from across the EU to compete with national incumbents, while improved interconnection would reduce cross-border transport costs and increase competition.

The first, second and third EU Electricity Market Directives of 1996, 2003 and 2009 focused on unbundling the industry and on a gradual opening of national markets (see Oliveira et al., 2012 for a more extensive review on the progress of European energy).

As of the end of 2011, the many of Member States continue to regulate retail prices, especially for households, and only allow an appreciation that is no bigger than the rise of the general price level.

Table 1. Status of EU Member-State regulated prices

Country	House-holds	Small businesses	Medium to large businesses	Energy intensive industry
Bulgaria	100%	100%	98%	
Croatia	100%			
Cyprus	100%	100%	100%	100%
Denmark	94%	95%	NA	NA
Estonia	Derogation	Derogation	100%	100%
France	96%	83%	94%	82%
Greece	100%	100%	100%	
Hungary	100%	NA		
Ireland	80%	52%	28%	
Italy	91%	78%		
Latvia	99%	99%		
Lithuania	100%	NA		
Netherlands	100%	100%		
Poland	100%			
Portugal	92%	88%	39%	62%
Romania	100%	NA	NA	
Slovakia	100%	100%		
Spain	91%			

Legend

	>95 % of customers have regulated prices
	>50 % of customers have regulated prices
	>10 % of customers have regulated prices
NA	Information not available

Source: ERGEG, 2010.

In a way, this could explain the alignment of retail prices for electricity and inflation, as shown in the above Table 1.

3. Review of earlier studies

One of the earliest analyses of the reform process and electricity prices is the empirical analysis by Steiner (2001). This author studied the effect of regulatory reforms on the retail prices for large industrial customers as well as the ratio of industrial price to residential price, using panel data for 19 OECD countries for the period 1986-1996. In her study, Steiner (2001) carried out a panel data analysis including electricity price, ratio of industrial to residential electricity price, capacity utilization rate and reserve margin. Using these variables, she tried to measure the competitive aspects and the cost efficiency of reform. As main conclusions, the study found that electricity market reforms generally induced a decline in the industrial price and an increase in the price differential between industrial customers and residential customers, indicating that industrial customers benefit more from the reform. It was also found that unbundling is not associated with lower prices but is associated with a lower industrial to residential price ratio and higher capacity utilization rates and lower reserve margins.

Hattori and Tsutsui (2004) examined the impact of the regulatory reforms on prices in the electricity industry. Comparable to Steiner (2001), they also used panel data for 19 OECD countries but for the period 1987-1999. Hattori and Tsutsui (2004) indicated that, first, expanded retail access is likely to lower the industrial price, while at the same time increasing the price differential between industrial and household customers. Second, they concluded that the unbundling of generation did not necessarily lower the price and may have possibly resulted in higher prices. Like Steiner (2001), their estimation showed that the effect of unbundling on the level of industrial price is statistically insignificant. Besides, they found that the introduction of a wholesale power market did not necessarily lower the price, and may indeed had resulted in a higher price.

Pollitt (2009) mentions two other empirical studies that examine the price impacts of reform by Ernst & Young (2006) and Thomas (2006). Ernst & Young (2006) prepared a report for the UK government's Department of Trade and Industry (DTI). Using a sample of EU-15 countries and they tried to produce some policy suggestions for electricity and gas industries with a large number of simple regressions. As a result of their consultancy report, they concluded that liberalization lowers prices; liberalization lowers costs and price-cost margins; liberalized markets increase price volatility; liberalization inhibits investment; liberalized markets provide reliable and secure supply; and liberalized markets interact effectively with other public policies (such as on climate change). Thomas (2006) examined a number of reports including those of European Commission, which are related to electricity prices. He argued although these studies suggest that reforms in the EU have been associated with lower prices for consumers, the evidence does not support these assertions. The price reductions, he continued, that have occurred in the past decade took place mostly in the period 1995-2000, before liberalization was effective in most of the European Union and since then, prices have risen steeply, in many cases wiping out the gains of the earlier period. Other factors, not properly accounted for, such as fossil fuel price movements, technological innovations and changes to regulatory practices were more likely to have led to the price reductions that occurred in the period 1995-2000 than reforms that had not then taken effect

Nagayama (2007) used panel data for 83 countries covering the period 1985-2002 to examine how each policy instrument of the reform measures influenced electricity prices for countries in Latin America, the former Soviet Union, and Eastern Europe. The research findings suggested that neither unbundling nor introduction of a wholesale pool market on their own necessarily reduces the electricity prices. In fact, contrary to expectations, there was a tendency for the prices to rise. He argued, however, coexistent with an independent regulator, unbundling may work to reduce electricity prices. Nagayama (2009) aimed at clarifying whether the effects of electric power sector reforms should be different either across regions, or between developing and developed countries. He analyzed an empirical model to observe the impact of electric power prices on the selection of a liberalization model in the power sector. This was achieved by the use of an ordered response, fixed effect and a random effect model. An instrument variable technique was also used to estimate the impact of the liberalization model on the electric power price. The research findings suggested that higher electricity prices are one of the driving forces for governments to adopt liberalization models, a finding also noted by Joskow (2008), in the context of the US. However, the development of liberalization models in the energy sector does not necessarily reduce electricity prices. In fact, contrary to expectations, the study found that there was a tendency for the prices to rise in every market model.

Considering electricity prices and survey data on consumer satisfaction in the EU-15, the empirical findings by Fiorio et al. (2011) rejected the prediction that privatization leads to lower prices, or to increased consumer satisfaction. They also found that country specific features tend to have a high explanatory power, and the progress toward the reform paradigm is not systematically associated with lower prices and higher consumer satisfaction.

As earlier emphasized in the introduction, Cruciani (2011) shows that the liberalization of electricity markets in the EU ‘has not had a major effect on prices', results that are contrary to what the European Commission has always aimed. He also shows that opening up and connecting markets does not necessarily lead to a more efficient system.

4. Emprical study

This section describes the empirical study and the results obtained. The first subsection describes the data used and the second shows the model specification and the estimation results.

4.1 Data

The data herein presented was retrieved from the databases containing the most precise information, the most constant over time and the most homogenized among European Member-States, which belong to the European Commission, managed by Eurostat. Because the values on electricity prices to the industry remain contestable, because contracts with industry often include confidential clauses, the present study only deals with household prices. However, it is important to highlight that though Eurostat introduced a methodological break in the series in 2007, it was possible to obtain series comprising one area of acceptable approximations between 1999 and 2009 for the 23 out of 27 European Member States[1].

The variables used were the electrical price (*Ep*) as described before and as explanatory variables (retrieved for the same countries, from 1999 to 2009 and from the same sources) were, the electric household consumption in tons of oil equivalent per capita (*ECHpc*) and the real GDP *per capita* (*GDPpc*) measured in thousands of Euros, to control for demand factors. The oil barrel price measured in Euros (*OILp*), the electricity production of renewable sources as share of the overall gross electric consumption (*RESe*), the greenhouse gas emission in thousands of tonnes *per capita* (*GGEpc*), to control for supply factors. And to access the effect of market liberalization we included the share of the largest electric producer as share of the total production (*ECG*), the date of market liberalization[2] (*Lib*) and if the country still had regulated prices in 2010 (*Reg10*)[3] (see Table 2).

Finally, we should note that the electricity price and the ECG variables are not available for the entire data span (1999-2009) in all countries leading to an unbalanced panel. Description of data availability, as the date of market liberalization and if the country still had a regulated electric price is described in the Appendix.

Table 2 Descriptive statistics of the variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Ep	224	0.0955643	.0278141	.0457	.1789
GDPpc	253	18.30906	10.9205	2.624104	41.98588
GGEpc	253	.0103346	.003037	004331	.0181855
ECHpc	253	.0001391	.0000828	.0000293	.0004083
OILp	253	38.08036	14.32036	17.089	65.8896
ECG	237	.6222658	.2732685	0.165	1
RESe	253	.1466402	.1411632	0	.5637756
Lib	253	.3754941	.4852101	0	1
Reg10	253	.6521739	.4772246	0	1

4.2 Estimation methodology and results

We use the Blundell and Bond (1998) two-step system GMM methodology with the Windermeijeir (2005) errors correction. This methodology is justified on the basis that traditional fixed effects estimator is biased in the presence of the lagged dependent variable as regressor and it also accounts for possible endogeneity of some of the dependent

[1] The countries included were: Belgium, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Italy, Cyprus, Latvia, Lithuania, Hungry, Malta, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden and the United Kingdom.

[2] The variable took the value 0 before the year of liberalization and 1 afterwards. In countries where the liberalization occurred at July, the variable took the value 0 as the price was measured during the first semester.

[3] The variable took the value 0 for countries that did not have regulated prices in 2010 and 1 for the others.

variables. We should remark that alternative consistent estimators with lagged dependent variable, such as the one of Bruno (2005), are only valid when the explanatory variables are strictly exogenous. In our model we consider that the *GDPpc*, *ECHpc*. *GGEpc* and *RESe* are endogenous as these also respond to the variations on the electriccity price and that *OIlP* and *ECG* variables can be at least pre-determined.

Moreover, as Soto (2009) reveals, the system-GMM presents the lowest bias and highest precision when the N dimension in the panel (in our case the number of countries) is small and the series are moderately or highly persistent, when compared to other widely used estimators: the fixed effect or the difference GMM.

The estimated model, taking the logarithm of the household electrical price, *l.ep*, as dependent variable is:

$$l.ep_{it} = \alpha + \delta l.ep_{it-1} + \beta X_{it} + \sum_{k=2000}^{2009} \gamma_k d_k + \varepsilon_i + \mu_{it} \qquad (1)$$

for i = 1,..., 23 and t = 2000,..., 2009, with δ<1. The disturbances μ_{it} and ε_i are not cross correlated and have the standard properties. That is,

$$E(\varepsilon_i) = 0; \quad E(\mu_{it}) = 0; \quad E(\varepsilon_i \mu_{it}) = 0 \qquad (2)$$

for i = 1,..., 23 and t = 2000,..., 2009.

And that time-varying errors are assumed uncorrelated:

$$E(\mu_{it}\mu_{is}) = 0 \quad , \; for\; i = 1, \dots, 23 \; and \; t \neq s \qquad (3)$$

Note that following Soto (2009) no condition is imposed on the variance of u_{it}, as the moment conditions used to estimate the model do not require homoscedasticity.

In the different models estimated below the vector of explanatory variables X_{it} comprises a subset of {$l.GDPpc_{it}$, $l.ECHpc_{it}$, $l.OILp_t$, $l.GGEpc_{it}$, ECG_{it}, $RESe_{it}$, Lib_{it}, $Reg10_i$} where the *l.* means that the variable was logarithmized and the d_k are time dummies[4]. Table 3 summarizes the nine model estimation results.

[4] Not only the time dummies make the assumption of no correlation across individuals in the idiosyncratic disturbances more likely to hold (see, Roodman (2009)) but also controls for the change in the methodology of measuring the electricity price.

Table 3 Model estimation results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Constant	**-1.53*****	**-1.513***	**-2.24*****	-1.278	-0.788	**2.343****	0,656	1.281	-0.157
	(0,000)	**(0,069)**	**(0,001)**	(0,110)	(0,502)	**(0,0341)**	(0,638)	(0,485)	(0.789)
Lag_l.Ep	**0.574*****	**0.568*****	**0.598*****	**0.623*****	**0.658*****	**0.590*****	**0.662 *****	**0.651*****	**.771*****
	(0.000)	**(0,000)**	**(0,000)**	**(0,000)**	**(0,000)**	**(0,000)**	**(0,000)**	**(0,000)**	**(0.000)**
l_GDPpc	**0.173****	**.171****	**0.149***	0.103	0.094	---	---	---	---
	(0.045)	**(0,029)**	**(0,068)**	(0,187)	(0,268)				
l.ECHpc	---	---	---	---	---	0.445	0.237	**0.359***	.0223
						(0,114)	(0,233)	**(0,098)**	(0.790)
l.OILp	**0.656*****	**.723****	**0.466*****	**0.383*****	**0.347*****	**0.444***	**0591***	**0,288****	**0.224****
	(0,001)	**(0,012)**	**(0,005)**	**(0,001)**	**(0,008)**	**(0,055)**	**(0,053)**	**(0,012)**	**(0.012)**
l.GGEpc	.320	.370	---	0.177	.257	0.227	0.351	---	0.268
	(0,220)	(0,290)		(0,459)	(0,305)	(0,490)	(0,347)		(0,110)
ECG	**0.349****	**0.355****	**0.305****	**0.289****	**0,287****	0.083	0.106	-0.020	**0.212***
	(0,018)	**(0,018)**	**(0,041)**	**(0,032)**	**(0,040)**	(0,700)	(0,457)	(0,969)	**(0.069)**
RESe	**1.663****	**1.56****	**0.956***	**0.722***	**.946****	**1.587***	**1.895****	**0.952****	**1.049*****
	(0,067)	**(0,049)**	**(0,083)**	**(0,058)**	**(0,035)**	**(0,058)**	**(0,011)**	**(0,038)**	**(0.003)**
Lib	**-0.169***	**-0.188***	-0.111	---	---	**-0.205***	**-0,260***	-.157	---
	(0,089)	**(0,096)**	(0,326)			**(0,071)**	**(0,063)**	(0,119)	
Reg10	.0415	---	---	---	0.042	0,187	---	.121	---
	(0,594)				(0,495)	(0,106)		(0,174)	
Observations	197	197	197	197	197	197	197	197	197
AR(1)	-2.18	-2.34	-2.31	-2.31	-2.19	-2.78	-2.69	-2.93	-2.45
	(0,029)	(0,019)	(0,021)	(0,021)	(0,028)	(0,005)	(0,007)	(0,003)	(0.014)
AR(2)	-1.18	-1.27	-1.12	-0.88	-0.85	-0,57	-1.22	-0.64	-0,89
	(0,238)	(0,203)	(0,265)	(0,381)	(0,396)	(0,566)	(0,222)	(0,521)	(0.373)
Instruments	22	22	21	22	22	22	21	22	21
Sargan test	6.78	7,18	7,81	10,34	8,78	5,45	4,11	7.31	11.14
	(0,342)	(0,411)	(0,350)	(0.242)	(0,269)	(0,606)	(0,767)	(0,503)	(0.194)
Hansen Test	3,09	2,94	4,57	5,72	5.50	1,82	1,96	3,63	5.69
	(0,798)	(0,890)	(0,713)	(0.679)	(0,599)	(0,969)	(0,962)	(0,889)	(0.682)

*, **, *** significant at 10%, 5% and 1%, respectively. The *p*-values are reported between parenthesis and all regressions included a set of time dummies.

First, following Roodman (2009), it should be clarified that all the specifications have less instruments than cross-groups to avoid overspecification that may bias the statistics of the instrument validity tests. It should be noted that according to Soto (2009), the restriction to render instruments inferior to the number of cross-groups does not hinder the properties of the estimators when N is so small that it is not possible to exploit the full set of linear moment conditions, as is the case with the dataset used in the current study.

As for the specification tests none of the nine models fail the specification tests. All reject the null hypothesis of AR(1), showing that in fact the correct specification is a dynamic model. Also, all of them do not reject the null hypothesis of the AR(2), Sargan and Hansen tests. The results of the AR(2) test show that no further autocorrelation is present in the model after introducing the lag of the dependent variable, as the other test confirm the validity of the instruments used in each model.

As for the determinants of the electricity price, the two variables that control economic activity, (*l.GDPpc* and *l.ECHpc)* are positive as expected, but its significance is not robust across specifications. This is an indicator that although the demand factors set play a role in determining the price, it is not as strong as the other factors included in the model. Nonetheless, we should note that the point estimates when using *l.GDPpc* are more consistent across specifications than the point estimates when using *l.ECHpc*. This might be an indicator that the lagged moments taken from the first variable are better suited as instruments than the ones taken from the second.

As for the supply factors, we highlight that the oil price impact is positive and robust across specifications and that the greenhouse emissions are not significant. Additionally, the share of renewable sources is robustly significant with a positive impact with an semi-elasticity point estimate between 1 and 1,8, meaning that an increase of 1% of these sources on the overall share leads to a 1 to 1,8% increase in the price.

As for the market structure, the market concentration has a positive impact as expected and is robust when we use the GDP as the determinant to control the demand side. The point estimate measures an increase of around 0,3% in the electricity price when there is a 1% increase in the share of the biggest producer.

The impact of liberalization is robust across specifications (just in one case the *p*-value is much higher than 0,10) with an estimated price reduction around 20%.

Finally, the variable that measures if there was still a regulated tariff in 2010 is consistently not significant. Nonetheless, we should note that this variable is a poor approximation of the impact of the end of the regulated market, and thus it remains challenging to generalize that it does not impact the price. What can be said is that the countries that ended the regulated tariff earlier did not present an increase in the household electricity price.

5. Conclusions

Network industries around the world share a trend towards the deregulation, as the electricity industry. Coppen and Vivet (2006) state that whereas empirical evidence generally suggests that deregulation has had a positive impact on efficiency and consumer welfare in telecommunications and air travel for example, the results expected for the electricity sector are much more ambiguous so far. One of the reasons these authors allege, confirmed by the results from the models estimations herein presented, resides in the fact that not all the countries have fully completed their deregulation process. It was also possible to show that factors external to the deregulation process in the strict sense cause interference. For instance, increasing oil, prices as well as the enforcement of the Kyoto protocol, assessed via green gas emission, are responsible for much of the increase in electricity prices.

In a large number of European countries, price regulation still exists, especially for the household segment where not much progress can be seen; this may be because the

European Directives leave room for interpretation regarding price regulation. In fact, as stated in ERGEG (2010), a recent judgment of the Court of Justice of the European Union (Case 265/08, 20 April 2010) confirms that end-user price regulation, under certain restrictive conditions, can be, as a temporary measure, in compliance with the Directives.

In the current study several factors were found influencing household electricity prices that are common to all European Member-States. In sum, it is possible to confirm that the evolution of the regulatory framework has had an influence on prices. Additional work is being conducted to deepen the knowledge on the EU energy policy accomplishment outcomes.

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Appendix

Table 5. Data availability on electricity price, market share of bigger producer, date of market liberalization and regulated market until in 2010

	Ep	ECG	Lib	Reg10
Belgium	1999-2009	1999-2009	2007	No
Czech R.	2000-2009	1999-2009	2006	No
Denmark	1999-2009	1999-2009	2003	Yes
Germany	1999-2009	1999-2009	1998	No
Estonia	2002-2009	1999-2009	2009	Yes
Ireland	1999-2009	1999-2009	2005	Yes
Greece	1999-2009	1999-2009	July/2007	Yes
Spain	1999-2009	1999-2009	2003	Yes
France	1999-2009	1999-2009	July/2007	Yes
Italy	1999-2007	1999-2009	July/2007	Yes
Cyprus	1999-2009	1999-2009	--	Yes
Latvia	2004-2009	1999-2009	July/2007	Yes
Lithuania	2004-2009	1999-2009	July/2007	Yes
Hungry	1999-2009	1999-2009	July/2007	Yes
Malta	1999-2009	1999-2009	--	Yes
Poland	2001-2009	1999-2009	July/2007	Yes
Portugal	1999-2009	1999-2009	2006	Yes
Romania	2005-2009	2004-2009	July/2007	Yes
Slovenia	1999-2009	2002-2009	July/2007	No
Slovakia	2004-2009	2004-2009	July/2007	No
Finland	1999-2009	2002-2009	1997	No
Sweden	1999-2009	1999-2009	1996	No
UK	1999-2009	1999-2009	1990	No

Source: Adapted from ERGEG, 2010.

Causes of the volatility of electricity spot price in Brazil

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Abstract:

The Brazilian Electricity Sector faced two reforms in the last decade, in 1996 and 2004. These reforms introduced market mechanisms in the sector, among them a short-term Market. However, the price of electricity in this market has experienced significant volatility. Thus, the aim of this study is to analyze the causes of volatility of the Price of settlement of differences (PLD), which is the spot price. The study concludes that there are three causes: the reduction of investments in the period immediately after the energy rationing in 2001, the environmental constraints imposed by the Federal Constitution of 1988 and the criteria for the order of Brazilian model.

Keywords: Brazilian Electricity Sector – Spot Price - Volatility

JEL: D40 – Q41 – L94

1. INTRODUCTION

Market reforms had important consequences on the electricity sector worldwide. Among these are: the impacts on the organization of the industry, on new forms of investment in the industry and on transactions in the industry. In this sense, there is a need to develop an electricity spot market to meet some important functions: increase flexibility of transactions; allow adjustments between the contracted power and the energy generated and reference to long-term contracts. Namely, a spot market is an important adjustment mechanism between demand and supply (Newbery, 1998).

As regards the Brazilian electricity sector, contrary to what occurs in other countries, there is a spot market that in fact fulfills the functions mentioned above. There is a settlement of market differences where the variances between the amounts of energy available and those actually generated are settled on the basis of the settlement price of the differences, which can be interpreted as a proxy for the price seen in the Brazilian electricity sector. In recent years, it has been observed a significant increase in the number of free consumers, partly spurred by short-term price, who until 2005 was at relatively low levels. However, from 2005, due to higher economic growth and the consequent strengthening of the relationship between demand and supply, the Settlement Price of Difference (PLD) has suffered significant volatility and unpredictability, making the short-term electricity market environment characterized by a high degree of uncertainty. In fact, the price of energy in various systems tends to demonstrate high degree of volatility in both thermal systems (Mount, 2001; Burger et al. 2004; Newbery, 1998; Silva, 2007) and in hydrothermal systems, which is the case of Brazil (Leite and Santana, 2006; Rodrigues, 2007).

In this sense, one of the biggest concerns of the Brazilian electric sector agents, particularly those that operate in the Free contracting environment (ACL), refers to the volatility, and the consequent unpredictability, the settlement price of differences (PLD). These characteristics represent a significant tariff and financial risk for agents that act in the electric sector (Costa, 2012).

So, this article aims to analyse the causes of volatility of the PLD in Brazil. To achieve this goal, this paper is divided into three parts, in addition to this introduction. The first section presents the theoretical foundations of the formation of spot price in electric power markets. The following section deals with the Brazilian electricity sector. The fourth section examines the PLD and the causes of its volatility. Finally, the conclusions of this work are presented.

2. Background

The transition to competitive electricity market has raised new questions as to the most efficient way to ensure new investments in generation facilities, including facilities to provide reserves. Mechanisms that were appropriate under public monopoly may not be the most efficient under a restructured industry.

The Brazilian Electricity Sector (BES) has undergone through, in the recent past, serious supply problems. In 1996, the BEI was restructured and the main purpose of this reform was to introduce competition and enhance investments in the industry. Nearly 80% of the distribution companies (Distcos) and 20% of the generation companies were privatized. Some companies remained state-owned and two (CEMIG and COPEL) were not unbundled. The 2001 supply crisis made clear that investments, both private and public, in electricity had decreased. After 2003, President Luis Inacio Lula da Silva proposed a new model for the BEI that strengthen the role of the State in the industry.

Though these reforms tried to introduce competition, it is possible to say that the BEI is far from being a competitive market. As Araujo (2001) states, in a hydroelectrical system like in Brazil, coordination is more important than competition in pure energy markets. So, in this paper, we propose that a capacity market for the Brazilian Electricity Industry would be an important tool to enhance competition and liquidity. And, more important, it would also enhance reliability in the industry.

The most important features of short-term Brazilian market are: existence of two market operators, with distinct functions. On the other hand, the physical system operator, the national system operator (ONS), responsible for the coordination and control of the operation of installations for the generation and transmission of electric energy in the national interconnected System (SIN), under the supervision and regulation of the National Electric Energy Agency (ANEEL). On the other hand, the electric energy trading Chamber (CCEE) that centralizes transactions of purchase and sale of energy; costs (and prices) are attached directly to the economic order; ANEEL, in order to permit the sale of electricity between dealers, permission holders and authorized services and electric power installations, as well as those with its consumers, in the national interconnected System, by hiring regulated or free, in accordance with the law and its regulation.

2.1 Spot market in Brazil

The PLD calculation is based on the marginal price model system (PMS), as described in Silva (2001), calculated ex-ante in a weekly basis; based on non-active demand in the wholesale market; and in the non-existence of payments for capacity. The system considered by the market operator consists of more than 70 shells. To reduce computational overhead and to represent their hydrological interdependence, they are aggregated in reservoirs. Four subsystems are then represented by their corresponding shells equivalent, in which the main features are the generating capacity and the flow of energy. These four subsystems are called sub-market, (Southeast and Mid-West; South; Northeast and North), and are characterized mainly by transmission constraints among them.

The National Electric System Operator (ONS) uses two optimization model (Newave, for long run and Decomp, for short run) to determine the minimum cost of operation dispatch (Mendes and Santana, 2003). Also, a stochastic dual dynamic programming models is used to define the profile of generation units for each planning horizon to calculate the marginal cost of short-term operation (CMO) for the four sub-market. The information that are essential for an optimal operation are: the prediction of water flows, load profile, network configuration, availability of resources and the generation and transmission planning (Maceira et al., 2001).

These prices are limited by a minimum price and a maximum price, in the following range: R$ 17, 47MWh PLD ≤ PLD ≤ R$ 569, 59MWh. Given the fact of having maximum and minimum limits, the LDP can differ from the CMO. In addition the PLD despite using the same deck as entry removes the restrictions of intra stream sub-system.

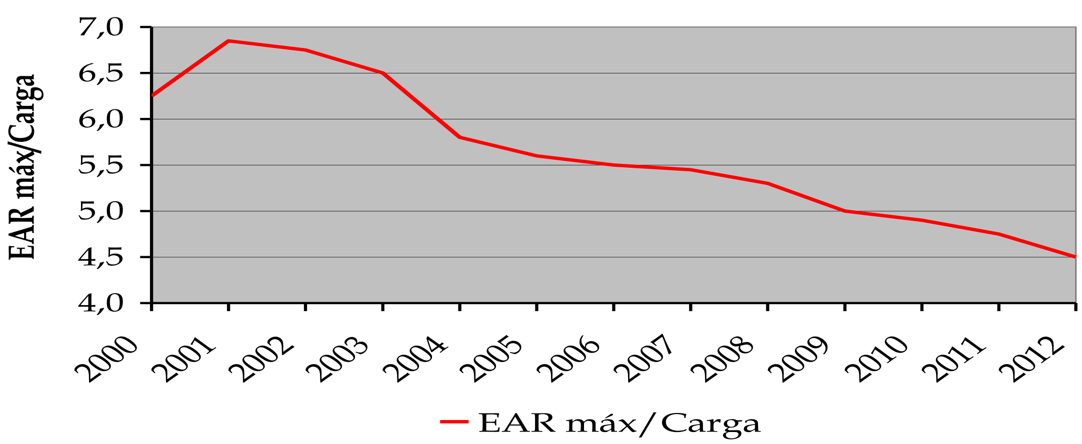
3. Spot Price dynamics: volatitlity and its causes

In the case of the Brazilian electricity sector, the price of electricity is a function of the characteristics of the industry, i.e., the availability of water in reservoirs and pluviometric precipitation level, thermal transmission constraints, availability and cost of the deficit. In most systems, the hydroelectric energy prices tend to be somewhat volatile in the short term and more volatile in the medium term. This is because, in the short term, there's a transfer energy from low-load hours to the cutting edge by modulating the supply and reducing price volatility. While, in the medium term, the price of energy is more volatile because the hydraulic systems were designed to ensure the supply of electricity in adverse hydrological conditions.

The high volatility is related mainly with the dynamics of inflows. Another problem of the PLD is the fact that it does not take into account the reaction of demand, being just the hydrology-present and future-predicting the price forming. In short, it is a consensus among the various agents in the industry that there is significant volatility of PLD (Rodrigues, 2007; Leite and Santana, 2006).

Figure 1 shows the evolution of the regularization of the reservoirs in Brazil, from 2000 to 2012. Note that when there is a significant decrease in this capacity, measured in terms of stored energy.

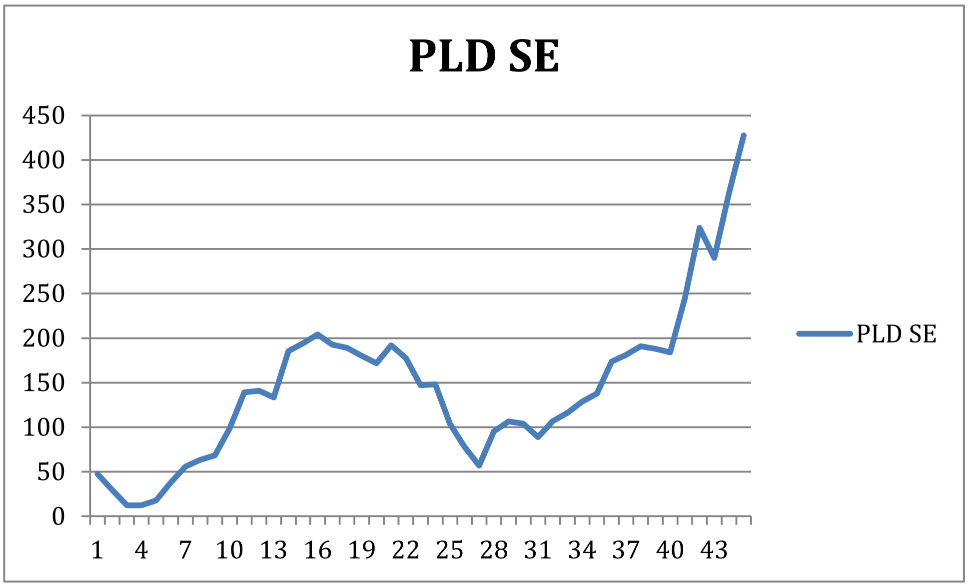
Figure 1 – Capacity of reservoirs regularization



Source: Chipp (2008)

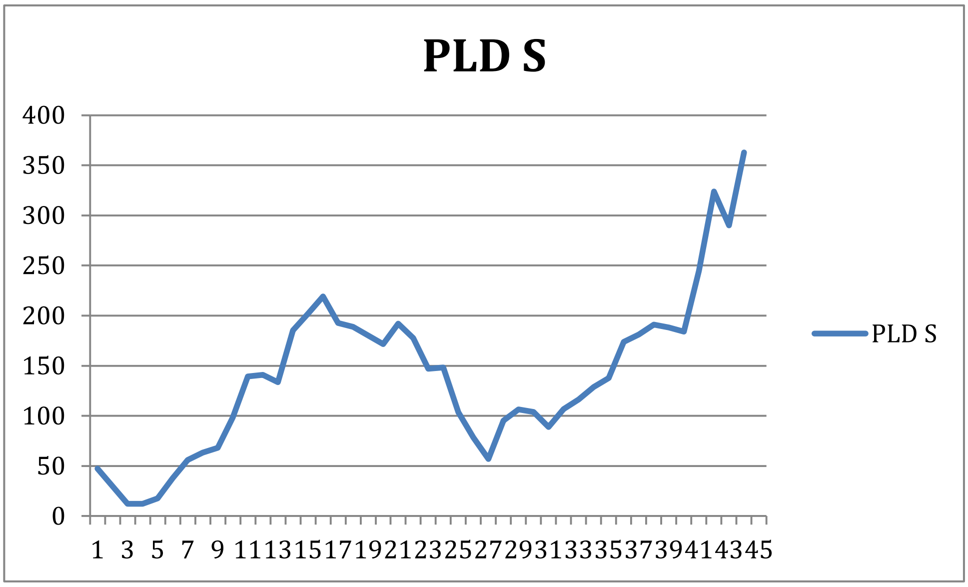
Figures 2, 3, 4 and 5 present, respectively, the historical series of the PLD from January to December 2012 for the four sub-markets. one can notice similar behavior. It is possible to notice that prices changed dramatically throughout the year.

Figure 2 – PLD in the Southeast & Mid West Market



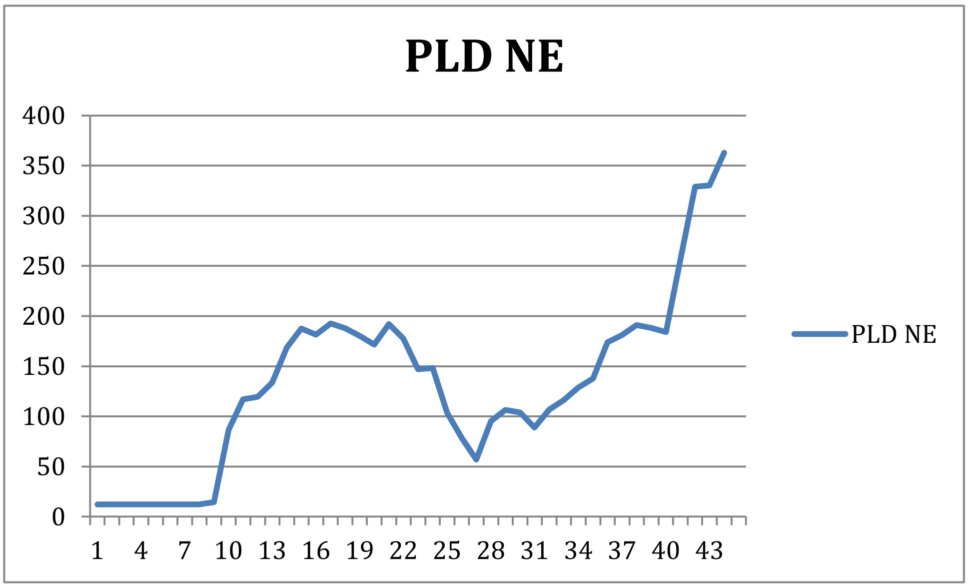
Source: CCEE (http://ccee.org.br)

Figure 2 – PLD in the South Market



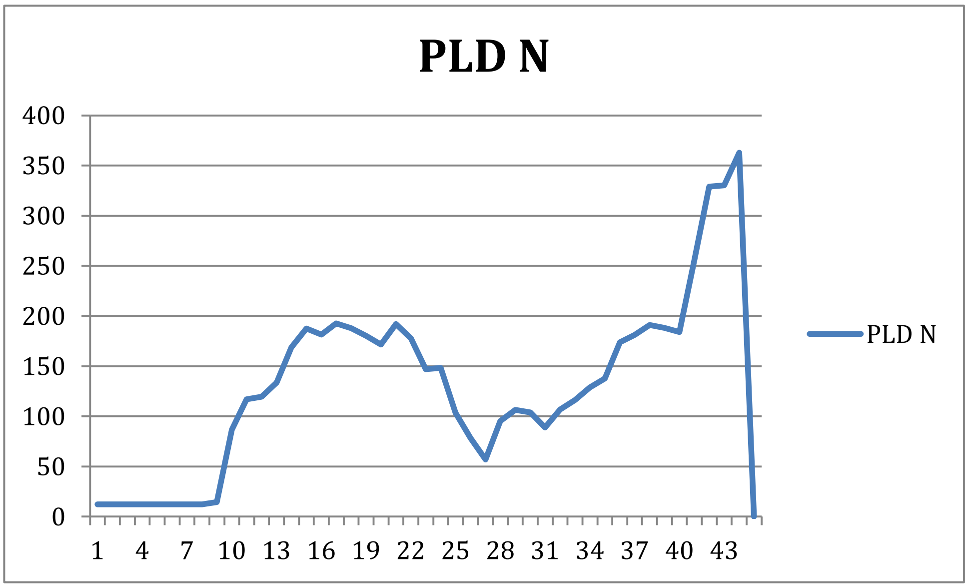
Source: CCEE (http://ccee.org.br)

Figure 3 – PLD in the Northeast Market



Source: CCEE (http://ccee.org.br)

Figure 4 – PLD in the North Market



Source: CCEE (http://ccee.org.br)

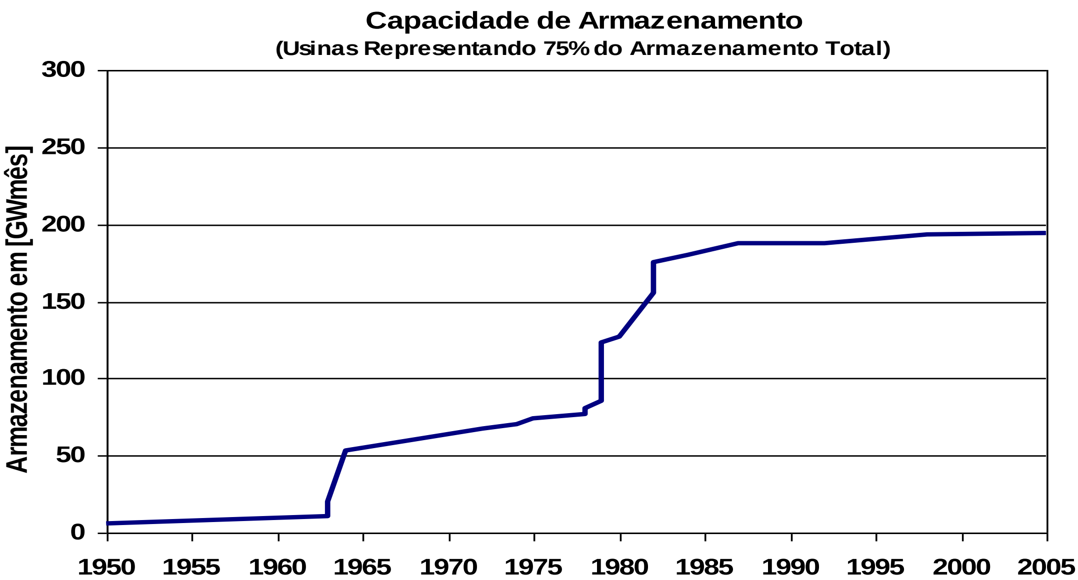
Essentially, there are three causes of such volatility. First, there was, in the period immediately after the energy rationing in 2001, a significant reduction of investments in the expansion of the system.

Another cause is related to the promulgation of the Federal Constitution in 1988, which brought to the fore a greater concern with environmental issues. These issues deal specifically with the consequences of flooding caused by the construction of large reservoirs, which entailed reducing the construction of new reservoirs of hydroelectric plants.

In fact, the hydropower plants built in the last two decades are of the run of the river type. The large reservoirs were used mainly to maintain the security of the system, and provide better control of the production of electricity in dry seasons. With the reduction of the volume of water stored in relation to demand, the volume of electricity generated from water source became more volatile, since it depends on more rainfall. And, this made the operator include more thermal plants in the calculation.

Figure 5 shows the historical series of storage capacity of the reservoirs of hydroelectric power plants in Brazil. Note that, although the industry's installed capacity increase storage capacity is constant, entrant power plants built have low load factor and little storage capacity, which implies greater volatility of the PLD and greater tendency to use thermal plants to generate power in dry seasons.

Figure 5 – Storage capacity of water reservoirs in Brazil



Source: Moreira, 2008

It is estimated that the hydraulic potential yet to be tapped, the country is approximately 126GW. Of this total, approximately 70 lies in the Amazon basin, where lowland rivers predominate and there are no conditions to build large reservoirs, so that the power plants to be auctioned will be the water line. Exclusive the remaining potential not individualized (28,000 MW), the potential in the basin is estimated at 77,058 MW spread over 13 sub-basins, and four of them (Tapajós, Xingu, Madeira and Trumpets) focus almost 90 of this potential. However, according to data from the PNE-2030 (EPE), only 38 of the potential can be classified as still viable without significant environmental constraints (milk, 2009).

The increased participation of the run-of-river hydro plants – wire without seasonal adjustment-will reduce the ability of strategic reserve system and will require greater operational flexibility of existing reservoirs. In addition to requiring increased installed capacity of back-up plants, i.e., flexible thermal, especially during periods of unfavourable hydrology.

Conclusions

This article analyzed the dynamics of the settlement price of the differences (PLD) in the Brazilian Electricity Sector in 2012, with emphasis on the causes and their volatility. The PLD, corresponding to the spot price, has been very volatile and, by consequence, substantially unpredictable. These characteristics reduce the degree of certainty of the economic agents of the electricity sector to increase considerably the economic and financial risks.

The main cause of this volatility is related to the characteristics of the industry. Approximately, 90% of the energy generated in Brazil comes from hydro plants. The PLD is calculated in an ex-ante weekly basis through stochastic dynamic programming dual models that analyze the current flow and the flow rates in the short, medium and long term. Thus, the PLD is the result of computer models, and by failing to take into account the demand side, the PLD is inadequate and inconsistent signal to signal future investments and provide long-term contracts. In relation to the volatility of the PLD, examined mainly three factors: a shortage of investment in the period pós-racionamento, the end of the construction of new reservoirs and the order of the system operator. It was noted that these elements are interdependent, which implies that there is a trend increasingly explicit, the PLD will become an even more volatile variable, contributing to instability in the Brazilian electricity market.

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The Welfare Cost of Energy Insecurity

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Abstract

Although energy security is considered as an important objective of energy policy in many countries, there is limited information about the consequences and the economic impact of energy insecurity. Most of the literature on energy security has focused on the definition and indicators, and little attention has been placed on quantifying its economic cost. The aim of this paper is to contribute to this literature quantifying the welfare cost of energy insecurity. We focus on the economic risks and, therefore, we relate energy security to the volatility in the energy price. A standard Dynamic Stochastic General Equilibrium (DSGE) model is used to quantify the welfare cost of energy price fluctuations. We calibrate the model for the Spanish economy, and find that in the last 30 years the welfare loss of energy insecurity has been around 0.8% of average consumption as a percentage of output.

Keywords: Energy security, Welfare cost, Price volatility, Spain

JEL classification numbers: Q43, E32

1. Introduction

The 1973-1974 oil crisis revealed the vulnerability of the industrial countries to oil price shocks. The oil embargo by a number of Arab producers led to a sharp rise in oil prices, which caused a decline of economic activity. Since then, energy security is considered as an important objective of energy policy in many countries around the world. An example is the creation in 1974 of the International Energy Agency (IEA), whose primary mission is to help member countries to coordinate a collective response to major disruptions in oil supply. The increasing uncertainty in energy markets in recent years has made energy security be a major issue in the energy domain again. For instance, the European Union has included energy security as one of the three pillars of its energy policy, together with efficiency and sustainability (European Commission (EC) 2008; European Commission (EC) 2006).

Despite the importance of energy security, there is limited information about the consequences and the economic impact of energy insecurity. The literature on energy security has mainly focused on the definition and indicators of energy security.

Probably the most accepted definition is that of the IEA, which defines energy security as ``the uninterrupted physical availability at a price which is affordable". European Commission (2000) extends the IEA definition, with the inclusion of environmental and sustainability issues. The Asia Pacific Energy Research Centre (APERC, 2007) defines energy security as ``the ability of an economy to guarantee the availability of the supply of energy resources in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy". According to that view, energy security is affected by four factors: availability, accessibility, affordability and acceptability. From an economic perspective, Bohi and Toman (1996) define energy insecurity as the loss of welfare resulting from a change in the price or physical availability of energy.

Another strand of the literature has focused on the measurement of energy security. The literature on indicators of energy security is quite extensive. In a survey that oversees this field, Kruyt et al. (2009) state that there is no ideal indicator and, therefore, it is needed the application of several indicators for a broader assessment and understanding of energy security. Scheepers et al. (2007) propose two quantitative indicators: the Supply/Demand Index based on objective information contained in energy balances and the Crisis Capability Index, which measures the ability of countries to manage short-term supply interruptions. The IEA has developed a Model of Short-Term Energy Security (MOSES) to evaluate short-term security of energy supply in IEA countries (IEA, 2011). The model is based on a set of quantitative indicators that measures both the risk of disruptions in energy supply and the ability of the energy system to deal with those eventual disruptions.

So far the literature has provided useful information on the definition and indicators of energy security. However, it is unclear whether energy security is important from an economic point of view. Few studies have attempted to estimate the cost of energy insecurity. Hence, in this paper we try to go a step beyond the definition and indicators of energy security. The aim of this paper to contribute to this literature quantifying the welfare cost of energy insecurity.

The definition and indicators of energy security make clear that the estimation of the welfare cost is not straightforward. In order to quantify the welfare cost, it is necessary to consider different dimensions of energy security. The European Commission's Green Paper on the security of energy supply (EC, 2000) identifies several sources of energy risks: physical risks (permanent and temporary energy disruptions), economic risks (volatility in energy prices), political risks, regulatory risks, social risks and environmental risks.

However, from a financial perspective, we can consider that all risks are reflected in the price. In a perfect market, futures prices capture the probability of future events, so that prices internalize all possible risks. As argued by Killian (2009), oil supply disruptions are reflected in the price of oil. Exogenous political events, such as the Iranian Revolution or the Persian Gulf War, lead to physical supply disruptions and higher precautionary demand, which ultimately translate into higher prices. Hence, in this paper we focus on the price dimension of energy risks. We relate energy insecurity to the uncertainty in energy prices, and therefore, estimate the welfare cost caused by energy price fluctuations.

To calculate the welfare cost of energy price volatility, we use a standard representative-agent Dynamic Stochastic General Equilibrium (DSGE) model. Energy enters the model as both an input in the production function and a good in consumers' utility function. Energy price fluctuations lead to increase the volatility of output, energy and non-energy consumption, leisure and investment. Thus, the welfare of risk adverse households decreases with increasing fluctuations in energy prices. There are three key parameters in the model: the elasticity of substitution between energy and capital in the production function, the elasticity of substitution between non-energy and energy consumption in households' utility function and households risk aversion. The elasticity of substitution determines how easy it is to substitute energy for capital or non-energy consumption. When households and firms cannot substitute easily energy for other goods (i.e., a low elasticity of substitution), oil price fluctuations have a higher impact on the economy. On the other hand, households risk aversion measures the attitude toward uncertainty, and therefore, oil price volatility causes a higher welfare loss when households are more risk adverse.

We calibrate the model for Spanish economy to analyze how past energy price fluctuations have affected the economy. We use oil price data to estimate the energy price process. This can be a good proxy, since energy price fluctuations are mainly explained by oil price fluctuations. In Spain, oil and gas represent around 75% of total primary energy consumption. Furthermore, in the European market, natural gas contracts are linked to the price of oil and, therefore, there is a strong link between the oil and natural gas prices (Hedenus et al. 2010). Hence, we consider that the welfare cost of energy price fluctuations can be mainly explained by oil price fluctuations.

To obtain a measure of the welfare cost of energy insecurity, we compare two scenarios. In the first scenario, we analyze an economy without fluctuations, that is, an economy where energy prices are constant. In the second scenario, we consider an economy where energy prices fluctuate and the average energy price is equal to the constant price of the economy without fluctuations. We compute the welfare of households in both scenarios, and propose as a measure of the cost of energy insecurity, the welfare difference between the two economies.

We find that, in Spain, past energy price fluctuations have caused a welfare loss of around 1% of average consumption as a percentage of output. Energy price fluctuations lead to increase the volatility of energy consumption, which causes most of the welfare loss in our model. When we perform a sensitivity analysis for the key parameters of the model, the results show the importance of the elasticity of substitution of energy both in the production function and in the utility function. As expected, the welfare loss is higher when firms find harder to substitute energy with capital. Likewise, energy price fluctuations have a higher effect on the utility when the elasticity of substitution between energy and non-energy consumption is lower.

This paper is related with two literatures. First, our work is linked to the literature on oil price shocks. In an influential paper, Hamilton (1983) pointed out that seven of the eight postwar recessions in the United States had been preceded by a rise in oil prices. He argued that the correlation between oil prices and output cannot just be a coincidence, and therefore claims that changes in oil prices have an effect on economic activity. These findings have been corroborated by many authors (Hamilton 1983, Burbidge and Harrison 1984, Gisser and Goodwin 1986, Raymond and Rich 1997, and Hamilton 2003)[1]. However, it is not obvious how the price of oil affects economic activity. The standard approach to modeling energy price shocks has been to consider imported oil as an input in the production function. Thus, Kim and Loungani (1992), Rotemberg and Woodford (1996) and Finn (2000) have studied the effects of energy price shocks in RBC models. However, there are problems in explaining economic declines based on this intermediate input cost because the share of oil in GDP is relatively small, less than 5% in a developed economy such as the US. Consequently, there is no reason to expect large effects on the economy due to higher production costs (Kilian, 2007). Bernanke (1983) stated that an increase in energy prices would primarily slow economic growth through its effects on consumers' expenditure. Changing prices may create uncertainty about the future and, therefore, consumers would respond by increasing their precautionary savings and postponing purchases of energy-intensive durable goods such as automobiles. Indeed, Hamilton (2005) stressed that higher uncertainty about future energy prices is the main mechanism through which energy shocks affect the economy.

Second, our paper is related with the literature on the welfare cost of business cycles. Lucas (1987) showed that the welfare cost of consumption volatility is small. He finds that the welfare gain of a smooth consumption path is 0.05% of average consumption. However, two strands of the literature have found that this value can be higher. First, Imrohoroglu (1988), Atkenson and Phelan (1994) and Krussell and Smith (1999) show that in the absence of a representative agent and complete insurance markets the welfare cost of business cycle is higher. Second, a higher cost is also found when recursive preferences[2] such as those in Epstein and Zin (1989) are used (Obstfeld 1994). In our model, two mechanisms lead to higher welfare costs. First, consumption volatility is not only caused by production fluctuations but also by the presence of energy goods, which leads to a higher volatility when energy price moves. Second, in contrast to Lucas (1987), we use a DSGE model and, therefore, we capture precautionary behavior. The results show that the average value of households' consumption

[1] Hamilton (2005) presents a complete survey of the relation between oil prices and the macroeconomy.
[2] Recursive preferences allow to separate risk aversion and intertemporal elasticity of substitution.

is not the same with or without price fluctuations. In presence of price fluctuations, consumers' risk aversion leads to reduce non-energy and energy consumption (precautionary savings), which implies a lower consumption level and, consequently, a welfare loss (Fernandez-Villaverde et al 2011).

The rest of the paper is organized as follows. Section 2 introduces the model. In Section 3, we calibrate the model and describe the solution method used. Section 4 presents a measure of the welfare cost of energy insecurity and the results. In section 5 we conclude.

2. The Model

The model described in this section is a dynamic stochastic general equilibrium model. The economy consists of a representative household and a firm. Energy enters the model as a consumption good for households and as a production input for firms. Energy is imported from abroad at an exogenous world price (*p*). Each period energy imports are paid with domestic output and, thus, current account clears. The basic structure of the model is similar to De Miguel and Manzano (2011).

The representative firm uses labor (*n*), capital (*k*) and energy (*ef*) to produce the final good. Technology is given by the following CES function,

$$F(n_t, k_t, ef_t) = n_t^{\theta}\left((1-a)k_t^{\nu} + a ef_t^{-\nu}\right)^{-\frac{1-\theta}{\nu}}, \qquad (1)$$

where θ is the labor share and 1/ (1 +v) is the elasticity of substitution between capital and energy. The firm, which operates under perfect competition, maximizes profits

$$\max_{n_t, k_t, ef_t} \qquad F(n_t, k_t, ef_t) - w_t n_t - r_t k_t - p_t ef_t\,, \qquad (2)$$

where *w* is the wage, *r* is the interest rate and *p* the relative energy price[3]. From firm's maximization problem, we obtain the following equilibrium conditions

$$w_t = \frac{\partial F(n_t, k_t, ef_t)}{\partial n_t}, \qquad (3)$$

$$r_t = \frac{\partial F(n_t, k_t, ef_t)}{\partial k_t}, \qquad (4)$$

$$p_t = \frac{\partial F(n_t, k_t, ef_t)}{\partial ef_t}. \qquad (5)$$

Equations 3, 4 and 5 state that the marginal productivity of labor, capital and energy are equal to the wage, the interest rate and the relative energy price, respectively.

The representative household is infinitely-lived and has preferences over non-energy and energy consumption, and leisure that are defined in the following utility function

[3] The price of the final good is normalized to one, thus, *p* can be considered as the relative energy price.

$$U(A_t, n_t) = \frac{\left[A_t^{1-\mu}(1-n_t)^{\mu}\right]^{\sigma}}{\sigma} \qquad (6)$$

with $$A_t(c_t, eh_t) = \left[(1-\gamma)c_t^{\alpha} + \gamma eh_t^{\alpha}\right]^{1/\alpha} \qquad (7)$$

A is the aggregate good that combines non-energy (*c*) and energy consumption (*eh*). The elasticity of substitution between non-energy and energy is 1/(1-α). Notice that household's endowment of time is normalized to 1 so that leisure is equal to 1-*n*. The representative household also accumulates capital according to the law of motion:

$$k_{t+1} = (1-\delta)k_t + i_t\,, \qquad (8)$$

where δ is the depreciation rate and *i* is investment. Thus, the representative household maximizes expected intertemporal utility subject to the budget constraint:

$$\max_{c_t, eh_t, n_t} \qquad E\sum_{t=0}^{\infty}\beta^t U(A_t, n_t) \qquad (9)$$

$$\text{s.t.} \qquad c_t + p_t eh_t + i_t = w_t n_t + r_t k_t\,, \qquad (10)$$

where β is the discount factor. The first order conditions for households problem are:

$$U_{eh_t} = -U_{c_t} p_t\,, \qquad (11)$$

$$U_{n_t} = -U_{c_t} w_t\,, \qquad (12)$$

$$U_{c_t} = \beta U_{c_{t+1}}(1-\delta+r_{t+1})\,. \qquad (13)$$

Equations 11 and 12 state that the marginal utility of non-energy consumption is equal to the marginal utility of energy consumption and leisure, respectively. Equation 13 is the standard Euler equation that determines intertemporal consumption allocation.

The equilibrium of the economy is a sequence of prices $\{\Pi_t\} = \{p_t, r_t, w_t\}$ and quantities $\{\Theta_t\} = \{c_t, eh_t, n_t, k_t, ef_t, i_t, y_t\}$ such that:

1. Given a sequence of prices $\{\Pi_t\}$, $\{c_t, eh_t, n_t, i_t\}$ is a solution to be representative household's problem;
2. Given a sequence of prices $\{\Pi_t\}$, $\{k_t, ef_t, n_t\}$ is a solution to the representative firm;
3. Given a sequence of quantities$\{\Theta_t\}$, $\{\Pi_t\}$ clears the market.

3. Calibration and Solution Method

To find a numerical solution is necessary to calibrate the model. Hence, the model is calibrated following De Miguel and Manzano (2011). The parameters are chosen to reproduce the main long-run characteristics of the Spanish economy. We define one period as a quarter, and thus, set the discount factor, β, to 0.99, which implies a real interest rate of 1%. The depreciation rate of capital, δ, is set to 0.025, implying an annual rate of 10%.

There are three key parameters in our model: the elasticity of substitution between energy and capital in the production function (1/(1+ν)), the elasticity of substitution between non-energy and energy consumption in households utility function (1/(1-α)) and households risk aversion (σ). We choose standard values for our benchmark simulation. Following Thompson and Taylor (1995) estimations, the elasticity of substitution between capital and energy is set to 0.76. We also set a standard value for the elasticity of substitution between non-energy and energy consumption (0.85), obtained from Goulder et al (1999). In the literature we find a wide range of estimates for the relative risk aversion, here (σ) is equal to -1 which lies between the intervals of many empirical studies. In section 4.2 we perform sensitivity analysis along these three parameters and analyze how the results vary.

The parameter μ in households' utility function is 2/3 which implies that the representative household works one-third of its time. In the production function, we set a standard value for the labor share, (θ=0.64). The parameters, γ and *a*, are chosen to approximate household and firm energy consumption to the values observed in the data. Table 1 presents parameter values.

Table 1: Parameter values

Preferences		
Subjective discount factor	β	0.99
Energy consumption share	γ	0.036
Elasticity of substitution between energy and non-energy consumption	1/(1-α)	0.85
Preference for leisure	μ	2/3
Risk aversion	σ	-1
Technology		
Labor share	θ	0.64
Rate of depreciation	δ	0.025
Elasticity of substitution between energy and capital	1/(1+ν)	0.76
Prices		
Persistence	ρ	0.95
Standard deviation	σ_p	0.18

To estimate the price process, we use oil prices rather than energy prices. This can be a good approximation given that energy price fluctuations are mainly explained by oil price volatility. In Spain, oil and natural gas account for 75% of energy consumption and, furthermore, the price of natural gas is linked to oil price. To obtain the relative price we divide oil price by the Spanish GDP deflator. We use quarterly log prices from 1970Q1-2007Q4 to estimate

$$p_t = (1-\rho)p_{ss} + \rho p_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim N(0, \sigma_p)\,. \tag{14}$$

To solve the model, we use the stochastic perturbation method, i.e., linearization around the steady-state, to approximate the dynamics of our economy. We run the program Dynare Version 4.2 to obtain the policy functions (see Adjemian et al (2011) for the methodological details). Two different approaches are used to linearize the model: a first-order and a second-order Taylor expansion. As argued by Schmitt-Grohé and Uribe (2004) second-order approximation techniques are best suited to handle welfare comparisons. The problem is that using a first-order approximation some second-order terms of the equilibrium welfare function are ignored while others are not. For instance, a limitation of a first-order approximation is that the decision rules of the representative agent follow the certainty equivalence principle. This limitation implies that the unconditional means of endogenous variables coincides with their non-stochastic steady state values, and therefore, precautionary savings due to volatility are ignored. This is an important issue in this paper, since we want to analyze the economic impact of energy price fluctuations. Thus, we solve the model using both a first-order and a second-order approximation technique, and compare the results. We do not find significant differences when a higher order approximation is used. A further discussion of the accuracy of this solution method can be found in Arouba et al (2006).

4. The welfare cost of energy insecurity

In this section we propose a measure of the welfare cost of energy insecurity. As mentioned above, we associate energy insecurity to energy price fluctuations. We apply this measure to the Spanish economy and calculate the welfare cost caused by energy price fluctuations from 1970 to 2007. We use observed real data in this period to evaluate the consequences of energy price volatility in the economy.

We construct our measure comparing two economies: an economy where energy price fluctuates (as observed in the real data) and an economy where energy price is constant and equal to the mean value of the observed energy price (Figure 1). The average energy price and the starting initial conditions are the same in both economies. Our measure of energy insecurity relates the difference between the expected intertemporal utility of the representative agent in this two economies. To obtain the measure we derive the second-order approximation of expected utility around the steady state,

$$E[U(c_t, eh_t, n_t)] = U(c_{ss}, eh_{ss}, n_{ss}) + \left(\frac{\partial U}{\partial c_t}\bigg| c_{ss} \;\; \frac{\partial U}{\partial eh_t}\bigg| eh_{ss} \;\; \frac{\partial U}{\partial n_t}\bigg| n_{ss} \right) E \begin{pmatrix} c_t - c_{ss} \\ eh_t - eh_{ss} \\ n_t - n_{ss} \end{pmatrix} + \frac{1}{2} \left(\frac{\partial^2 U}{\partial^2 c_t^2}\bigg| c_{ss} \;\; \frac{\partial^2 U}{\partial^2 eh_t^2}\bigg| eh_{ss} \;\; \frac{\partial^2 U}{\partial^2 n_t^2}\bigg| n_{ss} \right) E \begin{pmatrix} (c_t - c_{ss})^2 \\ (eh_t - eh_{ss})^2 \\ (n_t - n_{ss})^2 \end{pmatrix}. \quad (15)$$

Notice that $E(c_t) = c_{ss}$, $E(eh_t) = eh_{ss}$, $E(n_t) = n_{ss}$, $E(c_t - c_{ss})^2 = Var(c_t)$, $E(eh_t - eh_{ss})^2 = Var(eh_t)$ and $E(n_t - n_{ss})^2 = Var(n_t)$. Therefore, from equation 15, we get

$$D = U(c_{ss}, eh_{ss}, n_{ss}) - E[U(c_t, eh_t, n_t)] = -\frac{1}{2}\left(\frac{\partial^2 U}{\partial^2 c_t^2}\bigg| c_{ss}\, Var(c_t) + \frac{\partial^2 U}{\partial^2 eh_t^2}\bigg| eh_{ss}\, Var(eh_t) + \frac{\partial^2 U}{\partial^2 n_t^2}\bigg| n_{ss}\, Var(n_t)\right). \qquad (16)$$

Where D is the difference between the utility in an economy without and with fluctuations. However this value is not very meaningful, since it depends on the size of the economy. Hence, we construct the measure as the percentage increase in non-energy consumption required to leave households indifferent between an economy with energy price fluctuations and an economy with a perfectly smooth price path. Thus, the measure we propose is given by

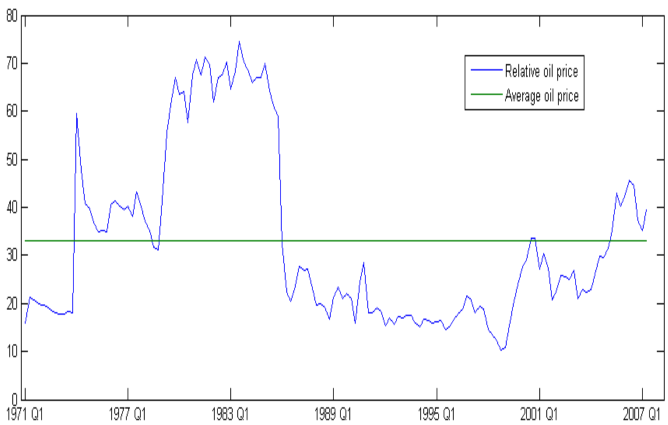
$$U(c_{ss}, eh_{ss}, n_{ss}) = E[U(c_t(1+x), eh_t, n_t)]. \qquad (17)$$

Where x is the percentage consumption increase needed to equalize both utilities. Finally we express the welfare cost as a percentage of the GDP. Therefore our measure is obtained from the following expression:

$$WC = x\,\frac{c_{ss}}{y_{ss}}, \qquad (18)$$

Where WC is the percentage increase in the GDP needed to make households indifferent between an economy with and without energy price fluctuations.

Figure 1: Relative oil price (€2000)



4.1. Numerical results

As mentioned before, we apply the measure to the Spanish economy. The objective is to estimate the cost of energy price fluctuations between 1970 and 2007. We use real data and, thus, the economy with fluctuations is simulated using observed energy prices.

Notice that we use the relative energy price expressed in euros (2000€). Consequently, there are three possible sources for fluctuations: energy price, inflation rate and euro-dollar exchange rate. Even if the energy price is constant the relative price can fluctuate. First, a decline in the price of other consumer goods implies an increase in the relative price of energy. And second, even if the energy price in dollars does not change, a depreciation of the euro leads to an increase in the relative energy price in euros. In this paper, we do not distinguish between the sources of fluctuations. Therefore, when computing the welfare cost of energy price fluctuations, these can be caused by fluctuations in inflation and exchange rates.

Table 2 summarizes the welfare results of energy price fluctuations. We present the results under different scenarios and, as mentioned before, we solve the model using a first-order and second-order approximation method.

In our benchmark model, the welfare cost of energy insecurity is 0.84% of the average consumption in terms of GDP. This result implies that households would be willing to give up 0.84% of consumption in terms of GDP to avoid fluctuations in energy prices. In other words, in absence of energy price fluctuations, the households' utility would increase 0.84% of the average consumption. Notice the difference in the results when the model is solved using a first-order approximation method. In this case, the welfare loss is 0.59%. As argued before, a first-order approximation method does not account for precautionary savings. Actually, non-energy consumption level at the steady state is 0.11% higher in an economy without fluctuations. Likewise, energy consumption is 0.08% higher and labor supply is 0.08% lower. This is because uncertainty leads consumers to protect themselves against possible price increases in the future. Hence, in a first-order approximation method, which does not account for precautionary savings, the welfare loss of price fluctuations is lower.

In our benchmark model both households and firms demand energy and, therefore, energy price fluctuations are transmitted through these two channels to the main variables of the economy. However, most of the welfare loss is generated through energy consumption by households. In an economy in which energy is only used for production (γ=0), the welfare cost of energy price fluctuations is around 0.026%. Notice that our model replicates an economy without rigidities, and therefore, fluctuations in energy prices do not have a significant impact on firms. In absence of capital-energy complementarities (Atkeson and Kehoe, 1999) and endogenous capital utilization (Finn, 2000), firms can quickly adjust to energy price shocks.

Table 2: Welfare Cost of Energy Insecurity

	Benchmark model		**γ=0**	
	1st Order	**2nd Order**	**1st Order**	**2nd Order**
Benchmark model	0.59%	0.84%	0.025%	0.026%
σ=0	0.58%	0.83%	0.022%	0.023%
σ=-5	0.64%	0.91%	0.041%	0.042%
$1/(1-\alpha)$=0.5	1.35%	1.59%	-	-
$1/(1-\alpha)$=1	0.42%	0.65%	-	-
$1/(1-\nu)$=0.5	1.17%	1.47%	0.48%	0.50%
$1/(1-\nu)$=1	0.54%	0.77%	0.001%	0.001%

In absence of energy consumption, the framework is similar to Lucas (1987), and thus, we obtain similar results. Energy price fluctuations generate small cycles on real output and the final effect on the main variables of the economy is also very small, consequently, the welfare loss is insignificant. Therefore it is necessary to highlight the importance of energy consumption by households as a determining factor in the welfare loss of energy price fluctuations.

4.2. Sensitivity analysis

We perform sensitivity analysis for the key parameters of the model. Apart from the benchmark value of σ=-1, we calculate the welfare cost when households are risk neutral σ=0 and when they are more risk averse σ=-5. Risk neutrality dos not reduce much the results; in this scenario, the welfare cost of energy price fluctuations is 0.83% of the average consumption in terms of output. On the other hand, when consumers are more risk adverse, volatility in energy prices can cause a welfare loss of 0.91% of the average consumption.

We find that the elasticity of substitution between energy and both non-energy goods (households) and capital (firms) has a higher impact than the risk adverse parameter. The benchmark value of α=0.18 corresponds to an elasticity of substitution between energy and non-energy consumption of 0.85. We also pick a smaller elasticity of 0.5 which corresponds to α=-1. In this case, the welfare cost of fluctuations in the energy price is 1.59%. This is an expected result, since price volatility should have a higher impact on the welfare when it is more difficult to replace one consumption good for another. Likewise, we pick an elasticity of 1 which corresponds to α=0. As expected, when it is easier to replace energy for non-energy consumption, the welfare cost of fluctuations is lower.

The elasticity of substitution between energy and capital also has an important effect on the welfare loss. In addition to the benchmark value of 0.76 (ν=0.32), we pick a lower elasticity of 0.5 (ν=1) and a higher elasticity of 1 (ν=0). We find that the lower is the elasticity the higher is the welfare loss caused by fluctuations in energy price. When, it is more difficult to replace energy for capital, energy price volatility leads to a welfare loss of 1.47%. On the other hand, in a scenario with a higher value for the elasticity parameter, the welfare loss is around 0.77%.

The sensitivity analysis shows the importance of the elasticity of substitution between energy and both non-energy goods and capital in the proposed measure for the welfare costs of energy insecurity. In contrast to the risk adverse parameter, changes on the elasticity of substitution have significant effects on the results. Thus, the ability to facilitate energy substitutability for both households and firms is crucial to reduce the costs of energy insecurity.

5. Conclusion

In recent years, energy security has become once again a priority of energy policy. The high volatility and uncertainty on the energy markets has increased the interest in this dimension of the energy policy. The literature has put much effort into trying to define and measure energy security. Nevertheless, little is known about its economic consequences.

The aim of this paper is to provide a macroeconomic measure of the welfare cost of energy insecurity. We relate energy security to energy price volatility and, therefore, quantify the welfare cost caused by the fluctuations in the energy price. We focus on the price dimension of energy security. Although this may be seen as a limitation in our measure, we believe that most of the energy risks are reflected in the final price. Thus, analyzing the fluctuations in the price of energy is a good way to quantify energy security.

We use a standard DSGE model which is calibrated for the Spanish economy. In the model, energy is a consumption good for households and a production input for firms. Thus, energy price fluctuations affect households' utility in two ways. First, energy enters utility function as a consumption good, and therefore, energy price fluctuations have a direct impact on energy consumption and, consequently, on households' welfare. Second, firms use energy for production and, thus, the fluctuations in the energy price lead to increase the volatility of output, leisure and non-energy consumption, which affect ultimately households' welfare.

We find that the fluctuations in the energy price have a significant impact on households' welfare. In the last 30 years, the welfare loss caused by energy price volatility in Spain has been around 0.8% of average consumption in terms of GDP. This is an important result that reveals the economic consequences of energy insecurity. In particular, we show the significant impact on households' welfare due to fluctuations in energy prices. This result should make clear the importance of energy security when planning an energy policy. In addition to the political and social costs, energy insecurity causes a significant economic cost.

Our results show that energy price fluctuations mainly affect utility through household energy consumption. They increase the volatility in energy consumption which causes a decline in households' welfare. On the other hand, energy price fluctuations have not a significant impact on the volatility of output, non-energy consumption and leisure. Consequently, in an economy in which energy is only used for production, the welfare loss caused by price fluctuations is much lower.

The sensitivity analysis shows the importance of the elasticity of substitution between energy and both non-energy consumption goods and capital. The welfare cost of energy price fluctuations is highly dependent on how difficult it is to replace energy with non-energy consumption. Likewise, when firms find harder to substitute energy with capital, the welfare loss due to energy price fluctuations is much higher.

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Explanatory variables on south-west spot electricity markets integration

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Sustainable Energy Systems – MIT-P

Abstract

This paper aims to assess some determinants on the integration level of the South West Europe regional electricity spot markets created under the initiative launched by the European Regulators Group for Electricity and Gas. The integration of the European South-West regional electricity spot market relies on the physical interconnection between two pairs of Transmission Systems: Portugal-Spain and Spain-France. Interconnection capacity is thought to be critical to ensure electricity market integration and was therefore studied. Two other determinants were included in our study, corresponding to ambient conditions: temperature and wind. Whilst temperature is thought to have influence on demand, wind on the other hand should have influence on available generation. Results obtained from a vector autoregression model specification show interconnection capacities related exogenous variables to not improve the model, whilst average temperature contributes slightly to improve the model. It is to note that the introduction of the exogenous variable average wind speed improves all models' specification. Strong integration was found between both MIBEL markets, leading to the conclusion that Price Coupling mechanism is efficient and contributes to the integration of spot electricity markets. Also, as demonstrated by Grange-causality and impulse response analysis, there is a weak integration level between MIBEL and Powernext.

Keywords: electricity market integration, South-West region, VARX modeling

JEL: C13, C32, O13, Q43

1. Introduction

The Council Directive 90/547/EEC of 29 October 1990 on the transit of electricity through transmission grids (European Union, 1990a) and Council Directive 90/377/EEC of 29 June 1990 concerning a procedure to improve the transparency of gas and electricity prices charged to industrial end-users (European Union, 1990b), provided the first steps for the creation of the internal European electricity market (Bower, 2002).

The European Directive 2003/54/EC and lately the European Directive 2009/72/EC reviewed the European Directive 96/92/EC which for the first time established common rules for the various electricity markets in Europe, based on the liberalisation of the sector without prejudice of the public service required and the access by the generators and consumers to the transmission and distribution grids (Jamasb and Pollitt, 2005). These requirements are guaranteed by regulating authorities established in each country (Silva and Soares, 2008).

The European Directive 2001/77/EC repealed by the European Directive 2009/28/EC called for the promotion of electricity generation by renewable energy sources (RES) in Europe in order to reduce dependency on imported fossil fuels and to allow the reduction in Green House Gas (GHG) emissions. The RES electricity (RES-E) generation capacity in Europe was 239.2 GW by 2010 with 52.1% hydroelectric, 25.7% wind, 17.86% biomass, 3.3% solar, 0.93% geothermal and 0.08% tidal or wave generation (Jäger-waldau et al., 2011). The RES-E generation technologies are in different stages of development which explain the different shares of deployment achieved in each technology (Brown et al., 2011). The large deployment of RES-E generation in Europe was achieved by strong financial support mechanisms (Meyer, 2003), like feed-in tariffs, fiscal incentives, tax exemptions and other (Jager et al., 2011).

To guarantee the supply of electricity, to reduce costs, maintaining competition, ensuring security of supply and respecting the environment were the objectives set for the European energy policies. However different degrees of market opening and development of interconnectors between electricity transmission grids across European countries are observed. European countries took necessary measures to facilitate transit of electricity between transmission grids in accordance with the conditions laid down in the Directives. The adequate integration of national electricity transmission grids and associated increase of electricity cross-border transfers should ensure the optimization of the production infrastructure.

In 2006 the European Regulators Group for Electricity and Gas (ERGEG - currently the Agency for the Cooperation of Energy Regulators – ACER established by European Commission Regulation 713/2009 of 13 July 2009) launched seven Electricity Regional Initiatives (ERI) (Meeus and Belmans, 2008; Karova, 2011) for the creation of seven Regional Electricity Markets (REMs). The objective for the creation of these REMs was to provide an intermediate step for the consolidated European Electricity Market (ERGEG, 2006).

Consequently, the aspect of transmission costs determination plays an important role and its allocation methods are usually either Flat Rate based or Flow-based. Flat rate methods are simple to calculate and implement, however, according to (Galiana et al., 2003) unfair to generators that use less capacity and extent of the transmission lines.

On the other hand, flow-based costs are most commonly used due to their dependence on the capacity and extent used by each generator of the transmission lines. Explicit auctioning, where interconnector capacity is sold to the highest bidder or implicit auctioning, which integrates electricity and transmission markets and also called Market Splitting/Price Coupling, are both used across Europe (Coppens and Vivet, 2006).

In the Spain-France interconnection, the method of explicit auctioning is used however the mechanism of Market Splitting/Price Coupling is applied to the Portuguese-Spanish interconnection.

In this framework, an initiative, denominated Price Coupling of Regions (PCR) was launched at the Florence Regulatory Forum in 2009 by three power exchanges: Nordpool, EPEX and MIBEL (Europex, 2009), to be implemented by the end of 2012. In the mean time additional members joined the initiative, APX-Endex, Belpex and GME, reaching the 2860 TWh/year of potential electricity trading (Europex, 2011) and to be fully implemented by the end of 2014.

Building on previous work by the authors (Figueiredo and Silva, 2012), the objective of this paper is to assess the level of integration of the South West REMs. In Section 2 spot electricity market data used in this study is presented and discussed and in section 3 VAR model specifications are presented. Analysis and results of additional impulse response functions to account for causal impacts are presented and discussed in Section 4 and, finally, in Section 5 final remarks can be found.

2. Data

Day-ahead spot electricity prices in €/MWh (base, peek and off-peak), obtained from *Redes Energéticas Nacionais* (REN) for Portugal (MIBEL_PT), *Red Electrica de España* (REE) for Spain (MIBEL_ES) and *Réseau de transport d'électricité* (RTE) for France (Powernext and EPEX since April 2009), were used in this study from the 1st of January 2009 to the 31st of December 2011.

As an example we can see the data plotted for the MIBEL (Portuguese) day-ahead base, peak and off-peak spot electricity prices in Figure 1.

Price spikes are observed in electricity markets, which confirms the high volatility behaviour of electricity spot prices, as in Goto and Karolyi (2004), Hadsell et al. (2004) and Higgs (2008). The limited possibility of storage, the physical characteristics of simultaneous electricity production and consumption, technical constraints in transmission and generating plants are the main reasons for these spikes (Coppens and Vivet, 2006; Silva and Soares, 2008).

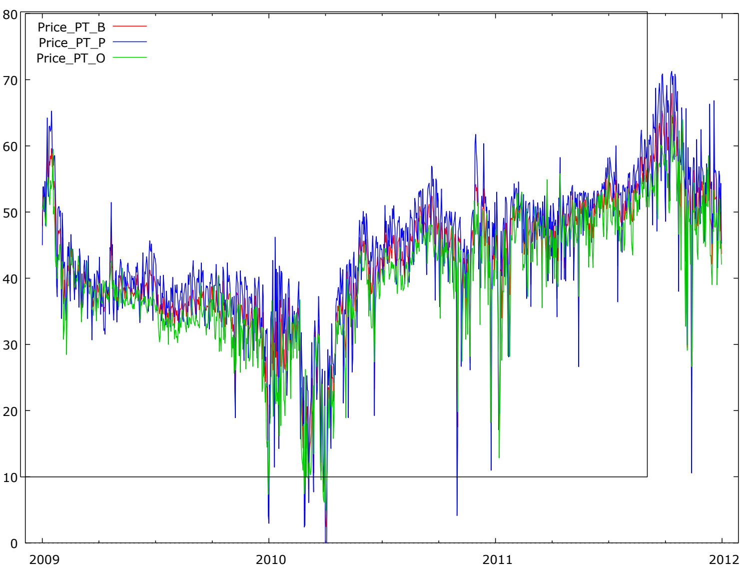

Figure 1 – Day-ahead base spot electricity prices – Price_PT, Price_ES and Price_FR

Daily average interconnection capacities were obtained from the corresponding system operator (REN, REE and RTE) and daily average climate data were retrieved from the website www.wunderground.com, which gathers data from weather stations throughout the world.

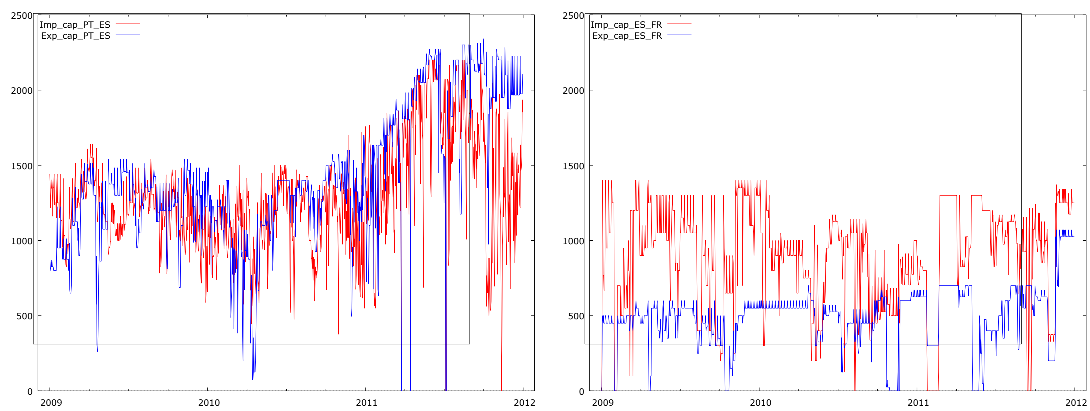

Figure 2 – Import and export interconnection capacities between Portugal-Spain and Spain-France [MW]

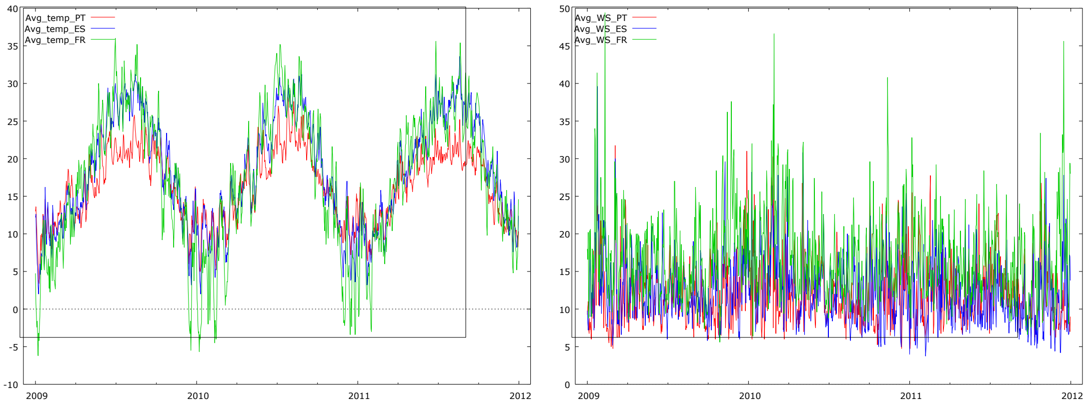

Figure 3 - Ambient temperature [ºC] and wind speed [km/h] in Portugal, Spain and France

After transforming the prices into their natural logarithms, to obtain directly the elasticity values from the parameter estimates, summary statistics were calculated. Skewness and kurtosis values also indicate non-normal distribution, which is confirmed by JB statistic.

Table 1 - Summary Statistics Daily-log Spot Electricity Prices

	L_PRICE_PT_B	L_PRICE_PT_O	L_PRICE_PT_P	L_PRICE_ES_B	L_PRICE_ES_O	L_PRICE_ES_P	L_PRICE_FR_B	L_PRICE_FR_O	L_PRICE_FR_P
Mean	3.69222	3.642223	3.709901	3.678976	3.623363	3.700324	3.792854	3.614025	3.937147
Median	3.738275	3.687357	3.778949	3.723291	3.663455	3.767902	3.83218	3.663418	3.975863
Maximum	4.218502	4.16815	4.26644	4.17919	4.15943	4.260447	6.417983	4.368455	7.044566
Minimum	0.902868	1.596015	-6.907755	0.902868	1.222549	-6.907755	2.420898	2.321546	2.402604
Std. Dev.	0.324171	0.325663	0.648665	0.331366	0.326743	0.661153	0.296169	0.299297	0.316105
Skewness	-3.005576	-2.261602	-12.43765	-3.175834	-2.299267	-11.94032	-0.239695	-0.655172	-0.203956
Kurtosis	19.28493	10.88605	198.5134	20.5178	12.06239	184.5813	10.19017	3.692534	13.91981
Jarque-Bera	13748.31	3770.871	1772271	15841.78	4711.854	1530356	2369.23	100.22	5448.022
Probability	0	0	0	0	0	0	0	0	0
Sum	4042.981	3988.234	4062.341	4028.478	3967.583	4051.855	4153.175	3957.357	4311.175
Sum Sq. Dev.	114.9653	116.0258	460.3183	120.1253	116.7966	478.2129	95.96111	97.99939	109.3148
Observations	1095	1095	1095	1095	1095	1095	1095	1095	1095

Unit root tests were made to all daily-log spot electricity prices. As per Table 2 we observe that all time series are considered to be stationary at 5% agreeing with findings in Park et al. (2006) and Bunn and Gianfreda (2010).

Table 2 – Unit root test with structural break

	L_PRICE_PT			L_PRICE_ES			L_PRICE_FR		
	Base	Peak	Off-peak	Base	Peak	Off-peak	Base	Peak	Off-peak
ADF test	-3.924034	-7.652745	-4.427227	-4.33109	-7.106798	-4.740748	-3.349638	-3.312797	-3.246916
(p-value)	(0.0019)	(0.0)	(0.0003)	(0.0004)	(0.0)	(0.0001)	(0.013)	(0.0146)	(0.0177)
PP test	-7.923531	-13.72823	-8.162465	-9.410447	-13.5048	-9.201629	-17.10808	-21.38244	-10.09937
(p-value)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)

3. Model Estimation

The VAR model has proven to be especially useful for describing the dynamic behavior of economic and financial time series and for forecasting. It is known to provide superior forecasts to those from univariate time series models and elaborate theory-based simultaneous equations models. In addition to data description and forecasting, the VAR model is also used for structural inference and policy analysis (Sims, 1980; Lütkepohl, 2005). In structural analysis, certain assumptions about the causal structure of the data under investigation are imposed, and the resulting causal impacts of unexpected shocks or innovations to specified variables on the variables in the model are summarized. These causal impacts are usually summarized with impulse response functions, as is performed in section 0 of this work.

A VARX model was then considered to proceed with the evaluation of the determinants in the electricity market integration, due to its ability in capture the linear interdependencies among multiple time series

Considering a VARX model for the three log prices:

$$Y_t^{(z)} = C^{(z)} + \sum_{i=1}^{p} A_i^{(z)} Y_{t-i}^{(z)} + B^{(z)} X_t^{(z)} + \Psi^{(z)} D_t^{(z)} + u_t^{(z)} \tag{1}$$

where z is the base, peak or off-peak model, $Y_t^{(z)} = (l\_Price\_PT_t^{(z)},\ \ l\_Price\_ES_t^{(z)},\ \ l\_Price\_FR_t^{(z)})'$ the day-ahead electricity price matrix, $X_t^{(z)}$ the exogenous variables matrix, $C^{(z)}$ are (3x1) constant matrices, $A^{(z)}{}_i$ and $B^{(z)}$ are (1x3) coefficient matrices, $\Psi^{(z)}$ are (1x3) coefficient matrices, $D^{(z)}{}_t$ are working day dummy variables and $u^{(z)}{}_t$ are (3x1) matrices of unobservable error terms. In order to determine the order of each the models, successive VAR models were estimated by a sequential test procedure, starting with the estimation of the models with $p = 21$ lags and calculating-down for lower lags the Akaike information criterion (AIC), the Schwarz Bayesian criterion (BIC) and the Hannan-Quinn criterion (HQC).

In Table 3 the best values for the endogenous variable lags where criteria are minimised are presented. For each model a lag exclusion Wald test was performed in order to detect lags where the respective coefficients do not present significance in the model. These were then removed as indicated also in Table 3. Autocorrelation testing in all models was performed with results presented in Table 3 (Davidson and Mackinnon, 2004).

The introduction of exogenous variables was evaluated through the Akaike information criterion (AIC), the Schwarz Bayesian criterion (BIC) and the Hannan-Quinn criterion (HQC) (Lütkepohl, 2005) and presented in Table 4.

Table 3 – Lag selection for VAR models

	Price model with dummy			
	Base			
Lag Length Criteria	Lags	AIC	SC	HQ
	8	-4.274077*	-3.912463	-4.137116*
Breusch-Godfrey LM test		test value	p-value	Note: Lag 6
	9	16.5526	0.0562	removed
	Off-peak			
Lag Length Criteria	Lags	AIC	SC	HQ
	3	-4.253471	-4.100481*	-4.195526*
Breusch-Godfrey LM test		test value	p-value	
	4	9.729316	0.3728	
	Peak			
Lag Length Criteria	Lags	AIC	SC	HQ
	9	-1.280405	-0.877066*	-1.127640*
Breusch-Godfrey LM test		test value	p-value	
	10	14.95174	0.0923	

Table 4 – Criteria results for the introduction of exogenous variables

	Lag Length Criteria			
	Base			
Exogenous vars included	Lags	AIC	SC	HQ
Weekend Dummy	8	-4.274077*	-3.912463	-4.137116*
Weekend Dummy and Average Temperature	8	-4.299329*	-3.895991	-4.146565*
Weekend Dummy, Average Temperature and Average Wind Speed	8	-4.517245	-4.072182	-4.348677*
Weekend Dummy, Average Temperature, Average Wind Speed and Interconnection Capacities	8	-4.519545*	-4.018849	-4.329906*
	Off-peak			
Exogenous vars included	Lags	AIC	SC	HQ
Weekend Dummy	3	-4.270076	-4.118549*	-4.212719*
Weekend Dummy and Average Temperature	3	-4.306157	-4.113306*	-4.233158*
Weekend Dummy, Average Temperature and Average Wind Speed	3	-4.544969	-4.310792*	-4.456327
Weekend Dummy, Average Temperature, Average Wind Speed and Interconnection Capacities	3	-4.563131	-4.273854*	-4.453632
	Peak			
Exogenous vars included	Lags	AIC	SC	HQ
Weekend Dummy	9	-1.280405	-0.877066*	-1.127640*
Weekend Dummy and Average Temperature	9	-1.298992	-0.853929	-1.130424*
Weekend Dummy, Average Temperature and Average Wind Speed	9	-1.366813	-0.880025	-1.182442*
Weekend Dummy, Average Temperature, Average Wind Speed and Interconnection Capacities	9	-1.365437	-0.823016	-1.159995*

* lower criterion value

4. Analysis and discussion of results

The results shown in Table 4 demonstrate that the exogenous variables related with the interconnection capacities do not improve the model specification, whereas the average temperature just improves the model in some cases. A relevant improvement in all models specification is found by incorporating as an exogenous variable the average wind speed.

Therefore, three models with only the average wind speed as exogenous variable were considered and estimated. Estimation results can be found in Table 6 Appendix A.

As per Figure 4 all equations in the three models satisfy the stability condition of no roots outside the unit circle.

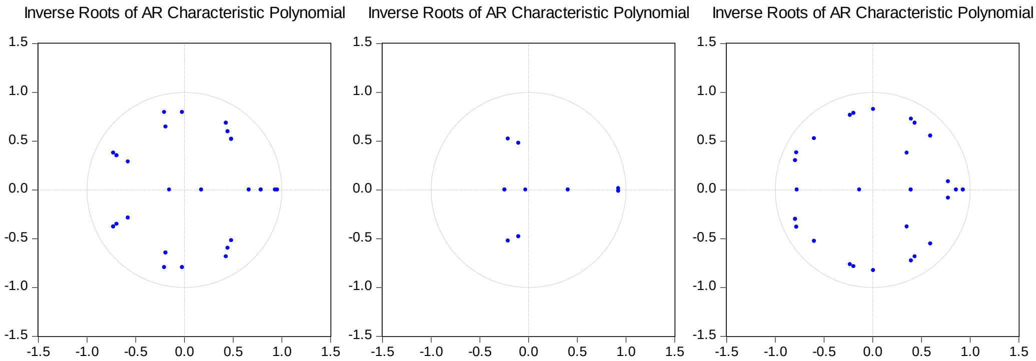

Figure 4 – Unit circle for base, off-peak and peak models

The average wind speed in Portugal and Spain related coefficients are significant for the Portuguese and Spanish log-daily spot electricity price equations in the base and off-peak models with a negative contribution to prices, in particular for the Portuguese side of the MIBEL (log-daily electricity base prices in Portugal -0.010247 *vs* Spain -0.004601).

In the peak model only the Portuguese average wind speed has significant contribution for both MIBEL market prices.

In the Powernext related equations the average wind speed for Portugal and Spain do not present significant coefficients in all models (base, off-peak and peak). However, the French average wind speed has significant coefficients in all models in these equations.

Granger Causality tests to the time-series variables and impulse response analysis displaying the responses of each daily-log price time-series to a standard error shock in one of the time-series were carried out to the models considered and are presented, respectively, in Table 5 and in Figure 5 to Figure 7.

Table 5 – Granger Causality test output

Base				Off-peak				Peak			
Dependent variable: L_PRICE_PT_B				Dependent variable: L_PRICE_PT_O				Dependent variable: L_PRICE_PT_P			
Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.
L_PRICE_ES_B	87.63229	7	0	L_PRICE_ES_O	37.99502	3	0	L_PRICE_ES_P	342.3331	9	0
L_PRICE_FR_B	24.61589	7	0.0009	L_PRICE_FR_O	7.173183	3	0.067	L_PRICE_FR_P	46.97791	9	0
All	116.906	14	0	All	45.82277	6	0	All	396.5655	18	0
Dependent variable: L_PRICE_ES_B				Dependent variable: L_PRICE_ES_O				Dependent variable: L_PRICE_ES_P			
Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.
L_PRICE_PT_B	32.57547	7	0	L_PRICE_PT_O	50.43781	3	0	L_PRICE_PT_P	405.6915	9	0
L_PRICE_FR_B	26.28788	7	0.0004	L_PRICE_FR_O	19.53734	3	0.0002	L_PRICE_FR_P	45.30403	9	0
All	59.30553	14	0	All	62.83295	6	0	All	457.8594	18	0
Dependent variable: L_PRICE_FR_B				Dependent variable: L_PRICE_FR_O				Dependent variable: L_PRICE_FR_P			
Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.	Excluded	Chi-sq	df	Prob.
L_PRICE_PT_B	9.00829	7	0.252	L_PRICE_PT_O	3.340557	3	0.342	L_PRICE_PT_P	13.08845	9	0.159
L_PRICE_ES_B	11.189	7	0.131	L_PRICE_ES_O	3.417224	3	0.332	L_PRICE_ES_P	12.94373	9	0.165
All	23.59712	14	0.051	All	4.369107	6	0.627	All	23.0598	18	0.188

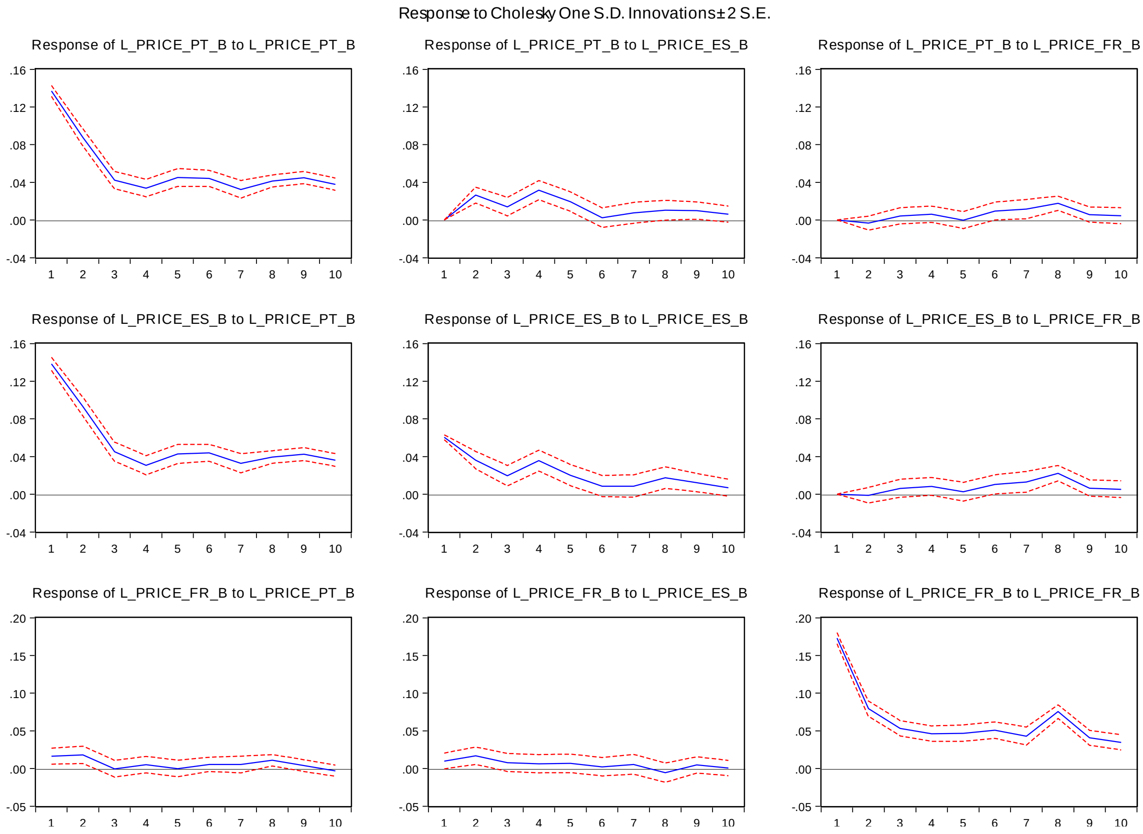

Figure 5 - Impulse response plots for daily-log base price models

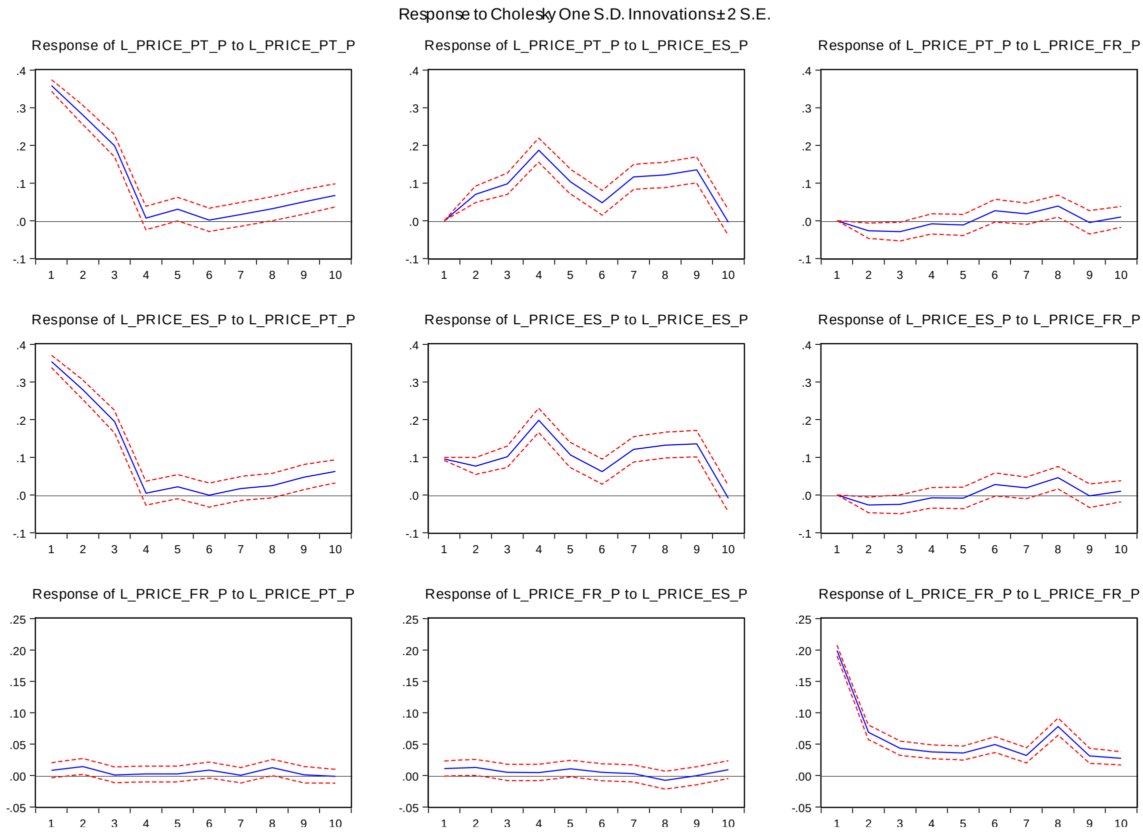

Figure 6 - Impulse response plots for daily-log peak price models

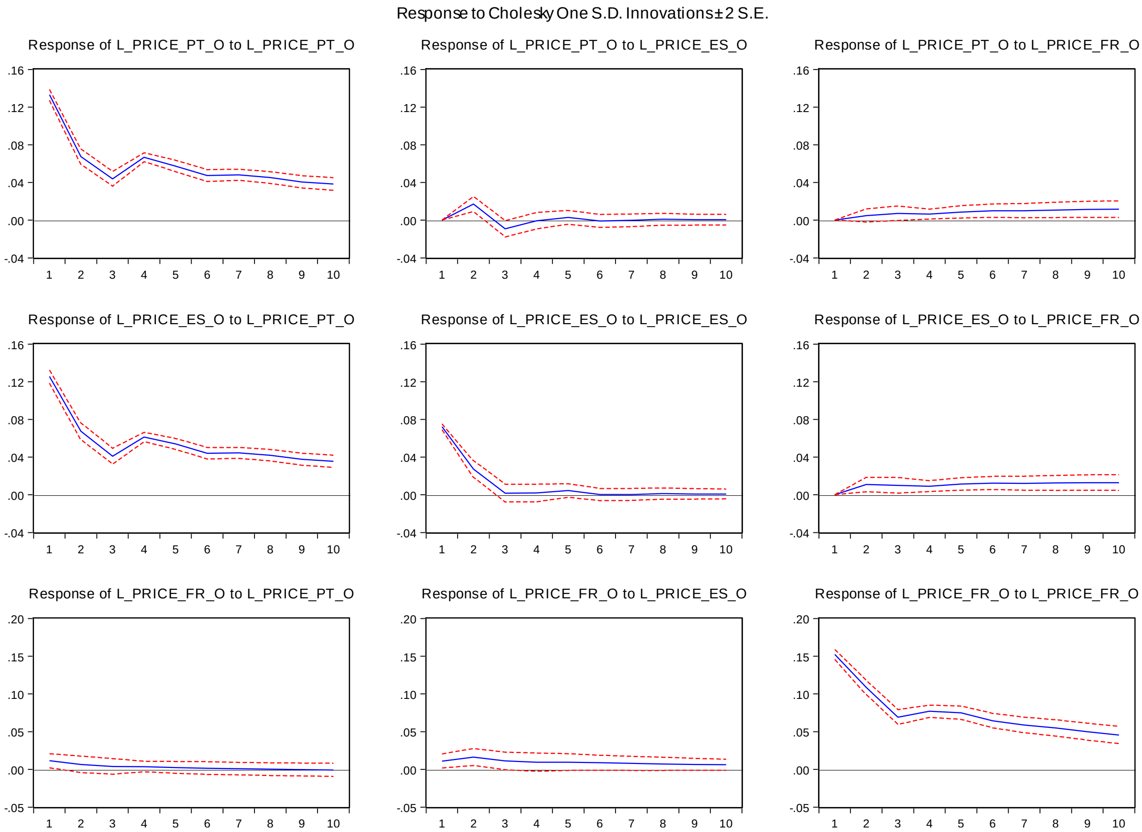

Figure 7 – Impulse response plots for daily-log off-peak price models

Outcomes in Table 5 show that both MIBEL market prices fail to Granger-cause the Powernext market prices on a pairwise relation. This can likewise be observed in the impulse response of the EPEX market prices, which is practically inexistent to a shock in any one of the MIBEL market prices.

In spite the Powernext market prices Granger-cause the MIBEL_ES price in all models, the impulse response analysis indicates a very weak effect. Additionally, there is a Granger-causality relation between Powernext and MIBEL_PT base and peak prices, yet fairly weak as confirmed by the impulse response analysis.

Within Iberia both MIBEL prices Granger-cause each other in all base, peak and off-peak models, which confirms the good integration between both Iberian electricity markets. There is a stronger response of the MIBEL_ES to a shock in the MIBEL_PT in all base, off-peak and peak models, nonetheless this is not case in the response of MIBEL_PT to a shock in MIBEL_ES where the effect is smaller and only felt after two days in the base and peak models. In the off-peak model the response in this case is weak.

5. Final Remarks

The level of integration and some determinants on the South West Europe regional electricity market are evaluated in this study in order to assess the degree of accomplishment of the building of the European Internal market as aimed by the consecutive European Directives.

A future common competitive electricity market is aimed by European policy giving guidance to Member-State policy and statutes. The Electricity Regional Initiative was later on launched along this long process to attain the common electricity market. Simultaneously, the promotion of electricity generation by renewable energy sources was similarly an objective in Europe, reducing the dependency on imported fossil fuels and allowing GHG emissions mitigation. Large deployment of RES-E generation in Europe has been achieved through strong financial support mechanisms.

Results obtained from the model specification herein presented show that the interconnection capacities related exogenous variables do not improve the model, whilst the average temperature contributed to a slight improvement to the model significance. It is to note that the introduction of the exogenous variable average wind speed improves all models specification.

The average wind speed both in Portugal and Spain show a significant negative influence for the Portuguese and Spanish base and off-peak log-daily spot electricity prices. Only the Portuguese average wind speed has significant contribution to the peak log-daily spot electricity price. The average wind speed for Portugal and Spain do not have significant impact in all Powernext base, off-peak or peak log-daily spot electricity prices. This is not the case for the French average wind speed, where there is a significant negative contribution in all Powernext base, off-peak and peak log-daily spot electricity prices.

Strong integration was found between both MIBEL markets, leading to the conclusion that the Price Coupling mechanism is efficient and contributes to the integration of spot electricity markets. Also, as demonstrated by Grange-causality and impulse response analysis, there is a weak integration level between MIBEL and Powernext.

Findings in this article related with the impact of wind generation on interconnected markets are aligned with conclusions reached by several studies, albeit relying on a novel data and modelling approach. Results herein shown, highlight the importance of efficient electricity market design and effective renewable policies in facilitating RES-E penetration as in Klessmann et al. (2008), Milligan et al. (2009), Cruz et al., (2011) or Cutler et al., 2011.

Nevertheless, it is relevant to emphasize that in spite of the fact that the interconnection capacities available do not improve model specification *per se*, these are extremely important to transport the electricity generated by renewable sources and more specifically wind generation. The lack of sufficient interconnection capacity between France and Spain is likely to explain the non-significance of Spanish average wind speed on the French electricity market price. Additional work is currently being pursued to tackle this issue with more depth.

In sum, having the current Internal Energy Market Directive aim as guideline, conclusions found in this study support that coupling and interconnection capacity expansion should be continuously sought between the French and Spanish electricity markets in order to achieve a full functioning South West Electricity regional market.

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Appendix A

Table 6 – VARX model estimation with Wind Speed as exogenous variable

Vector Autoregression Estimates	n	t-stat critical values	Base	Off-peak	Peak
Sample (adjusted): 1/09/2009 12/31/2011	1087	df	1061	1073	1055
Included observations: 1087 after adjustments		0.01	2.580471009	2.58041901	2.580497452
Standard errors in ( ) & t-statistics in [ ]		0.05	1.962202331	1.96217727	1.962215076
		0.1	1.646291053	1.646274963	1.646299235

	L_PRICE_PT_B	L_PRICE_ES_B	L_PRICE_FR_B
L_PRICE_PT_B(-1)	0.197255	0.074397	-0.130011
	-0.07493	-0.08257	-0.09517
	[2.63256]	[0.90106]	[-1.36603]
L_PRICE_PT_B(-2)	0.000433	-0.057803	-0.049415
	-0.07484	-0.08246	-0.09506
	[0.00579]	[-0.70096]	[-0.51985]
L_PRICE_PT_B(-3)	-0.284787	-0.353447	0.03873
	-0.07458	-0.08218	-0.09473
	[-3.81849]	[-4.30078]	[0.40883]
L_PRICE_PT_B(-4)	0.253777	0.264371	-0.024102
	-0.07479	-0.08242	-0.095
	[3.39306]	[3.20778]	[-0.25371]
L_PRICE_PT_B(-5)	0.226733	0.133366	0.055253
	-0.07356	-0.08105	-0.09343
	[3.08241]	[1.64541]	[0.59138]
L_PRICE_PT_B(-7)	0.116649	-0.003822	0.233667
	-0.0737	-0.08121	-0.09362
	[1.58269]	[-0.04706]	[2.49600]
L_PRICE_PT_B(-8)	0.128348	0.127581	-0.092333
	-0.07268	-0.08009	-0.09232
	[1.76584]	[1.59294]	[-1.00011]
L_PRICE_ES_B(-1)	0.44033	0.599825	0.204788
	-0.06888	-0.07589	-0.08748
	[6.39314]	[7.90336]	[2.34084]
L_PRICE_ES_B(-2)	-0.119023	-0.07159	-0.0809
	-0.07002	-0.07716	-0.08894
	[-1.69974]	[-0.92780]	[-0.90956]
L_PRICE_ES_B(-3)	0.397097	0.432175	0.037404
	-0.06962	-0.07671	-0.08843
	[5.70396]	[5.63366]	[0.42299]
L_PRICE_ES_B(-4)	-0.114213	-0.126775	-0.035432
	-0.071	-0.07824	-0.09018
	[-1.60864]	[-1.62042]	[-0.39289]
L_PRICE_ES_B(-5)	-0.210214	-0.113536	-0.01449
	-0.06896	-0.07599	-0.0876
	[-3.04813]	[-1.49401]	[-0.16541]
L_PRICE_ES_B(-7)	-0.000826	0.10482	-0.202927
	-0.06808	-0.07502	-0.08647
	[-0.01213]	[1.39728]	[-2.34669]
L_PRICE_ES_B(-8)	-0.123363	-0.129216	0.046831
	-0.06861	-0.0756	-0.08714
	[-1.79809]	[-1.70921]	[0.53739]
L_PRICE_FR_B(-1)	-0.019575	-0.007044	0.458071
	-0.02153	-0.02372	-0.02735
	[-0.90918]	[-0.29689]	[16.7501]
L_PRICE_FR_B(-2)	0.041151	0.045159	0.096977
	-0.02197	-0.0242	-0.0279
	[1.87345]	[1.86574]	[3.47583]
L_PRICE_FR_B(-3)	0.00086	0.003698	0.075848
	-0.022	-0.02425	-0.02795
	[0.03907]	[0.15250]	[2.71376]
L_PRICE_FR_B(-4)	-0.035533	-0.029297	0.083297
	-0.02204	-0.02429	-0.02799
	[-1.61220]	[-1.20634]	[2.97544]
L_PRICE_FR_B(-5)	0.061332	0.056598	0.081148
	-0.02032	-0.02239	-0.02581
	[3.01834]	[2.52772]	[3.14405]
L_PRICE_FR_B(-7)	0.038459	0.053974	0.22816
	-0.02474	-0.02726	-0.03142
	[1.55454]	[1.97988]	[7.26059]
L_PRICE_FR_B(-8)	-0.063553	-0.082547	-0.16528
	-0.022	-0.02424	-0.02794
	[-2.88883]	[-3.40518]	[-5.91481]
C	0.419749	0.475014	0.492397
	-0.08572	-0.09445	-0.10888
	[4.89686]	[5.02904]	[4.52245]
DW	0.069183	0.05773	0.235424
	-0.01264	-0.01393	-0.01606
	[5.47180]	[4.14366]	[14.6593]
AVG_WS_PT	-0.010247	-0.008051	-0.001554
	-0.00108	-0.00119	-0.00138
	[-9.44969]	[-6.73756]	[-1.12827]
AVG_WS_ES	-0.004601	-0.007633	0.001572
	-0.00122	-0.00134	-0.00155
	[-3.77951]	[-5.69015]	[1.01693]
AVG_WS_FR	-0.001934	-0.002345	-0.004621
	-0.00089	-0.00098	-0.00113
	[-2.17035]	[-2.38759]	[-4.08156]

	L_PRICE_PT_O	L_PRICE_ES_O	L_PRICE_FR_O
L_PRICE_PT_O(-1)	0.285044	0.152914	-0.12274
	-0.05968	-0.06496	-0.06866
	[4.77606]	[2.35413]	[-1.78756]
L_PRICE_PT_O(-2)	0.339183	0.197381	0.013515
	-0.05904	-0.06426	-0.06793
	[5.74486]	[3.07170]	[0.19897]
L_PRICE_PT_O(-3)	0.266235	0.238052	0.010823
	-0.05902	-0.06423	-0.0679
	[4.51093]	[3.70596]	[0.15939]
L_PRICE_ES_O(-1)	0.231528	0.367888	0.116992
	-0.05524	-0.06012	-0.06355
	[4.19152]	[6.11941]	[1.84094]
L_PRICE_ES_O(-2)	-0.28976	-0.165403	-0.013023
	-0.0552	-0.06008	-0.06351
	[-5.24912]	[-2.75307]	[-0.20505]
L_PRICE_ES_O(-3)	0.045736	0.043596	-0.016373
	-0.05507	-0.05994	-0.06336
	[0.83048]	[0.72735]	[-0.25841]
L_PRICE_FR_O(-1)	0.032175	0.071175	0.712779
	-0.02291	-0.02493	-0.02635
	[1.40465]	[2.85496]	[27.0469]
L_PRICE_FR_O(-2)	-0.001142	-0.015993	-0.057956
	-0.02896	-0.03152	-0.03332
	[-0.03942]	[-0.50732]	[-1.73920]
L_PRICE_FR_O(-3)	0.008868	0.01267	0.221329
	-0.02286	-0.02488	-0.0263
	[0.38801]	[0.50932]	[8.41692]
C	0.542884	0.63537	0.437645
	-0.07107	-0.07735	-0.08176
	[7.63883]	[8.21437]	[5.35255]
DW	-0.025327	-0.044338	0.182901
	-0.00912	-0.00992	-0.01049
	[-2.77824]	[-4.46885]	[17.4391]
AVG_WS_PT	-0.008621	-0.007219	-0.001851
	-0.00104	-0.00113	-0.00119
	[-8.30465]	[-6.38922]	[-1.54979]
AVG_WS_ES	-0.006509	-0.010473	0.001221
	-0.00118	-0.00129	-0.00136
	[-5.50621]	[-8.14028]	[0.89786]
AVG_WS_FR	-0.00233	-0.002515	-0.004322
	-0.00086	-0.00094	-0.00099
	[-2.70203]	[-2.68011]	[-4.35716]

	L_PRICE_PT_P	L_PRICE_ES_P	L_PRICE_FR_P
L_PRICE_PT_P(-1)	0.043616	-0.026511	-0.06166
	-0.11699	-0.11952	-0.06499
	[0.37282]	[-0.22181]	[-0.94882]
L_PRICE_PT_P(-2)	-0.460242	-0.501878	-0.001798
	-0.1165	-0.11902	-0.06472
	[-3.95046]	[-4.21660]	[-0.02779]
L_PRICE_PT_P(-3)	-1.478284	-1.593322	0.010688
	-0.11566	-0.11817	-0.06425
	[-12.7810]	[-13.4838]	[0.16635]
L_PRICE_PT_P(-4)	0.713462	0.670618	-0.018185
	-0.12552	-0.12824	-0.06973
	[5.68397]	[5.22949]	[-0.26080]
L_PRICE_PT_P(-5)	0.128477	-0.028319	-0.003356
	-0.12631	-0.12905	-0.07017
	[1.01713]	[-0.21945]	[-0.04783]
L_PRICE_PT_P(-6)	-1.066352	-1.082513	0.030236
	-0.12647	-0.1292	-0.07025
	[-8.43195]	[-8.37845]	[0.43040]
L_PRICE_PT_P(-7)	0.243424	0.103288	0.220023
	-0.1306	-0.13343	-0.07255
	[1.86389]	[0.77412]	[3.03285]
L_PRICE_PT_P(-8)	-0.166639	-0.126761	-0.008589
	-0.13206	-0.13491	-0.07336
	[-1.26188]	[-0.93958]	[-0.11709]
L_PRICE_PT_P(-9)	1.051355	1.104893	-0.110498
	-0.12678	-0.12952	-0.07042
	[8.29276]	[8.53047]	[-1.56903]
L_PRICE_ES_P(-1)	0.751122	0.81767	0.094989
	-0.1144	-0.11688	-0.06355
	[6.56549]	[6.99581]	[1.49471]
L_PRICE_ES_P(-2)	0.407913	0.44044	-0.038143
	-0.11627	-0.11878	-0.06458
	[3.50840]	[3.70794]	[-0.59058]
L_PRICE_ES_P(-3)	1.123109	1.242409	0.003153
	-0.11581	-0.11831	-0.06433
	[9.69810]	[10.5010]	[0.04901]
L_PRICE_ES_P(-4)	-0.326751	-0.305469	0.029108
	-0.12148	-0.12411	-0.06748
	[-2.68977]	[-2.46132]	[0.43136]
L_PRICE_ES_P(-5)	-0.264607	-0.095163	0.002269
	-0.12093	-0.12355	-0.06718
	[-2.18802]	[-0.77023]	[0.03378]
L_PRICE_ES_P(-6)	1.041168	1.065316	-0.045985
	-0.12237	-0.12501	-0.06797
	[8.50862]	[8.52158]	[-0.67652]
L_PRICE_ES_P(-7)	-0.045623	0.066862	-0.186935
	-0.12482	-0.12752	-0.06933
	[-0.36551]	[0.52433]	[-2.69611]
L_PRICE_ES_P(-8)	0.098176	0.074138	-0.028967
	-0.12578	-0.1285	-0.06987
	[0.78057]	[0.57697]	[-0.41461]
L_PRICE_ES_P(-9)	-0.998338	-1.05628	0.113486
	-0.12462	-0.12732	-0.06923
	[-8.01086]	[-8.29629]	[1.63934]
L_PRICE_FR_P(-1)	-0.134398	-0.13258	0.345973
	-0.05058	-0.05168	-0.0281
	[-2.65701]	[-2.56556]	[12.3132]
L_PRICE_FR_P(-2)	0.00766	0.025084	0.102518
	-0.05284	-0.05398	-0.02935
	[0.14498]	[0.46469]	[3.49291]
L_PRICE_FR_P(-3)	0.077319	0.072224	0.076404
	-0.0469	-0.04791	-0.02605
	[1.64867]	[1.50742]	[2.93288]
L_PRICE_FR_P(-4)	-0.095042	-0.08193	0.063048
	-0.04673	-0.04774	-0.02596
	[-2.03386]	[-1.71613]	[2.42888]
L_PRICE_FR_P(-5)	0.182075	0.173338	0.129235
	-0.04967	-0.05074	-0.02759
	[3.66604]	[3.41621]	[4.68440]
L_PRICE_FR_P(-6)	-0.029689	-0.033539	-0.021816
	-0.04764	-0.04867	-0.02646
	[-0.62317]	[-0.68907]	[-0.82437]
L_PRICE_FR_P(-7)	0.077768	0.109164	0.26542
	-0.05653	-0.05775	-0.0314
	[1.37579]	[1.89029]	[8.45293]
L_PRICE_FR_P(-8)	-0.136786	-0.145315	-0.141637
	-0.0533	-0.05445	-0.02961
	[-2.56626]	[-2.66854]	[-4.78370]
L_PRICE_FR_P(-9)	0.079149	0.062303	-0.004152
	-0.05101	-0.05211	-0.02833
	[1.55173]	[1.19560]	[-0.14655]
C	0.796628	0.834987	0.587368
	-0.23505	-0.24014	-0.13057
	[3.38915]	[3.47711]	[4.49855]
DW	0.152926	0.149531	0.303955
	-0.03807	-0.0389	-0.02115
	[4.01679]	[3.84442]	[14.3725]
AVG_WS_PT	-0.011217	-0.008572	-0.000821
	-0.00282	-0.00288	-0.00157
	[-3.97581]	[-2.97418]	[-0.52420]
AVG_WS_ES	-0.00336	-0.006882	0.000946
	-0.00314	-0.00321	-0.00174
	[-1.07113]	[-2.14725]	[0.54270]
AVG_WS_FR	-0.003604	-0.004558	-0.004736
	-0.00232	-0.00237	-0.00129
	[-1.55216]	[-1.92111]	[-3.67120]

DAY 10 - 11:30		
Room 626 - Technological Change and the Environment 2		
Preparation and Characterization of LaCoO3 Using in Purify Pollutant for Example in Gas Refinery	H.Haghparast[1]	[1]4TH refinery south pars gas complex
Environmental and Socio-Economic impact assessment of the production of kenaf (HIBISCUS CANNABINUS L.) when irrigated with treated waste waters	Bruno Barbosa[1]; Ana Fernando[1]; Benilde Mendes[1]	[1]New University of Lisbon
Electro-coagulation of raw water in batch using aluminium and iron electrodes	BELHOUT Dalila[1]	[1]National Polytechnic School, Algiers, Algeria
Pollution Offshoring: Myth or Reality? Evidence from the United States and the European Union	Claire Brunel[1]	[1]Georgetown University

Preparation and Characterization of $LaCoO_3$ Using in Purify Pollutant

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Abstract

The aim of this research work was to prepare the efficient catalyst to purify pollutant output gases such as SO_2, NO_2 and CO .This catalyst ,lanthanum cobaltat (LaCoO3) was prepared by the proper method in the analysis laboratory of Tabriz Oil .The first materials were chosen through calcination operation and the temperatures of operation related to the Tamman temperature, therefore the basis for the first material of catalyst was nitrate and aqueous and since we had no availability to lanthanum nitrate, lanthanum oxide was used to prepare the nitrate one. Before all else, the first materials of catalyst were mixed together with the equal mole proportions and then, at the lower and upper temperatures of Tamman temperature, calcination operation was performed. To determine the molecular structure, the XRD analysis was utilized and specified that prepared lanthanum cobaltat was sixth aqueous and had the crystal structure type Triclinic.

Keywords: Catalyst preparation, XRD analysis, Tamman temperature, Calcination operation

1. Introduction

$LaCoO_3$ has presented a vast interest because of its special electrical, magnetic and catalytic properties [1-4]. The catalyst $LaCoO_3$ can be prepared by means of several methods such as spray drying, freeze drying and also co-precipitation [5-12]. Some methods including hydrothermal, sol gel and citrate [13] This material usually has been synthesized by ceramic method and certainly the high temperature for the calcination operation. [14]. Lanthanum catalysts have been researched because of having such an active state [15] . One of the unique properties of this catalyst is the simultaneous conversion of pollutant elements. Nowadays CO oxidation has important applications in environment protection, such as indoor air cleaning and automotive exhaust treatment. LaCoO3 is one of the most important catalysts for CO oxidation. It has been reported that the properties of the catalyst could be improved effectively by controlling its morphology [16-17]. There are a lot of applicable properties show the significance of catalyst LaCoO3 [17-21]. According to these useful properties, we tried to prepare this catalyst by the method described below. XRD analysis was utilized to characterize the prepared catalyst.

2. Experimental

Catalyst preparation:

To some briefly, the preparation of catalyst carried out in the following step: a) preparing lanthanum nitrate ($La(NO_3)_3.6H_2O$) from the reaction of nitric acid with La_2O_3; b) crystallization; c) drying of the crystals ($La(NO_3)_3.O$); d) Milling; e) preparing the mixed catalyst and adding cobalt nitrate ($Co(NO_3)_3.6H_2O$); f) two different calcination operations at two different temperatures.

At first, by mixing proper chemical compounds, structure of final catalyst would be obtained. Precursor, in microscopic scale has sufficient tissue for ultimate catalyst. To prepare the precursor, the first materials of catalyst $LaCoO_3$, lanthanum nitrate (La $(\mathrm{NO_3})_3.6\mathrm{H_2}$O) and cobalt nitrate (CO $(\mathrm{NO_3})_2.6\mathrm{H_2}$O) were used. The reasons of using aqueous and nitrate states of lanthanum and cobalt for preparing precursor were the elimination of water molecules and oxidation of nitrate ions ($\mathrm{NO_3}^-$) in the solid analysis stage through the calcination operation and finally making pores in the bulk of catalyst. The used lanthanum nitrate in this project was obtained through the reaction of nitric acid solution with weight fraction 0.7 and purity percent 99.9% and lanthanum oxide with purity percent 99.99%. To make sure about happening perfect reaction between nitric acid and lanthanum oxide, nitric acid was used 20 percent more than the stoichiometric value. The reaction of preparing lanthanum nitrate was:

$La_2O_3+6HNO_3 \rightarrow 2La(NO_3)_3+3H_2O$

For the next step, separating lanthanum nitrate from the solution, the crystallization operation was performed, for this purpose we used evaporation and supersaturating methods. So the solution of reaction was heated for 4-5 weeks slowly until separation of lanthanum nitrate by evaporation and supersaturating methods. Then the prepared crystal was put in the strainer at 100-120 °C for 12 h till separation of the unbonded water. After drying of the lanthanum nitrate, it was milled in the miller type" Ball Mill" until preparing the 300 meshed particles. For preparing the first mixture of LaCoO3 catalyst, after milling, the aqueous cobalt nitrate (CO $(NO_3)_2.6H_2O$) with the purity percent 0.99 was mixed with aqueous lanthanum nitrate (La $(NO_3)_3.6H_2O$) with the same mole proportions and consequently the next operation would be begun.

Calcination operation:

The desirable aims for calcination operation can be, obtaining the specific structure for active agents or catalyst-based; simultaneous controlling of tissue, surface and porous volume and achieving proper mechanical resistance.

For calcination operation comprehensive investigations were executed about the optimum temperature, and finally the desirable temperature for the calcination operation were chosen by measuring the Tamman temperature. Among the assumptions we had, the plasticity of tissue and catalyst′ s structure was happened by mass transfer phenomena in or on the surface of particle or passing through the gas film. These transfers were the driving force for sintering and important around the Tamman temperature. As it is known the Tamman temperature is equal to half of solid melting absolute temperature [22]. For measuring the Tamman temperature, cobalt nitrate (CO $(NO_3)_2.6H_2O$) and lanthanum nitrate (La $(NO_3)_3.6H_2O$) were mixed in the ceramic crucible and heated in the electric furnace. The melting point of catalyst mixture was determined 1900 °C and therefore Tamman temperature was obtained about 813 °C.

3. Results and discussion

After obtaining the Tamman temperature, the calcination operation was performed in two separable steps and two temperatures more and less than Tamman temperature in about the same range. The first calcination operation was done at 750° C and the second at 850 °C. Hence, three separate samples of catalyst mixture were transferred to the ceramic crucible after accurate weighing and calcination operation was executed in the electric furnace. Choosing of three mixtures with the same compositions was for eliminating probable errors through the experiments and the same operation was performed to all of these samples. Thorough the calcination operation, the weight of samples dwindled, and it was because of losing the bonded water molecules and the nitrogen of nitrate ions oxidation $(NO_3)^-$. The Data and Experimental Results of Preparing $(La(NO_3)_3.6H_2O$ and Catalyst $LaCoO_3$ are summarized in table 1.

Table 1. The Data and Experimental Results of Preparing of Catalyst $LaCoO_3$

Consumed/obtained material	Sample 1	Sample 2	Sample 3
La_2O_3 (gr)	25	25	25
Nitric acid (ml)	36	36	36
distillate water (ml)	120	120	120
$(La(NO_3)_3.6H_2O$ (gr)	9.39	7.05	4.77
$(Co(NO_3)_2.6H_2O$ (gr)	10.66	8.00	5.33
Obtained fresh $LaCoO_3$ (gr)	7.50	5.50	3.70
Proportion of catalyst (%)	37.0	37.0	37.0

The XRD analysis was employed to test the prepared lanthanum nitrate and the result showed that product was aqueous lanthanum nitrate type $(La(NO_3)_3.6H_2O$. As we compared the figures we simply realized that the prepared catalyst had the Triclinic structure. The figure of lanthanum nitrate obtained from the XRD analysis was shown by figure 1.

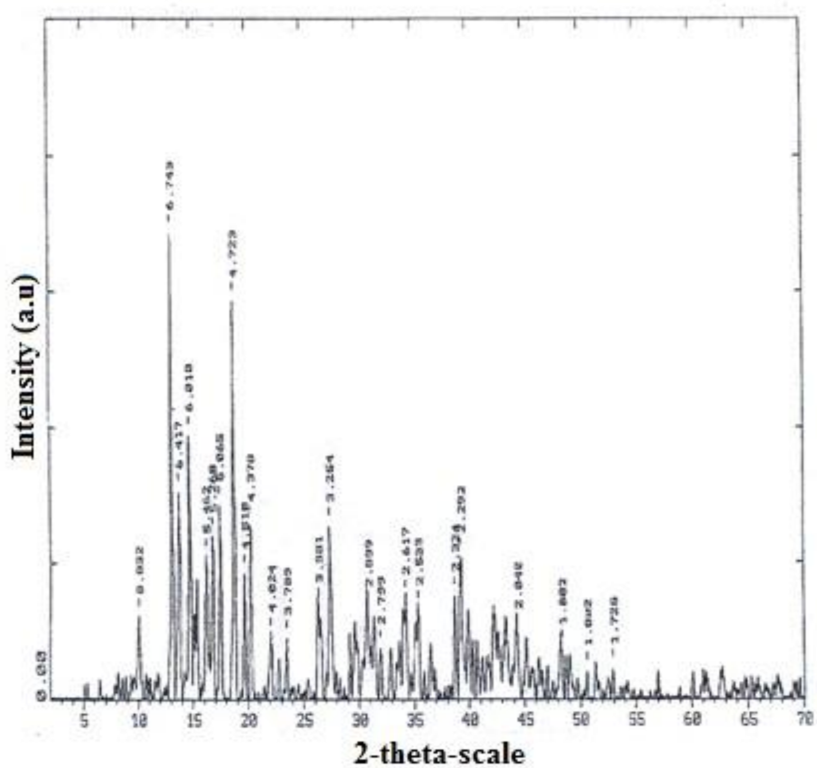

Figure 1. XRD pattern of lanthanum nitrate $(La(NO_3)_3)$

The data and experimental results were given. As we see, the proportion of weight loss for calcinated catalyst to the first mixture was about 0.37 that determined the preparing of LaCoO3 catalyst. To confirm this theory, some of the prepared catalyst was analyzed with XRD test after milling so that we could simply recognize the prepared catalyst ′s structure. The XRD pattern showed that the prepared catalyst had the molecule structure of $LaCoO_3$ and also had the high crystallinity. These properties demonstrated that this operation was efficient and proper for preparing the catalyst.

After the calcination operation, the process of preparing catalyst completed and the catalyst could be used after reduction. The XRD pattern of the prepared catalyst was given by figure 2:

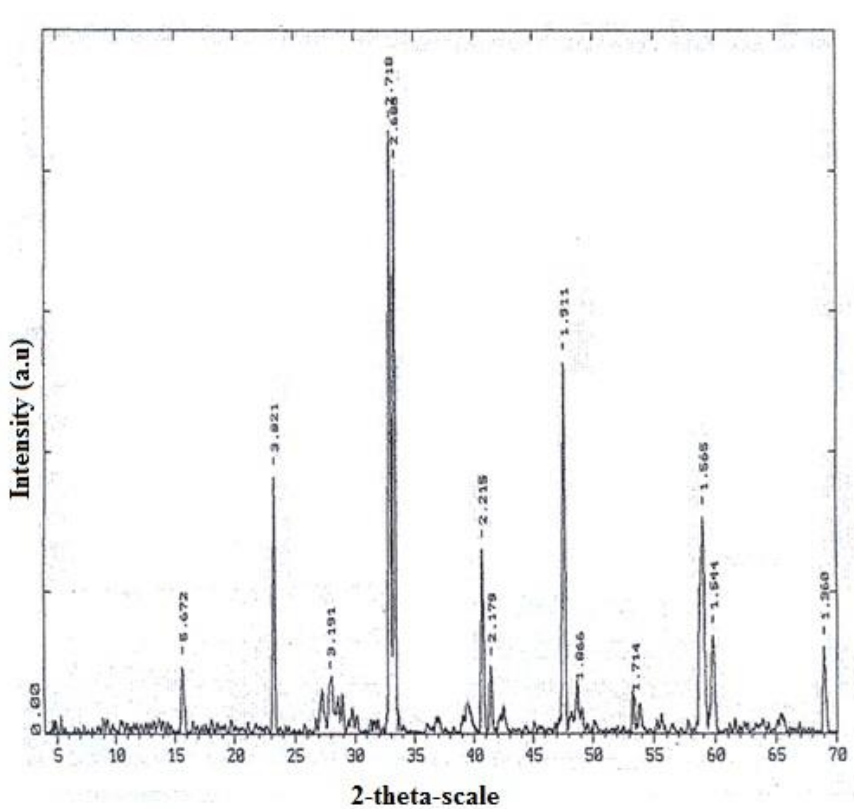

Figure 2. XRD pattern of the prepared catalyst

4. Conclusions

This project concentrated on preparing the efficient catalyst to purify pollutant output gases from “incinerator” furnace .The prepared catalyst could be able to convert the gas elements SO_2, NO_2 and CO with the proper reductive gases such as NH_3 , CO and H_2 to the inactive mixtures of sulfur, nitrogen and carbon dioxide. The active materials for catalytic converter consisting of $LaCoO_3$ were prepared by means of a systematic method in the laboratory. By choosing right chemical materials and series of unit operations, preparing the desirable catalyst that could have ability to eliminate the output pollutant gases, would be done. To confirm the molecular structure, XRD test was done. The result of test showed that the prepared catalyst was $LaCoO_3$ and had crystal structure. The calcination temperature was obtained, based on Tamman temperature. With respect to XRD analysis, it was determined that using Tamman temperature was proper for calcination operation and catalyst ′s character satisfied our aims.

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Environmental and socio-economic impact assessment of the production of kenaf (Hibiscus Cannabinus L.) when irrigated with treated wastewaters

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Abstract

The introduction of drought tolerant crops, with high efficiencies in the use of resources like water and nutrients, can promote the creation of crop rotation systems more resilient, adding economic value and social benefits to regions like the Mediterranean. The reuse of treated wastewaters and their load in their irrigation could be a strategy to minimize freshwater abstraction and energy consumption in the treatment of these sources of waters. Kenaf is an energy crop, suitable for the production of high quality cellulose that can be grown on soils of poor quality as degraded soils and irrigated with domestic treated wastewater. The crop is able for combating desertification, thanks to its high efficiencies in the use of resources and also to its strong and deep root system that promotes the control of runoff and erosion, and also aeration and increasing organic matter in the soil. We test the irrigation of kenaf using treated wastewaters containing different concentrations of ammonium ion (0, 15, 30, 60 mg dm^{-3} NH4) and also the effect of the presence/ absence of NPK fertilization (in pots). The plant was shown specificity on the wastewater phytodepuration, especially at 15 mg dm^{-3} (NH4), being capable to incorporate biomass at an average rate of 15 g day^{-1} m^{-2}, and biomass with commercial value, producing high quality fiber for cellulose and paper purposes, with low water and nitrogen consumption, in a short time period (90 days) and with low energy and production costs. The crop simultaneously controls the leaching of ammonium ion and other compounds that could contaminate groundwater and contribute to accelerate desertification and salinization processes in soils. Projects that merge the treatment of water resources containing ammonium ion up to 60 mg dm^{-3} NH4 with the production of kenaf biomass, which presents good quality and promotes the restoration of some soil properties/ economic valorization of degraded soils, should be implemented as a strategy for minimize energy consumption in tertiary treatment in the wastewater treatment plants, for reduce freshwater and fertilizers consumption in its implementation, for combating desertification and restore fertility and other soil properties, and to reduce the costs of importing fiber for the textile industry. In this framework, these thematic are modeled and discussed for Portugal.

Keywords: Kenaf; wastewater irrigation; environmental impact; energy balance; nutrient balance; social impacts.

Electro-coagulation of raw water in batch using aluminium and iron electrodes

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Abstract

Laboratory experiments were carried out to investigate electro-coagulation (EC) of water in batch using aluminium and iron electrodes without addition of chemicals, without pH modification, and without agitation. The optimal conditions are an applied voltage of direct current of 8 V and a current density 74 A m^{-2} (0.35 A) during 45 min for both electrodes.

The microbial pollution is completely removed by essentially electrical field whereas conductivity and turbidity are reduced at 27 and 85% respectively for Fe electrodes and 22 and 97% for Al electrodes by metallic cations. These results prove that water treatment by EC using Al electrodes (flotation) for low turbid water (7 NTU) is more convenient than Fe electrodes (sedimentation) for both turbidity and organic matter removal. A new parameter to be taken in consideration for EC reactor design the ratio r active volume on reactor volume which is full of water is introduced where the active volume is the active surface multiplied by the distance between the electrodes.

Keywords: Surface water; Drinking water; Electro-coagulation; Iron; Aluminium

Pollution Offshoring: Myth or Reality?

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Abstract

This paper determines whether US patterns of pollution intensity of manufacturing production and imports can be observed in other developed economies, by providing the first detailed investigation of the European Union. The results show that in the 1990s, US and EU manufacturing production increasingly specialized in clean goods – a "green" shift. However, in the 2000s the trend reversed as both regions experienced "brown" shift. Still, the shifts in composition were small, especially for the United States; the cleanups of US and EU manufacturing were overwhelmingly driven by improvements in technology. The most important difference between the United States and the European Union lies in the role trade played in the cleanup of manufacturing production. In the European Union, accounting for net imports would have reduced the brown shift of production. Since EU imports were simultaneously becoming less pollution intensive, there is little evidence of pollution offshoring from the European Union. On the other hand, the brown shift of US manufacturing production would have been larger if not for imports of polluting goods. Combined with a study of the composition of imports by trading partner, this suggests the United States might be offshoring pollution to lower-middle income countries.

JEL codes: D57, F18, Q55, Q56

Keywords: Input output table, Trade and environment, Environmental account and accounting, Technological innovation

1. Introduction

US manufacturing production rose 12 percent between 1995 and 2005, but emissions of sulfur dioxide from manufacturing fell 45 percent. Over the same time period, manufacturing production in the 15 core countries of the European Union grew 35 percent, while emissions of sulfur dioxide from manufacturing decreased 55 percent. One would expect emissions to rise as a result of the increase in output, yet both manufacturing sectors cleaned up their production. There are three potential sources for this cleanup. On the one hand, technological progress, be it in the form of cleaner fuels, better energy efficiency or end-of-pipe pollution abatement, could have led to cleaner production processes. Another possibility is that US and EU consumer demand could have switched to cleaner goods. Or changing patterns of international trade could have resulted in pollution offshoring: the United States and the European Union could have specialized in the production of cleaner goods at home, while importing the more pollution-intensive manufacturing goods from abroad.

This paper identifies which of the technology, demand, or trade channels was primarily responsible for the cleanup of the US and EU manufacturing sectors between 1995 and 2005. It also identifies how those channels differed between the two regions and how they evolved over time. The results show that the composition effect did not play a large role in the cleanup of either manufacturing sectors. Both regions initially specialized in the production of clean goods – a "green" shift. Starting in 2002, however, the European Union produced a dirtier composition of manufacturing goods – a "brown" shift –, and the same pattern began to emerge in the United States in 2004-2005. Still, those compositional changes were small, especially in the United States. Improvements in technique played an overwhelming role in the cleanup of US and EU manufacturing.

However, trade played a different role in the composition of US and EU manufacturing sectors. Both regions imported a mix of goods which on aggregate became cleaner faster than domestic manufacturing production. Dividing trading partners into income groups, however, shows that lower-middle income country imports into the United States were becoming increasingly pollution intensive between 1995 and 2005. Moreover, adding net imports to domestic production would have increased the brown shift of US manufacturing composition by about a third. Those facts combined suggest evidence of pollution offshoring from the United States to lower-middle income countries. By contrast, evidence of pollution offshoring from the European Union is limited to only a few products. Accounting for net imports would have reduced the brown shift of EU manufacturing composition by a third. EU demand was cleaner than EU production, and a portion of the brown shift of EU production can be accounted for by exports of increasingly dirty EU goods.

Identifying which of the channels is more prominent can help the European Union and the United States develop policies for a continued cleanup of the manufacturing sector or other sectors, and can provide interesting lessons for countries who might want to emulate the cleanup. Indeed, if the trade channel is significant, then the implementation of policies to counteract the effects of pollution offshoring might be justified. If the demand channel dominates, then cleaning up a sector or an economy involves raising environmental awareness in society. While if the result is driven by changes in technique, emulating the EU or US manufacturing cleanup in another sector or another country would entail policies to promote research and development in pollution abatement technologies.

To date, most of the empirical literature on pollution offshoring has focused on the United States before the year 2000. Levinson (2009) finds that, from 1987 to 2001, 90 percent of the US manufacturing cleanup was due to improvements in technique, and 10 percent to a green shift of production, of which no more than half could be accounted for by an increase in net imports. Two questions arise. First, are those results robust through the more recent decade? While the 1990s was a decade of economic expansion, the early 2000s were characterized by a slow-down of economic activity. This shift could have been reflected in changing trends of industrial specialization and household consumption. Therefore, this paper begins by updating the US results to include the 2000s.

Second, are patterns in other developed economies the same as in the United States? To inform the debate about the external validity of the US results, I develop the first detailed analysis of the pollution intensity of EU production and imports. A study of the European Union is particularly interesting because, like the United States, it has been a front runner in the design and implementation of environmental policies. As a result, questions about the impact of those policies on competitiveness feature prominently in environmental policy debates.

I replicate the methodology developed in Levinson (2009) to determine whether US and EU manufacturing production and imports have been getting more or less pollution intensive. The key to this method lies in the creation of an index of pollution intensity for a detailed decomposition of industries. Using the index developed by Levinson for US manufacturing, I update the US results to cover the period from 1995 to 2005. I then replicate the analysis for the European Union between 1995 and 2010. Ideally, one would construct the EU index using EU data on emissions, industry structure and industry composition. Unfortunately, those data are not available but this paper proposes a reasonable proxy. It constructs a pollution intensity measure for 350 industries in the EU manufacturing sector using US emissions inventory, US input-output tables, and EU industry composition.

2. Decomposition of manufacturing emissions

2.1. Method and Data

The analysis in this paper follows Levinson (2009). The total amount of pollution from EU manufacturing (P) can be written as:

$$P = \sum_i p_i = \sum_i v_i * z_i = V \sum_i z_i * \theta_i \qquad (1)$$

where i=1,…, n indexes manufacturing industries. V is total manufacturing output, z_i is the amount of pollution per dollar of value shipped in that industry ($z_i = p_i/v_i$), and θ_i is the industry's share of total output (v_i/V). In vector form, equation (1) becomes:

$$P = V\boldsymbol{z}\,\boldsymbol{\theta} \qquad (2)$$

Totally differentiating equation (2), one can identify the three sources of a change in emissions

$$dP = \boldsymbol{\theta}'\boldsymbol{z}dV + V\boldsymbol{z}'d\boldsymbol{\theta} + V\boldsymbol{\theta}'d\boldsymbol{z} \qquad (3)$$

The first term is the "scale effect", which measures how emissions should increase as a result of an increase in production V. The second term is the "composition effect", which captures whether the structure of production (**θ**) has switched towards cleaner goods. And the third term is the "technique effect", which assesses the impact of changes in pollution intensity (**z**).

Isolating the sources of changes in emissions requires data on pollution levels P, manufacturing output V, and emission intensities z. For the United States, the same sources are used as in Levinson (2009). The National Emissions Inventory (NEI) provides data on total manufacturing pollution in terms of sulfur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO) and volatile organic compounds (VOCs). Data on US manufacturing are taken from the NBER Manufacturing Productivity Database compiled by Eric J. Bartelsman and Wayne B. Gray (1996). The pollution intensity indices are created using the World Bank IPPS data for 1987 (Hettige et al. (1995)), which list pollution levels by 4-digit SIC codes for 1987 for the same four air pollutants. Due to data limitations for the European Union, carbon monoxide is excluded; the analysis in this paper looks at SO2, NO2 and VOCs. The pollution coefficients can only be calculated for 1987, so it is not possible to have a measure of changes in pollution intensity. The technique effect is thus calculated as the difference between actual pollution and the pollution predicted by the scale and composition effects.

For the European Union, the Environmental Database of Eurostat provides data on total EU manufacturing emissions. EU manufacturing data are available from Eurostat and are classified using the Nomenclature Générale des Activités Economiques de la Communauté Européenne (NACE rev 2). With the use of concordances provided by Eurostat and the US Census Bureau, NACE rev 2 can be converted into US SIC 1987 classification.

EU emissions data are available from the European Pollution Emissions Register (EPER) for 2001 and 2004. However, this database divides the manufacturing sector in just 14 industries while my calculations require a fine breakdown of the EU economy. Indeed, a high level of aggregation is problematic for two reasons. First, a sector is comprised of a variety of industries and products, some of which might be highly pollution-intensive even if the sector appears clean on average. For example, SIC sector 35, "industrial and commercial machinery and computer equipment" is relatively clean. However, industry 3592, "carburetors, new and rebuilt", is a polluting industry. Therefore, using a rough division of economic activities will hide some important pollution variations within sectors. Moreover, the high level of aggregation could overstate the role of technique as within-sector compositional changes would be recorded as technique.

Starting in 2007, EU emissions data are available at the four digit level, however the data pose some issues with regards to coverage of facilities and timing. Facilities below a certain threshold – which varies by industry – are not required to report emissions, which results in spotty data. For SO2 emissions, more than 80 percent of EU manufacturing industries do not report data. In contrast, in the US data only about 35 percent of manufacturing industries report zero or missing data for SO2 emissions. Moreover, examining EU production patterns between 1995 and 2005 using 2007 technology presents a different kind of problem. As technology improves over time, the range of pollution intensity narrows and there is less room for reducing pollution by switching production to less polluting goods. Therefore, using 2007 technology would understate compositional changes and overstate the role of technique in the cleanup on manufacturing. Since compositional changes account for a small part of the cleanup, I choose to run the analysis with earlier technology so as to not understate an already small effect.

For all these reasons, I construct the EU pollution indices using US technology based on World Bank IPPS data for 1987. While the level of emissions differs between the United States and the European Union, the relative rankings of polluting industries using EU or US emissions are highly correlated. For example, using aggregated data with 14 manufacturing industries, the rankings of EU and US emissions have a correlation of 0.83. Using data at the four digit level, over those industries that report emissions for the European Union, the correlation is 0.7. Therefore, the most highly polluting industries are generally the same in Europe and the United States. Since I study the evolution of the pollution intensity of production and imports over time, I am concerned with the relative rather than the absolute level of emissions. Therefore, the analysis considers pollution patterns in EU manufacturing production using US technology in 1987.

All the data are adjusted for inflation using industry by industry producer price indices (PPI), from Eurostat for EU data and from the NBER Manufacturing Productivity Database for US data. A preliminary analysis was done deflating by a single manufacturing wide measure of PPI. However, energy prices were far from stable in the 2000s and so it is important to consider how energy prices affect each industry depending on the industry's energy intensity. If the price of oil increases, the value of output per unit of emission will increase, everything else held constant. This leads to an overestimation of the scale effect, and therefore of the role of technology.

On the other hand, using industry specific PPI can generate issues with regards to the computer and electronics industry. The price index of those sectors has decreased significantly since 1995, dropping as low as 32 and 6 in 2005 from a baseline of 100 in 1995 in the European Union and the United States, respectively. But for this sector the rapid drop in prices captured by the PPI is a result of technological change rather than an estimate of inflation. Adjusting value shipped and trade flows of computers and electronics by industry specific PPI therefore overstates the weight of this industry in total output and predicted pollution, and understates the role of technique. The EU results presented below and the US results from Levinson (2009) are not altered by the removal of the computers and electronics industry from the analysis. But the computers and electronics industries do pose another problem for the comparison between Levinson (2009) and the update of the US results provided in this paper. Levinson (2009) uses preliminary estimates of industry specific PPI between 1997 and 2001. In the case of the computer and electronics industries, the preliminary estimates differ significantly from the final estimates used in the update, which render the comparison difficult. Consequently, the computers and electronics industries are excluded from the results exposed in this paper.

As explained in Levinson (2009), another potential concern regards purchases of electricity. If manufacturing firms were increasingly purchasing electricity from utility firms rather than generating their own, emissions from the manufacturing industry would have decreased. In the framework of this paper, that drop would have been erroneously attributed to the technique effect. It is therefore important to check that purchases of electricity as a share of electricity consumption remained stable. These data are not readily available at the EU level. However, in France, purchases of electricity as a share of electricity consumption remained relatively stable for the manufacturing sector, between 93 and 96 percent from 1996 to 2010 (INSEE 1996, 2010). The same figure for the United Kingdom went from 89 percent in 1996 to 91 percent in 2010 (UK DECC 2011). In Germany, the quantity of electricity produced as a share of consumption for manufacturing and mining went from 22 percent to 23 percent between 2002 and 2009 (Destatis 2002, 2009, AGEB 2002, 2009). Overall, those numbers indicate it is reasonable to assume that manufacturing sector auto-generation of electricity as a share of total electricity consumption was stable in the European Union. Similarly, in the United States, purchases of electricity as a share of net demand of electricity in the manufacturing sector were 87 percent in 1998 and 86 percent in 2006 (US EIA 2006).

Due to data restrictions from the NBER Manufacturing Productivity Database, the US analysis can only be executed through 2005. On the other hand, EU manufacturing data is not available before 1995 at the level of detail necessary for the computations. For comparative purposes, the analysis is therefore limited to the ten years between 1995 and 2005. The patterns observed in the European Union between 2005 and 2010 will be discussed where relevant.

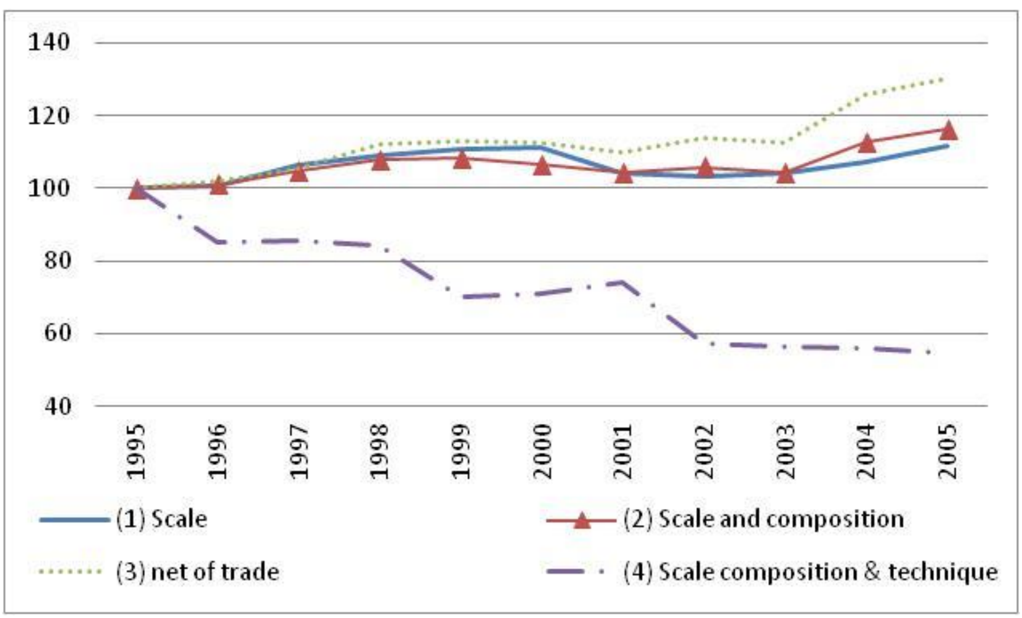
The period after 1995 is a time during which the European Union expanded its membership. To avoid issues related to enlargement of the European Union, the study is restricted to the 15 core countries of the European Union: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom. It is also a time during which EU environmental regulation became significantly more stringent, making the analysis particularly relevant.

2.2. Results

US and EU manufacturing productions essentially followed the same patterns from 1995 to 2005. Note that the exposition below differs from the one found in Levinson (2009) in that all graphs in this paper are indexed at 100 in 1995, whereas Levinson uses 1987 as the baseline. The graphs and discussion focus on SO2 for simplicity, but the tables include the results for all three pollutants (the results are also summed over all three pollutants as an indication, though the sum of a ton of SO2 with a ton a NO2 does not have an obvious interpretation).

Figure 1 presents the decomposition of the scale, composition, and technique effects for US manufacturing emissions of SO2, adjusted for industry specific inflation. Line (1) embodies the scale effect. It is the amount of emissions that would have been emitted from US manufacturing had the composition and technique of production remained constant through time. Since real US manufacturing increased 12 percent between 1995 and 2005, the scale effect predicts that emissions should similarly have increased by 12 percent. Line (4) represents actual emissions of SO2 from US manufacturing, which decreased 45 percent in the United States between 1995 and 1999. The difference between the scale effect and actual emissions is the total cleanup from manufacturing.

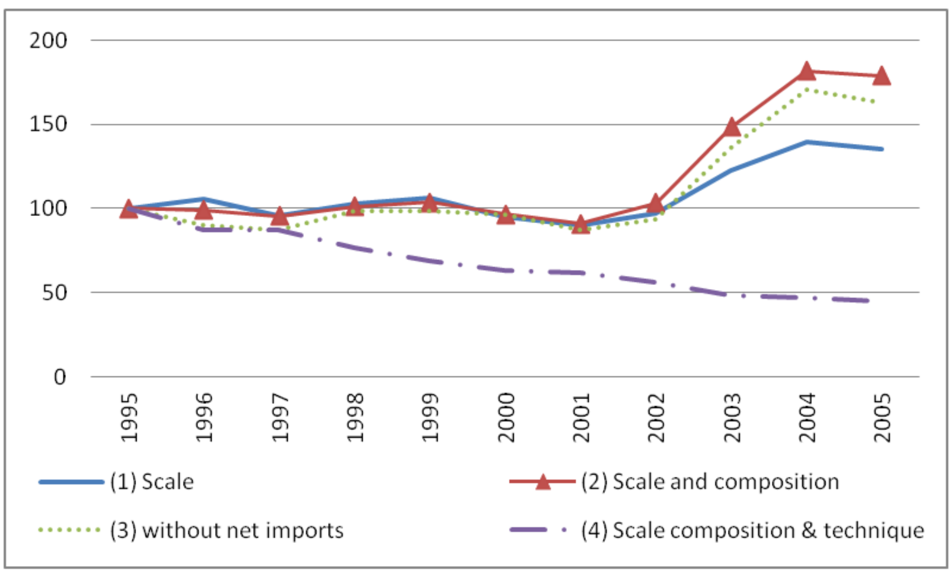
Figure 1. SO2 Emissions from US manufacturing, 1995-2005



Source: Author's calculations

The next step consists of determining what combination of composition and technique led to emissions being lower than the pure scale effect would predict. Line (2) cumulates the scale and composition effects. It multiplies output in each industry by the emission intensity coefficient z, holding constant the technique. The emissions predicted by the composition effect are represented by the difference between lines (1) and (2). Although hardly noticeable on the graph, line (2) remains below line (1) prior to 2000, and thus the composition of US manufacturing moved towards less polluting industries – a "green" shift of manufacturing production. But this shift is small and accounts for only 6 percent of the total cleanup. The remaining 94 percent of the total cleanup are attributable to the technique effect. Clearly, as in Levinson (2009), the technique effect was the main driver of the total cleanup of US manufacturing between 1995 and 2000. After 2000, however, the composition effect reverses. Line (2) is now above line (1), indicating that US manufacturing is now specializing in the production of dirty goods – a "brown" shift. Indeed, the combined scale and composition effects predicted an increase in emissions of 16 percent, which is above the 12 percent increase predicted by the scale effect.

Figure 2. SO2 Emissions from EU manufacturing



Source: Author's calcula

Figure 2 traces out the same lines for SO2 emissions in the EU-15, and the story that transpires is similar to the US case. Before 2000, the scale effect predicted that EU manufacturing SO2 emissions should have increased 6 percent between 1995 and 1999. Meanwhile, the combined effect of scale and composition predicted an increase in emissions of just 4 percent. This green compositional shift accounted for 8 percent of total cleanup, and technique for the remaining 92 percent. However, while the brown shift of US manufacturing was gradual and still limited by 2005, the picture was much starker on the EU side. Starting in 2000, the composition of EU trade switched towards dirty goods in a dramatic way. Based on the scale effect, SO2 emissions from EU manufacturing should have increased 35 percent between 1995 and 2005. The combined scale and composition effect predicted an increase in emissions of 79 percent. Therefore, the composition effect predicted an additional increase in emissions roughly equivalent to the pure scale effect. The brown shift of EU manufacturing was thus much more pronounced than the one observed in the United States.

A look at the detail of which industries contributed most to the US and EU brown shifts sheds some light on the reason for this large difference. In the United States, the largest increase in the emissions predicted by the combined scale and composition effects did not exceed 150 percent, and did not concern the top polluting industries. By contrast, over the same time period, the EU brown shift was largely driven by two highly pollution-intensive industries – electrometallurgical products (except steel) and blast furnaces and steel mills – whose predicted emissions from the scale and composition effects increased by factors of 38 and 50 respectively. Beyond those two industries, the increase in EU emissions predicted by the scale and composition effects were largely in line with those observed in US data.

Therefore, both regions' manufacturing sectors appeared to be specializing in the production of pollution intensive goods by 2005. But the brown shift does not mean that stricter environmental regulation did not encourage EU and US industries to specialize in the production of clean goods. The brown shifts of production might have been more pronounced without the presence of environmental regulation, but other forces were at play which led to an increasing specialization in pollution-intensive goods. Moreover, since actual emissions did decrease, environmental regulation might have had more of an impact on the technique of production rather than on the choice of goods produced. In fact, there could be an interactive dynamic between composition and technique which cannot be identified in this framework. As EU and US manufacturers adopted new techniques that drastically reduced the cost of producing pollution-intensive goods, it is possible that they were able to competitively produce those goods even in an environment with stricter environmental regulations. In other words, the composition effect might not have been brown if not for progress in technique.

Because the United States and the European Union saw a brown shift in their manufacturing production, the technique effect – the gap between lines (2) and (3) – was even larger than the total cleanup of manufacturing. Table 1 presents the breakdown of scale, composition and technique from 1995 to 2005 for all three pollutants. The technique effect was almost 1.5 times the size of the total cleanup in the European Union for each of the pollutants. On the other hand, reflecting a smaller brown shift of manufacturing, the technique effect was about 1.1 times the total cleanup of manufacturing for each of the pollutants in the United States. In all cases, the technique effect was large enough to offset the emission increases predicted by both the scale and the composition effects. Some caution must be applied here. It is possible that within each industry, some sub-industries switched to producing cleaner goods – a within-industry composition change which is categorized here as technique. The effect of technique could therefore be overstated by the level of aggregation used. Still, given the overwhelming role of technique, those sub-industry movements are unlikely to be large enough to reverse the conclusion that technique played a crucial role in the cleanup of US and EU manufacturing.

Table 1. Scale, composition and technique effects, 1995-2005

	Scale	Scale, composition and technique	Scale and composition	*Fraction due to technique*
United States				
SO2	0.12	-0.45	0.16	*1.08*
Nox	0.12	-0.29	0.16	*1.11*
VOCs	0.12	-0.31	0.20	*1.20*
All three	*0.12*	*-0.37*	*0.17*	*1.11*
European Union				
SO2	0.35	-0.56	0.79	*1.49*
Nox	0.35	-0.12	0.57	*1.48*
VOCs	0.35	-0.20	0.58	*1.42*
All three	*0.35*	*-0.32*	*0.66*	*1.46*

Notes: Since total cleanup is the difference between the scale effect and actual emissions, and the technique effect is the difference between scale and composition and actual emissions, the share of technique will be greater than 1 if the composition effect is a brown shift (i.e. if scale and composition is greater than pure scale)

Souce: Author calculations

Overall, both regions experienced important cleanups of their manufacturing sector between 1995 and 2005, due in large part to the technique effect. This cleanup occurred despite an increase in production and a specialization in dirty goods. The brown shifts of US and EU manufacturing should be interpreted with caution. Although the conclusion holds for all pollutants as indicated in Table 1, the green and brown shifts of the United States are both limited, and could lie within the margin of error of the calculations. Still, the US brown shift is robust to changing the time period and base year of the analysis. Running the calculations from 1987 to 2005, indexing at 100 in 1987, the brown shift of US manufacturing production remains. Moreover, EU data shows that the patterns exposed above continued through 2010 in the European Union. For SO2, the scale effect added 16 percent to emissions between 1995 and 2010, and scale and composition together added 94 percent, all while actual emissions decreased 45 percent. Therefore, the brown shift of EU manufacturing was further exacerbated in the late 2000s, and the technique continued to play an overwhelming role in the total cleanup. Since the trends of scale, composition and technique were alike for the United States and the European Union from 1995 to 2005, one could speculate that the brown shift of US manufacturing also endured through the end of the decade.

3. The role of international trade

3.1. Method and data

The previous section of this paper identified the three sources of change for emissions from the manufacturing sector. This section focuses on the composition effect, particularly the role of international trade in the compositional changes observed in US and EU manufacturing. The composition effect can be due to either a change in the preferences of consumers, who demand cleaner goods, or to the fact that instead of producing polluting goods, the United States and the European Union are now importing them from abroad. Therefore, despite small observed compositional changes, it is possible that the trade effect was significant if the demand channel worked in the opposite direction. In this section, I examine the pollution embodied in imports and the share of trade in the composition effect, and compare the results between the two regions.

Let P^M denote the amount of pollution that would have been emitted within a region had imports been produced at home:

$$P^M = \sum_i p_i^M = V^M \sum_i \theta_i^M * z_i \qquad (4)$$

Note this is an "imported industries" version of the equation above. V^M represents total imports, θ_i^M is the share of imports of industry i in total imports, and z is a measure of the pollution intensity.

There are two things to note about the way z is calculated in this section. First, P^M does not represent the amount of pollution emitted abroad when producing the imports, but rather the amount of pollution that would have been emitted in the United States or the European Union had the imports been produced domestically. Indeed, to determine whether there is evidence of pollution offshoring, the important metric is not the pollution created abroad, but rather the pollution not emitted at home as a result of the offshoring. The concept is similar to that of labor offshoring, where one is concerned with the jobs lost at home rather than those gained abroad. Therefore, the technology is still measured using US emissions data. Other papers in the literature use the technology of the source country to determine the pollution content of imports. For example Weber and Matthews (2007) compares the pollution of a developed country's domestic production, which is calculated using that country's technology, to the pollution embodied in its imports, which is calculated using the technology of the source country, and finds that imports are much more pollution intensive than exports. However, since developing countries have more polluting technologies overall, it is unclear whether these results reflect anything other than technology differences. Following Levinson (2009), I assign to imports the amount of pollution that would have been emitted had the good been produced in the United States or the European Union instead of being produced abroad.

Second, trade data only accounts for the goods that cross the border, not for the inputs into those goods. Studies of the compositional shift of imports which work with finished products (Schatan 2003, Khan 2003, Cole 2004) find that the pollution content of imports has fallen dramatically, and much faster than the pollution content of exports. However, accounting for inputs could reduce that difference. The example of car production in Levinson (2009) clearly sets out the issues associated with considering finished products only. Assembling a car is a not a pollution intensive process. However, producing the steel and the rubber that are used in car parts is. Therefore if imports into the United States or the European Union are dominated by finished products – as is usually the case for industrialized economies – then failure to account for the pollution content of inputs could significantly understate the pollution content of imports.

Consequently, I construct a pollution intensity index that embodies the pollution of the entire production chain. This index, denoted **z****, is constructed in the following way, following Leontief (1970). Let y_i be the final output, where y_i is a subset of x_i. Total output **x** is the sum of output used as intermediate goods and final output:

$$\boldsymbol{x} = \boldsymbol{DRx} + \boldsymbol{y}$$

where **x** is a vector of n outputs, one from each industry, and **DR** is an n × n matrix of direct requirements coefficients with elements $dr_{i\,j}$ representing the dollar value of input industry i needed to produce one dollar’s worth of industry j output – **DR** is the input-output matrix. Trade data give the vector **y**. Rearranging the above equation and isolating **x** gives:

$$\boldsymbol{x} = [\boldsymbol{I} - \boldsymbol{DR}]^{-1}\, \boldsymbol{y}$$

The matrix $[\mathbf{I}\text{-}\mathbf{DR}]^{-1}$ is the Leontief total requirements matrix (**TR**). The vector **x** represents the total amount of manufactured goods necessary to produce output **y**. Using matrix **TR**, the total pollution coefficients are given by:

$$\boldsymbol{z}^{*} = \boldsymbol{z}'[\boldsymbol{I} - \boldsymbol{DR}]^{-1}$$

However, this vector **z*** does not account for the fact that some inputs might have been imported. Therefore, it might overstate the pollution that would have been emitted by producing the good at home. To account for imports, the **DR** matrix is pre-multiplied by diag(**d**), where **d** is a nx1 vector of the share of each input that is supplied by domestic production. The total domestic requirements emissions coefficient is therefore:

$$\boldsymbol{z}^{**} = \boldsymbol{z}'[\boldsymbol{I} - diag(\boldsymbol{d})\boldsymbol{DR}]^{-1}$$

Where [**I**-diag(**d**)**DR**]$^{-1}$ is referred to as the total domestic requirement matrix (**domTR**).

Therefore, to construct the various requirements matrices following this methodology it is necessary to gather additional data on trade flows and input-output matrices to determine each industry's contribution to output. For the United States, data on trade flows comes from the Center for International Data, and the input-output table is from the US Bureau of Economic Analysis (BEA).

EU trade data at the four digit level based on the US SIC classification were collected from the World Bank World Integrated Trade Systems (WITS). Unfortunately, an input-output table of the EU economy is not available at a 4 digit level either. Consequently, the input-output tables are taken from the US Bureau of Economic Analysis for the year 1987. Those tables use their own classification but the BEA provides a concordance with US Standard Industrial Classification (US SIC) in 1987. One of the main issues with using the structure of the US economy to study the European Union is that the share of imported inputs could differ significantly between the two regions. To account for imported inputs, the US IO table is adjusted by EU shares of products supplied by domestic production. The **z**** matrix for the European Union is therefore computed using US emissions and US IO tables, but EU domestic shares.

3.2. Results

To investigate whether importing rather than producing goods limited or amplified the compositional shifts observed in the United States and the European Union, I first examine the evolution of the pollution intensity of US and EU imports. Figure 3 shows the amount of SO2 emissions embodied in US imports. Line (1) represents the scale effect. Based on the increase in the quantity of imports, the scale effect predicts an increase in the amount of pollution displaced by imports of 110 percent between 1995 and 2005. But the composition of imports changed as well. Line (2) represents the amount of US pollution displaced by imports using total domestic requirements (z**). It represents the amount of pollution that would have been emitted if all imports had been produced in the United States using US technology from 1987, accounting for inputs. Since line (2) is below line (1), US manufacturing imports increasingly consisted of a mix of goods that was less pollution-intensive between 1995 and 2005. Table 2 column (2) shows that compared to the increase predicted by the scale effect, the composition effect reduced SO2 emissions displaced by imports by 12 percent in the United States. Similarly, the green shift of imports resulted in decreases in predicted emissions of 12 percent and 6 percent respectively for NO2 and VOCs. Therefore, as in Levinson (2009), the evidence points to a green shift of imports in the United States.

The same pattern emerges in EU data. As can be seen in Figure 4, the scale effect predicted a 71 percent increase in SO2 emissions embodied in imports between 1995 and 2005. The plot clearly shows a sharp increase in real imports after 2002, in line with renewed economic expansion. Line (2) shows that the composition of EU imports also exhibited a green shift between 1995 and 2005, with SO2 emissions displaced by EU imports 31 percent lower than predicted by the scale effect. In fact, comparing Table 2, columns 1 and 2 shows that EU manufacturing imports became increasingly cleaner at roughly the same pace as EU manufacturing became dirtier. The results hold for NO2 and VOCs as well.

Therefore, imports into both regions exhibited a green shift. However, the green shift was significantly more pronounced for EU imports than for US imports. Moreover, since in both regions the green shift of imports occurred while manufacturing production underwent a brown shift, it would appear that the opposite of pollution offshoring is occurring. A breakdown of imports by origin country helps explain these findings. Columns (3), (4), (5) and (6) of Table 2 look at four groups of countries: low income, lower-middle income, higher-middle income, and high income. The income groups are based on the World Bank definition, and for EU trade the high-income country group excludes EU-15 members so as not to count intra-EU trade.

As can be seen in the last four columns of Table 2, the green shift of EU aggregate imports was not distributed evenly across income country groups. In fact, there appeared to be a clear schism between higher and lower-income countries. High and higher-middle income country imports experienced green shifts, while low and lower-middle income country imports were increasingly specializing in the production of pollution intensive goods. On the US side, imports from all country groups experienced a green shift with the exception of lower-middle income country imports. Since the patterns are similar for all pollutants, the discussion again focuses on SO2.

Table 2 - Difference between pollution predicted by total imports and industry specific production : The composition effect (1995-2005)

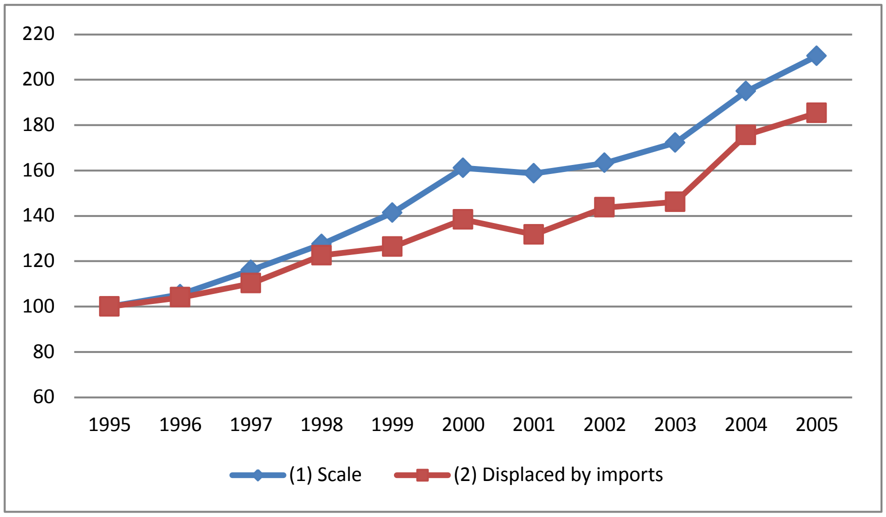
	(1) Manufacturing	(2) All imports	(3) High income country imports	(4) Higher-middle income country imports	(5) Lower-middle income country imports	(6) Low income country imports
United States						
SO2	0.04	-0.12	-0.04	-0.26	0.12	-0.24
NO2	0.04	-0.12	-0.03	-0.23	0.05	-0.37
VOCs	0.08	-0.06	0.01	-0.13	0.07	-0.13
All three	*0.05*	*-0.10*	*-0.03*	*-0.22*	*0.09*	*-0.25*
European Union						
SO2	0.33	-0.31	-0.31	-0.42	0.05	0.48
NO2	0.17	-0.34	-0.34	-0.43	-0.06	0.27
VOCs	0.17	-0.17	-0.15	-0.28	-0.03	0.27
All three	*0.23*	*-0.29*	*-0.28*	*-0.40*	*0.00*	*0.39*

Note: In this table, a positive number represents a brown shift, while a negative number indicates a green shift

Source: Author's calculations

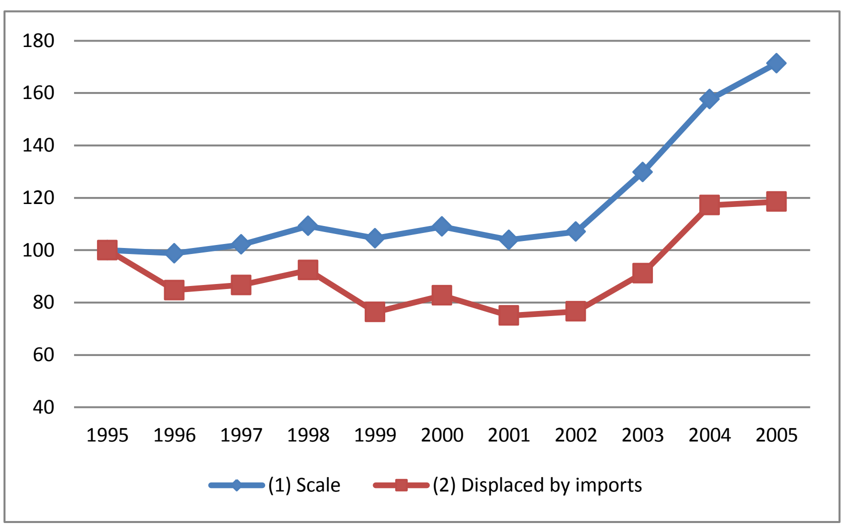
Low-income country imports into the European Union displayed a large green shift in the 1990s, yet by 2005 the phenomenon was reversed into a brown shift, with SO2 emissions displaced by imports rising 48 percent. This drastic shift first emerged in 2002 and amplified gradually through 2005. At first sight, this could imply evidence of pollution offshoring from the European Union to lower-income countries in the 2000s. However, the production of low-income countries is usually labor intensive, and thus relatively clean (based on US technology from 1987). Therefore, the production of just one dirty import can significantly alter the results from one year to the next. In fact, between 2000 and 2005, imports of primary aluminum (SIC 3334 and SIC 2819) drove the brown shift of low-income country imports into the European Union. The quantity of primary aluminum grew eight-fold between 1995 and 2005. Most of EU aluminum imports from the low-income country group originate from Mozambique. In 2000, Mozambique completed the creation of its first aluminum plant Mozal. A large portion of the operating costs of producing aluminum are due to electricity and Mozambique had newly secured access to cheaper

Figure 3. US Imports from all countries and displaced SO2 emissions, 1995-2005



Source: Author's calculations

Figure 4. EU Imports from all countries and displaced SO2 emissions, 1995-2005



Source: Author's calculations

electricity through the Motraco venture which in 1999 created two electricity transmission lines from South Africa (Well and Bueher 2000). Since starting to produce aluminum in 2000, Mozambique has become the 10^{th} largest exporter of primary aluminum to the European Union. By 2005 primary aluminum accounted for 13 percent of the value of low-income country imports and 85 percent of their pollution content. Removing this product from the calculations, the composition of low-income country imports has in fact been getting cleaner at a faster pace than overall imports. SO2 emissions displaced by low-income country imports decreased 61 percent, compared to 31 percent for imports from the world.

The small brown shift for lower-middle income country imports into the European Union is also driven by a single product. In 2005, SO2 emissions embodied in lower-middle income country imports were 5 percent higher than predicted by the scale effect. Lower-middle income country imports into the European Union grew most in low pollution intensity products, with the exception of one good: electrometallurgical products, except steel (SIC 3313). Imports of that polluting category quadrupled between 1999 and 2005 to become one of the top 20 imports from lower-middle income countries, which explains the small brown shift. Excluding this product reverse the compositional shift into a green shift. Therefore, evidence of pollution offshoring from the European Union is limited to only a few products.

For the United States, SO2 emissions displaced by low-income country imports were 24 percent lower than scale would predict by 2005, that is a larger green shift that overall imports (12 percent). In contrast with EU imports from this group, US imports did not include large quantities of highly polluting industries. US imports from low-income countries were in fact much more concentrated in apparel, a clean good category, than EU imports (77 percent and 53 percent concentrations respectively in 2005). On the other hand, SO2 emissions displaced by US imports from lower-middle income countries were 12 percent higher than emissions predicted by the scale effect in 2005, a relatively strong brown shit. Unlike the brown shifts of EU imports, this compositional shift cannot be attributed to one or two products. It is due to smaller, but more widely spread, increases in imports of highly polluting industries which represent some of the top imports from this country group. For example, imports of blast furnaces and steel mills (SIC 3312), petroleum refining (SIC 2911), and primary aluminum all doubled between 1999 and 2005. The rest of the increase is due to growth in a variety of industries that are somewhat polluting. This more global nature of this brown shift could suggest that pollution offshoring was occurring from the United States to lower-middle income countries.

However, low and lower-middle income country imports only account for 4 percent of US imports and 8 percent of EU imports. Therefore, those groups are not large enough to drive any compositional shift in aggregate imports. In fact, in both regions, the green shift of aggregate imports seems to be driven by the green shift in higher-middle income country imports. SO2 emissions embodied in EU imports from higher-middle income countries were 42 percent lower than predicted by scale in 2005. Moreover, those imports accounted for an increasing share of EU imports – from 18 percent in 1995 to 33 percent in 2005. EU imports from higher-middle income countries were dominated by apparel (15 percent) and telephone and telegraph apparatus (9 percent), both relatively clean industries. Beyond those, a variety of products accounted for some 2 percent of imports each, including some polluting categories such as blast furnaces and mills or primary aluminum. However, growth in those categories was muted compared to the growth of low-pollution goods between 1995 and 2005.

Similarly, higher-middle income countries were gaining an increasing share of US imports (from 24 percent in 1995 to 37 percent in 2005), and the green shift amounted to emissions displaced that were 26 percent less than predicted by scale, compared to a 12 percent green shift on aggregate. US imports from this country group were also dominated by clean products (apparel from purchased materials, telephone and telegraph apparatus, motor vehicles part and accessories, communication equipment and other electronic components). Petroleum refining and blast furnaces and steel mills were the largest polluting categories of imports, but they accounted for a much lower percentage of imports and grew less than their clean counterparts.

This group of countries includes emerging markets such as China, Brazil and Russia. Rather than being driven by a few products, the compositional shift of higher-middle income country imports into both the European Union and the United States appears to be due in large part to imports from a single trading partner, namely China. Excluding US and EU imports from China from the calculations decreases the green shift of higher-middle income countries into the United States and European Union by about half. That is not to say that imports are not in fact being produced using polluting technologies in China, but based on US technology, the goods imported from China into the United States or the European Union are increasingly clean.

Since low and lower-middle income country imports did not account for large shares of total EU and US imports, and since higher-middle income country imports behaved similarly between the two regions, the discrepancy in the green shifts of EU and US imports is largely explained by high income country imports. SO2 emissions displaced by high income country imports into the United States only decreased 4 percent between 1995 and 2005, whereas they decreased 31 percent into the European Union. US imports from high income countries experienced relatively high growth in some polluting import categories, which accounted for one or two percent of total imports from this group. On the other hand, among EU imports from high income countries, polluting goods which grew significantly accounted for less than 0.1 percent of imports from this group. Overall, EU imports from high income countries grew in cleaner industries than US imports from the same trading partners. The more pronounced green shifts of EU imports from higher-middle and high income countries explain why on aggregate EU imports have been getting cleaner at a faster rate than US imports.

Nonetheless, the scale and composition effects together imply that emissions from imports increased over time (85 percent for the United States and 18 percent for the European Union). This does leave room for a role of trade in the total cleanup of manufacturing. Going back to Figures 1 and 2, line (3) estimates the scale and composition effect including net imports. It sums the pollution from the production of manufacturing and the pollution that would have been emitted had the increase in net imports between 1995 and 2005 been produced domestically. In other words, it represents the amount of pollution embodied in the goods demanded by domestic consumers.

This exercise shows that the role of net imports in the composition shift was different in the United States and the European Union. In the United States (Figure 1), line (3) is upward sloping, so US consumers demanded increasingly pollution-intensive goods, but line (3) is strictly above line (2), and even slightly above line (1). Therefore, by 1999, emissions estimated by the composition effect including net imports were a touch higher than would have been predicted by the scale effect. This suggests that accounting for net imports would have reversed the green shift of US production. This result seems at odds with Levinson (2009), but the discrepancy can be explained by the difference in the index year chosen. The change in index year from 1987 to 1995 makes a noticeable difference when only a short 5-year period of time is considered. However, the patterns observed over the longer time period leading up to 2005 are robust to both index years.

Table 3. The share of trade in the total cleanup, 1995-2005

	Share of total cleanup
United States	
SO2	0.25
Nox	0.31
VOCs	0.34
All three	*0.28*
European Union	
SO2	0.18
Nox	0.29
VOCs	0.10
All three	0.19

Source: Author's calculations

In the 2000s, this pattern accentuates. Line (3) continues to rise further and further above line (1), so the brown compositional shift of manufacturing that appears in the 2000s would have been amplified if net imports were produced domestically. Running the analysis with an index year of 1987 confirms this trend, indicating that the result is not an artifact of the index chosen. By 2005, in terms of SO2 close to 25 percent of the total cleanup of manufacturing could be matched by increased imports of polluting goods (Table 3). The share of trade in the total cleanup amounts to about 30 percent for NO2 and VOCs as well. Therefore, the role of trade in the US compositional shift and total cleanup does leave room for pollution offshoring.

In the European Union, as shown in Figure 2, line (3) is strictly below line (2). In contrast with the United States, the green shift in EU manufacturing production was accentuated by adding on net imports. Despite the fact that the value of EU manufacturing imports was larger than the value of EU manufacturing exports, the pollution content of imports was lower than that of exports. Therefore, adding back the pollution content of net imports – a negative number – would have increased the green shift of EU manufacturing. In other words, the mix of goods imported by the European Union were increasingly relatively clean compared to domestic production, and especially compared to EU exports. The green shift of EU manufacturing production would have been larger if not for foreign demand for increasingly dirty EU goods. In terms of SO2, 18 percent of the total cleanup of EU manufacturing could be matched by increased exports of polluting goods. The share of trade in the total cleanups of US and EU manufacturing might not differ greatly in terms of magnitude, but it works in exactly opposite directions.

To summarize, in the United State, there was some evidence of a brown shift of imports from lower-middle income trading partners. Moreover, trade accounted for roughly 30 percent of the total cleanup of US manufacturing. Those two facts combined suggest that the United States might have been offshoring pollution, but only to lower-middle income countries, which account for just 4 percent of US imports in 2005. In the European Union, the brown shift of imports concerned both low and lower-middle income countries, but was restrained to only a few products. Moreover, accounting for net imports decreases the brown shift of manufacturing. And overall imports were increasingly consisting of cleaner goods at a faster pace than US imports. Therefore, evidence of pollution offshoring from the European Union was limited. This is not to say that pollution offshoring was not in fact happening; it might simply have been eclipsed by other factors.

4. Conclusion

The patterns observed in the United States and the European Union are similar in terms of manufacturing production. Both regions experienced a significant cleanup of their manufacturing industries, despite increases in output. While the composition of production was initially increasingly comprised of clean goods, EU and US manufacturing specialized in the production of increasingly pollution intensive goods by the early 2000s. However, compositional shifts played only a minor role in the cleanups of both manufacturing sectors. Improvements in technology were the overwhelming drivers of the total cleanup.

Nonetheless, the United States and the European Union differ in both the composition of imports and in the role of trade in the composition of manufacturing production. For the United States, accounting for net imports indicates that around 30 percent of the total cleanup could be matched by increased imports of polluting goods. Meanwhile, US imports experienced a green shift between 1995 and 2005, but this green shift was not uniformly distributed among trading partners. By 2005, US imports from lower-middle income countries showed evidence of a brown shift which was spread across a variety of polluting industries. The role of trade in the cleanup of US manufacturing, combined with the brown shift of lower-middle income country imports into the United States, suggests that the United States might have been offshoring pollution to this country group. On the other hand, the brown shift of EU production was much more pronounced, and roughly 20 percent of the total cleanup could be matched by increased exports of polluting goods. Moreover, the green shift of EU imports was also significantly more prominent than in the United States, and the brown shifts exhibited by imports of lower-income country groups were limited to only a few products. Therefore, evidence of pollution offshoring from the European Union is significantly more muted than from the United States.

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DAY 10 - 11:30		
Room 613 - Energy Markets 2		
Crude Oil nonlinear linkages with stocks: regional, country and sector effects	Carlos Pinho[1]; Mara Madaleno[1]	[1]Universidade de Aveiro
Impact of fossil fuel costs on electric power prices. Empirical evidence of the Spanish case	María Teresa García-Álvarez; Blanca Moreno	[1]Unviersity of Oviedo; [2]University of Coruna
The Impact of EU ETS on the Spanish Electricity Prices	Carlos Pereira Freitas[1]; Patrícia Pereira da Silva[2]	[1]Institute of Engineering, Polytechnic of Porto and Faculty of Economics, University of Coimbra; [2]Faculty of Economics, Univ. Coimbra, INESC Coimbra and Energy for Sustainability Initiative
Copulas and CoVaR, with applications for the energy market	Romain Decet[1]; and Thorsten Lehnerty[2]	[1]Risk & Credit Management, Enovos Luxembourg S.A., and Luxembourg School of Finance, University of Luxembourg; [2]Luxembourg School of Finance, University of Luxembourg

Crude Oil nonlinear linkages with stocks: regional, country and sector effects

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Abstract

This paper studies regional/country and sector stock price adjustment dynamics to oil price impacts on the basis of a nonlinear framework, because there is evidence of an asymmetric relationship between oil price and economic activity. By using a sample at the world level the aim of this article is to investigate the responses of sector stock markets to oil price changes. Our findings suggest that the strength of this association varies across sectors and regions, and for all sectors we find strong evidence of asymmetry in the reaction of stock returns to changes in the price of oil. Results seem to indicate that the MSVAR model manages to capture a satisfactory timing of the regimes that affected stock markets regions and sectors under analysis. Finally, we conclude that there is evidence of co movement among the series because we manage to extract common regime switching behavior among them. Finally, results suggest that oil price risk is significantly priced in the sample used and that this impact is asymmetric also with respect to market phases, where regimes have been associated with world economic, social and political events.

JEL classification: C22, E32, F30, G12, G15, Q43

Keywords: Oil markets; Nonlinear adjustment; Sector Stocks markets; Regional index sector stock markets

1. Introduction

Stock market is seen as a very significant component of the financial sector of any economy, because it plays a vital role in the mobilization of capital in many economies. Although there is no consensus about the nature and number of factors which really affect stock markets, oil prices with their recent swings turn out to be an attractive factor to be analyzed in this context. Oil price changes may influence stock prices, despite the fact that we do not find any closed consensus in the empirical literature which has emerged in this context (Hamilton, 1983, 2003). Inconclusive different results obtained in the literature up to the moment on the relationship between oil and stock returns may be due to the weakness of linear econometric techniques which have been applied up to date. Linear methods do not detect asymmetries and nonlinear linkages across oil and stock market returns (evidence for cointegration was found and adjustment to the implied long-run relationships may involve nonlinearities). Jawadi, Arouri and Bellalah (2010) were the first to propose a nonlinear model to investigate time dependency and reproduce the linkages between the oil and stock markets, but use general country market indices (USA, France, Mexico and the Philippines). They show a nonlinear mean-reverting mechanism which is activated by regime with an adjustment speed increasing with price deviations to their equilibrium level.

Many have been the attempts in the literature to study the links between oil prices and economic activity, which have established significant effects between both, being however mostly applied in the context of developed or emerging markets (Cologni and Manera, 2009; Kilian, 2008; Álvarez et al., 2011). Some of these have even showed that the link between oil and the economy is not linear (Hamilton, 2003; Cologni and Manera, 2009; Jawadi, Arouri and Bellalah, 2010). A lot less number of studies has appeared which strictly look at the level of sector and regional stock returns. Most studies only care about a few industrialized countries and over the short term interaction between energy price shocks and stock markets. Jones and Kaul (1996) study the response of international stock markets returns for Canada, UK, Japan and USA using a standard discounted dividend model to conclude that oil price shocks impact cash flows. Huang et al. (1996) find no evidence of impacts of oil prices over the S&P stock index return. Park and Ratti (2008) show that oil prices exert a negative impact over stock returns for both USA and twelve European countries. Apergis and Miller (2009) examine whether structural oil-market shocks affect stock prices in eight developed countries concluding that developed stock markets do not react significantly to oil price changes. Aloui and Jammazi (2009) apply the Markov- switching EGARCH model, to find that the net oil price (the WTI and Brent oil) variable plays a notable role in determining both the volatility of real returns and the probability of transition across regimes in developed stock markets. By using an industry focused study, Nandha and Faff (2008) investigate the short-term link between oil prices and thirty-five DataStream global industries to show that oil prices increases have a negative impact on all industries, except for oil and gas. Kilian and Park (2008) use the structural VAR model and find out that the response of aggregate US real stock returns may differ greatly depending on whether the increase in the price of crude oil is driven by demand or supply shocks in the crude oil market. Arouri et al. (2010) investigate the effects of oil shocks on the stock market of GCC region (oil exporting) countries applying linear and nonlinear model, showing that stock market returns significantly react to oil price changes in most of the countries. More recently, Arouri and Nguyen (2010) investigate sector return sensitivities to oil price shocks in European stock markets. Using a conditional version of two-factor market model and Granger causality test they find that reactions of stock returns to oil price fluctuations differ greatly depending on the activity sector. Chen (2010) employs a time varying transition-probability Markov-switching model to examine the impact of oil price changes on the behavior of the Standard & Poor's S&P 500 price index and provide evidence that higher oil price does push the stock market into bear territory. Arouri (2011) only investigates the responses of European sector stock markets to oil price changes, using linear and asymmetric models, but conclude that in some sectors there is strong evidence of asymmetry in the reaction of stock returns to changes in the price of oil. As evidenced, very few studies have looked at the impact of oil price changes on the stocks of individual sectors. Moreover, most of these studies are country specific and thus do not provide a global perspective. Studying the effects of oil price fluctuations sector by sector is important for several reasons (Arouri, 2011), because any market-wide consequence may mask the performance, not necessarily uniform, of any sector, sector sensitivities to changes in the price of oil may be asymmetric (ones more affected than others; Arouri, 2011). Finally, it is not only interesting to analyze different sector as well as different countries and/or regional markets in order to see how oil price changes may impact different regions attending to their inherent characteristics. The present article extends the understanding of this proved existent relationship between oil prices and stock returns in two different manners: first, by testing for nonlinear linkages and second, by using an industry/sector and regional focused view, in order to provide a broad range of conclusions. This study can provide investors advantages to make their own suitable investment decisions.

With this purpose this study investigates whether nonlinear relationships due to common regime switching behavior exists in the selected stock markets and oil price series, where we assume all series are regime dependent, using a two regime multivariate Markov switching vector autoregressive (MSVAR) model. Sudden changes are represented by probabilistic statements called transition probabilities, which specify which regime occurs at each point in time rather than imposing particular dates at priori, allowing the data to tell the nature and incidence of significant shifts. The MSVAR has gain attention in the literature due to its flexibility (it can capture regime shifts in the mean, variance and also in the parameter of the vector autoregressive process).

The rest of the work proceeds as follows. Section 2 presents the methodology followed and also the data used with this respect. In section 3 our main results and empirical findings are going to be presented and discussed, while section 4 concludes this work.

2. Methodology and Data

Nonlinear Regime Switching models allow capturing state-dependent behaviors which would be otherwise impossible to model. There seems to be a wide acceptance that relationships between macroeconomic variables may often be nonlinear. Nonetheless, the specification and estimation of nonlinear types of models is nothing but straightforward. Among nonlinear models, we have the Markov Regime Switching models (Hamilton, 2003).

The data used to analyze these nonlinear causalities between oil prices and stock returns respect to monthly prices of around 75 country and regional index sector stock return prices covering the period from November 1992 until October 2012. The sectors here analyzed are Basic Materials, Consumer Goods, Consumer Services, Financials, Healthcare, Industrials, Oil and Gas and Utilities. The oil price series used is the West Texas Intermediate (WTI), average monthly spot price. All price series have been converted into log returns and were denominated in US dollars. Given that country results revealed to be very similar to their regional/continent index counterparts, we have decided to present only the results obtained for 10 regions around the world (America, Asia, Australia, European Monetary Union (EMU), Latin America, North America, Europe, Brazil, Russia, India and China countries group (BRIC) and Developed Markets) and the World general and sector stock index representative.

Stationary analysis, or unit root tests, has been performed for data pertaining to the variables used in the study, using the Augmented Dickey-Fuller test. Test results have been omitted due to space restrictions but all series revealed to be stationary in returns. A long term relationship between time series has also been searched by applying the cointegration test developed by Johansen and Juselius[1]. For all series it was possible to confirm the existence of a cointegrating relationship among the variables under analysis. However, the main focus of this work is in the analysis of the series reactions and not their long term relationship. Meaning, we want to analyze how do movements in oil price affect the financial stock markets in different time moments, and so we test next for structural breaks in the series and apply the Markov Switching Vector Autoregressive (MSVAR) model.

The econometrics of structural change provides statistical answers to the questions of the existence, number and dates of structural shifts in the stock market/oil price relation series. This method has the critical advantage of dating the breaks without any a priori hypothesis about the length of the economic cycles. It also indicates how statistically significant the shifts are. The estimation focuses on the identification of breaks in the stock return / oil price series relationship between different periods. The model used for testing structural change and estimating the number of break dates is the following, for *m* breaks at dates T_m: $\Delta y_t = \beta_1 + \sum_{k=1}^{m} \beta_{k+1} I(t > T_k) + v_t$ where Δy_t is the index stock/oil return relationship, (β_1, …, β_m) the parameters, and v_t the error term. The Bai and Perron (1998, 2003) method of estimation of the candidate break dates is based on the least-squares principle and uses grid-

[1] Once again we do not present test results here, but results will be made available upon request.

search[2]. A maximum of 5 breaks have been allowed for this study. The methodology covers models at a level of generality that allows numerous practical applications. In particular, it

allows for autocorrelation and heteroskedasticity in the residuals and different distribution for the data and for the errors across segments. The results of the test are reported at conventional test sizes of 1%, 5% or 10%.

We employ a Markov-Switching Vector Autoregressive (MSVAR) model, which provides a natural and tractable model for processes with switching regimes. By estimating the MSVAR we can describe various types of regime dynamics and find the appropriate interactions among variables in each regime with the suitable state evolution. For estimation purposes we usually need to use the reduced form VAR in which each endogenous regressor appears only in its lagged form: $y_t = \Phi_1 y_{t-1} + \Phi_2 y_{t-2} + \ldots + \Phi_p y_{t-p} + \varepsilon_t$, where y is a nx1 vector consisting of n variables for examining dynamic relations, p is the lag length necessary to describe the dynamics of the system, and $\Phi_i = A_0^{-1} A_i$, being A_0 a nxn matrix with ones along the principal diagonal, A_i are the nxn coefficient matrices. Using the Markov switching framework we may write the reduced form VAR model as: $y_t = \Phi_1(s_t) y_{t-1} + \Phi_2(s_t) y_{t-2} + \ldots + \Phi_p(s_t) y_{t-p} + \varepsilon_t$ being s_t the latent variable taking the value 1 or 2 and so this MSVAR model allows us to specify different VAR models for different regimes. For the stochastic process of s_t, the MS model employs the Markov chain. The law of state evolution is governed by a transition probability matrix P, where the (I,j) element of P indicates $\Pr(s_t = i \mid s_{t-1} = j)$. For m regimes these transition probabilities can be collected in an mxm P matrix. The main characteristic of the MSVAR model is that the dynamics of the variables are conditioned on the unobserved Markov process followed by the regime. Because the Markov chain is unobservable, the recursive nature of the likelihood function prevents standard estimation techniques from providing the maximized likelihood. One alternative is the iterative maximum likelihood estimation technique known as expectation-maximization (EM) algorithm which is designed for a general class of models where the observed time series depend on some hidden stochastic variables. This estimation technique consists of two steps whereby the expectation step infers the hidden Markov chain conditioned on a given set of parameters and the maximization step re-estimates the parameters based on the inferred unobserved Markov process, and these steps are repeated until we have convergence.

[2] In each m-partition (T_1, …, T_m), the associated least squares estimates of the parameters (β_1, …, β_m) are obtained by minimizing the sum of squared residuals. Substituting the resulting estimates in the objective function and denoting the resulting sum of squared residuals S(T_1, …, T_m), the estimated break points $(\hat{T}_1, \ldots, \hat{T}_m)$ are the solution of the minimization of S(T_1, …, T_m) over all partitions. Only after, stability tests are implemented, in a sequential procedure. First, stability of the trend is tested against the hypothesis of one break. If stability is rejected, then one break date is imposed on the model, and the hypothesis of one break is tested against the hypothesis of two breaks. The second break date is obtained by testing all the possible models with two breaks knowing the first break date against the one break model. The procedure is repeated until the number of breaks and the corresponding break dates are determined.

4. Empirical Results

In this section we start by presenting the results obtained by the Bai and Perron (1998, 2003a,b) structural break tests for the sample of regions considered (for the oil and gas sector. The others have been omitted given the similar results obtained, which can easily be generalized), and then we present the MSVAR results only for the general world stock market index and for some world sector stock general index returns (due to space restrictions, but which can perfectly be translated for regional behaviors in sector terms), evidencing the periods where regime shifts were estimated and by associating these to special date events which have occurred.

Table 1 presents the test statistic results for the general world index and in each panel we have the structural break test results for each of the sectors under analysis and considering the different regions around the world. We see that for almost all sectors we are able to detect at least one significant structural break whose regime period is identified for each in that table. In the case of the Asian region, in all sectors sector we have no structural break regimes identified and for some sectors (Oil and gas and Financials) the identification of one regime shift is only significant at the 10% level. In each sector we have almost the same start and end periods were structural breaks have been identified, with very well noticed differences in the oil and gas sector, where these breaks occur sooner than in the other sectors. Given that the oil and gas sector are expected to be among all the other the most affected by oil price changes, we have decided to show the results obtained for all the regions considered in our sample estimates as well as for 2 countries. For UK the structural break is only felt during the financial crisis period. The rest of the results obtained for individual countries will be made available upon requested, but have been showed to be very similar to those of the region which represents them, and that´s why they have been omitted. Results for the oil and gas sector show the existence of strong positive links between oil price changes and stock returns, which was an expected results and in line with those obtained by previous authors like Mohanty et al. (2010) and Arouri (2011). As noticed by Arouri (2011), a particularity of oil and gas firms is that their value is driven by oil prices, where lower oil prices mean lower profit margins and reduced capital expenditures, and the opposite applies. As such, it is expected a strong and positive response of oil and gas sector companies to these oil price changes, which we are able to confirm latter in figure 3.

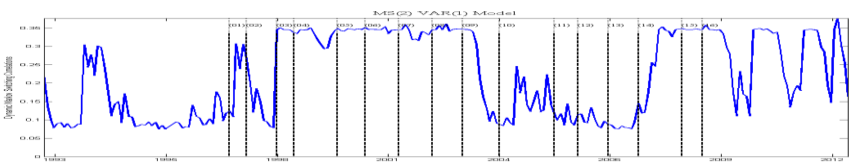
In figure 1 we show the dynamic Markov switching correlations obtained from the MS(2) VAR(1) model using the relation between the world general index (dependent variable) and oil price returns (independent). The plot allows us to conclude that in the period were we have regimes changes related to crisis periods (see figure 2) there exists a strong correlation between stock markets and oil price changes, reaching values between 0.3 and 0.4.

Table 1: Bai and Perron (1998) Test Statistics (1992:M10–2012:M10): index stock returns affected by oil price changes

Variable/Test statistic	Dmax tests against an unknown number of breaks				supF tests against a fixed number of breaks						Regime
	UDmax		WDmax (5%)		F(1|0)		F(2|1)	F(3|2)	F(4|3)	F(5|4)	
World general	24,91	***	24,907	**	24,91	***	1,7979	6,5268	1,8373	0,57	11/1992-7/2008 and 8/2008-10/2012
Utilities:											
America	15,04	***	15,043	**	15,04	***	2,2499	1,1677	0,3642	0	1/1993-8/2007 and 9/2007-10/2012
Asia	3,4		7,4613		3,003		2,2061	5,2795	0,2263	0	1/1993-8/2007 and 9/2007-10/2012
Australia	11,62	**	15,728	**	11,62	**	6,0736	1,8611	0,5337	0,5318	1/1993-8/2007 and 9/2007-10/2012
World	11,89	**	14,072	**	11,89	**	1,8168	1,4531	0,082	0	1/1993-8/2007 and 9/2007-10/2012
Europe	17,2	***	19,955	**	17,2	***	2,1916	2,0845	0	0	1/1993-8/2007 and 9/2007-10/2012
BRIC	7,738	*	12,272	**	7,738	*	2,6558	3,5406	0,0928	0,0928	1/1993-8/2007 and 9/2007-10/2012
Oil and Gas:											
America	17,45	***	17,452	**	17,45	***	2,9699	2,0178	1,5134	0,0309	1/1993-1/2005 and 2/2005-10/2012
Asia	7,284		7,2843		7,284	*	5,5474	5,5474	2,2576	0	1/1993-1/2005 and 2/2005-10/2012
Australia	21,33	***	26,601	**	21,33	***	3,1515	1,7638	1,7178	0	1/1993-9/2005 and 10/2005-10/2012
MEU	16,78	***	22,302	**	14,18	***	7,2044	1,954	1,7489	0	1/1993-5/2005 and 6/2005-10/2012
EU	14,29	***	18,191	**	13,24	***	7,7463	2,1087	1,5143	0,122	1/1993-5/2005 and 6/2005-10/2012
Latin America	12,51	***	21,51	**	10,77	**	5,34	3,9069	5,34	0	8/1994-1/2005 and 2/2005-10/2012
North America	16,56	***	17,193	**	16,56	**	2,4588	2,9261	1,6818	0,2027	1/1993-1/2005 and 2/2005-10/2012
UK	18,36	***	18,364	**	18,36	***	0,6458	1,271	2,5719	0	1/1993-10/2009 and 11/2009-10/2012
US	12,98	***	13,991	**	12,98	***	3,1357	4,0428	0,8569	0,4342	8/1994-1/2005 and 2/2005-10/2012
World	18,9	***	27,789	**	18,9	***	1,9753	1,9753	1,9753	0	1/1993-1/2005 and 2/2005-10/2012
Europe	22,21	***	22,214	**	22,21	***	3,1892	3,1892	1,6745	0,0489	1/1993-5/2005 and 6/2005-10/2012
BRIC	16,02	***	16,022	**	16,02	***	6,1983	5,8767	1,9149	0	8/1994-4/2005 and 5/2005-10/2012
Developed Markets	15,63	***	16,934	**	15,63	***	3,5826	5,2194	0,6211	0,0417	1/1993-1/2005 and 2/2005-10/2012
Basic Materials:											
America	18,6	***	18,596	**	18,6	***	2,8853	1,8967	3,0064	0	1/1993-7/2007 and 8/2007-10/2012
Asia	6,943		6,9434		6,943		1,6878	1,0069	2,028	0	1/1993-7/2007 and 8/2007-10/2012
Australia	21,96	***	21,956	**	21,96	***	1,898	1,6164	0,4462	1,3452	1/1993-9/2005 and 10/2005-10/2012
World	17,24	***	17,241	**	17,24	***	2,3683	1,7191	0,1746	0,0718	1/1993-7/2007 and 8/2007-10/2012
Europe	23,87	***	23,867	**	23,87	***	4,8387	2,1643	0,8909	0	1/1993-8/2007 and 9/2007-10/2012
BRIC	11,14	**	11,219	**	11,14	**	4,4482	4,0799	2,332	0	8/1994-6/2007 and 7/2007-10/2012
Consumer Goods:											
America	32,68	***	32,677	**	32,68	***	1,2645	0,6097	0,9832	0	1/1993-8/2008 and 9/2008-10/2012
Asia	6,836		8,124		4,719		2,7668	1,3654	1,508	0	1/1993-8/2008 and 9/2008-10/2012
Australia	14,07	***	14,071	**	14,07	***	1,6762	0,4934	2,3797	0,1024	1/1993-8/2008 and 9/2008-10/2012
World	22,86	***	22,86	**	22,86	***	2,3291	0,4431	3,9266	3,7266	1/1993-8/2008 and 9/2008-10/2012
Europe	29,39	***	29,389	**	29,39	***	1,8012	1,552	0,9657	3,2791	1/1993-8/2008 and 9/2008-10/2012
BRIC	27,13	***	27,126	**	27,13	***	3,4397	2,454	1,4489	0	8/1994-6/2008 and 7/2008-10/2012
Consumer Services:											
America	19,58	***	19,577	**	19,58	***	2,4275	1,8894	1,4784	0,0173	1/1993-8/2008 and 9/2008-10/2012
Asia	3,903		6,8564		3,903		1,4079	2,2111	3,0823	1,6713	1/1993-8/2008 and 9/2008-10/2012
Australia	11,09	**	11,088	**	11,09	**	1,5424	2,7572	2,7572	0,0938	1/1993-7/2008 and 8/2008-10/2012
World	15,75	***	15,755	**	15,75	***	3,7005	3,189	1,9847	0,5192	1/1993-8/2008 and 9/2008-10/2012
Europe	12,18	**	12,177	**	12,18	**	1,4648	3,7508	2,1583	0,3851	1/1993-7/2008 and 8/2008-10/2012
BRIC	19,14	***	19,799	**	19,14	***	2,4366	3,7109	1,6087	0	8/1994-7/2008 and 8/2008-10/2012
Financials:											
America	57,22	***	57,216	**	57,22	***	2,8919	1,5228	0,0258	0	1/1993-7/2008 and 8/2008-10/2012
Asia	7,797	*	7,7968		7,797	*	0,7056	2,4156	1,8055	2,6299	1/1993-7/2008 and 8/2008-10/2012
Australia	32,75	***	32,752	**	32,75	***	1,1741	3,5314	1,3699	0	1/1993-7/2008 and 8/2008-10/2012
World	34,84	***	34,843	**	34,84	***	5,5851	0,5472	2,1787	0	1/1993-7/2008 and 8/2008-10/2012
Europe	29,57	***	29,573	**	29,57	***	1,2836	2,3315	2,6149	2,4116	1/1993-7/2008 and 8/2008-10/2012
BRIC	12,33	**	12,846	**	12,33	***	6,7131	2,5388	0,0205	0	8/1994-5/2007 and 6/2007-10/2012
Health Care:											
America	20,83	***	20,831	**	20,83	***	1,1292	1,25	0,6468	0	1/1993-8/2008 and 9/2008-10/2012
Asia	1,73		3,3506		1,083		0,9512	1,0336	0,3651	0	1/1993-8/2008 and 9/2008-10/2012
Australia	18,04	***	23,827	**	13,12	***	2,5723	2,6471	3,9842	2,2243	1/1993-1/2007 and 2/2007-10/2012
World	22,06	***	22,061	**	22,06	***	0,3871	0,7308	0,2681	0	1/1993-8/2008 and 9/2008-10/2012
Europe	29,25	***	29,599	**	29,25	***	3,8947	1,2989	1,1054	0	1/1993-7/2008 and 8/2008-10/2012
BRIC	6,136		6,1362		6,136		1,9724	3,8704	0,6162	0	1/1993-8/2008 and 9/2008-10/2012
Industrials:											
America	19,72	***	19,725	**	19,72	***	4,3305	4,2799	4,1988	0,3596	1/1993-8/2008 and 9/2008-10/2012
Asia	6,822		9,8204		5,74		2,6789	3,1343	1,3731	1,3731	1/1993-7/2008 and 8/2008-10/2012
Australia	13,27	***	13,274	**	13,27	***	1,7266	0,2892	1,3609	0	1/1993-7/2008 and 8/2008-10/2012
World	19,09	***	19,088	**	19,09	***	4,6651	3,6844	3,336	0,2892	1/1993-8/2008 and 9/2008-10/2012
Europe	12,2	**	12,203	**	12,2	**	2,3535	1,2919	3,2245	0,2755	1/1993-6/2008 and 7/2008-10/2012
BRIC	6,15		6,3121		6,15		1,1837	1,2536	0,8927	0	1/1993-8/2008 and 9/2008-10/2012

*NOTE: *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels. The bracketed dates in the Regime column denote a 90 percent confidence interval for the end of the regime. F(1|0) stands for "if there is one break besides 0"; F(2|1) for "if there are two breaks besides one".*

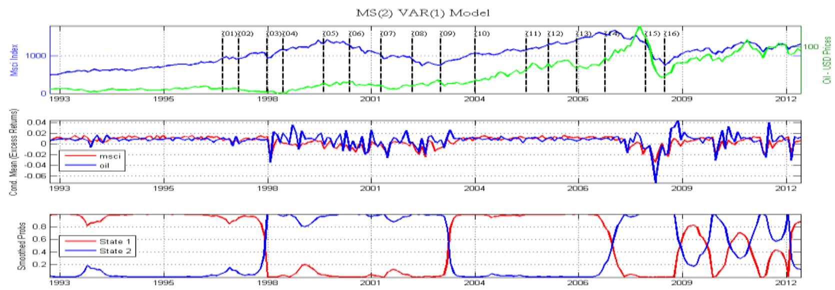
Figure 1 – Dynamic Markov Switching correlations



NOTE: See figure 2 note.

To justify our interpretation of the regimes identified using the estimated parameters of the MSVAR model, figure 2 shows the world and oil returns series (first plot), the conditional mean excess returns (second plot) and smoothed regime probability plots for states 1 and 2 (third plot) which are the probability of staying in either regime 1 or 2 at time t, considering the world general and world sector stock indexes (figure 3). As shown in figure 2, the smoothed probability plots manage to identify crises periods around the world that affected the stock market indices. From 1992 until August 1998 (the moment of the Russian Financial crisis), the world stock general index has shown a very stable behavior. We are able to detect two regime shifts given the results obtained by the MSVAR. From August 1998 until April 2003, then between April 2003 and August 2007 (another stable period among the two series analyzed) and finally another regime shift between August 2007 until 2012, which can be simply attributed to the start and ongoing effect of the world financial crisis. We can even say that in the period where the regime probabilities are near one, we have the recovery and expansion periods, whereas those close to 0 mean the most affected and crisis periods. The first regime change between August 1998 and April 2003 has associated several other historical events despite the start of the Russian Financial crisis. These are the Brazilian currency collapse in January 1999, the climax hit of the “dot-com-bubble” in March 2000, the US elections in November 2000, the terrorist’s attacks in the USA in September 2001, the WorldCom Accounting Fraud in June 2002 and finally the Iraq invasion in March 2003. With more or less impact these have been the main changes that have occurred within this first regime shift period and which may explain why do the series move in that way in that period.

Figure 2 – World general stock index returns (blue) and oil price returns (green) plot, conditional means and smoothed probability plots of the MS(2) VAR(1) model

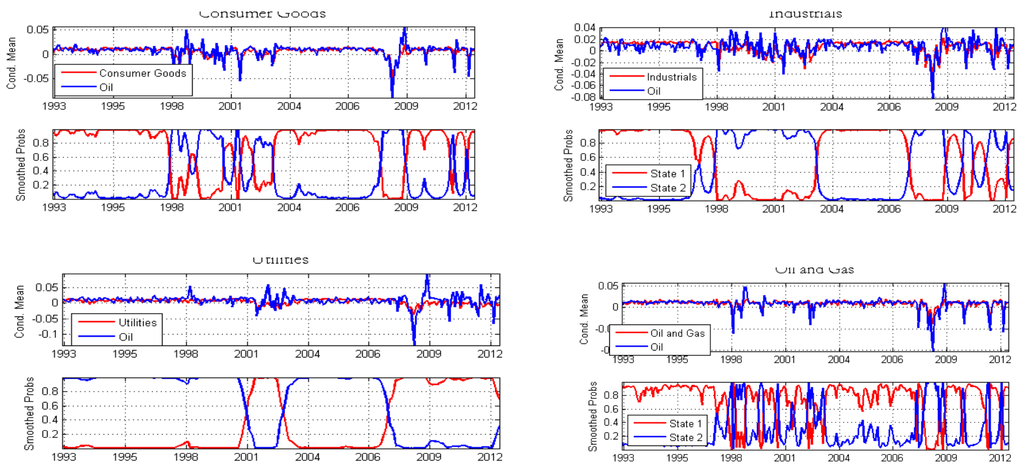


NOTE: (1) Jul-1997-Asian Financial Crisis; (2) Dec-1997-Kyoto Protocol; (3) Aug-1998-Russian Financial crisis; (4) Jan-1999-OPEC cuts production targets 1.7 mmbpd; (5) Mar-2000- Climax of the "dot-com-bubble"; (6) Nov-2000-US Elections; (7) Sep-2001-Terrorist Attacks in the USA; (8) Jun-2002-WorldCom Accounting Fraud; (9) Mar-2003-Iraq Invasion; (10) Mar-2004-Terrorist Attacks of Madrid; (11) Jul-2005-Terrorist Attack in London; (12) Feb-2006-Militant attacks in Nigeria; (13) Nov-2006-OPEC Cut Agreement;(14) Aug-2007-Financial (Sub-prime) Crisis; (15) Aug-2008-Global Financial collapse; (16) Feb-2009-OPEC cuts production targets 4.2 mmbpd

After April 2003 and until August 2007 we turn out to assist to another relatively calm and stable period between the series relationship, where we do not denote a greater impact of oil price changes over the stock market despite the events which happened within this period, namely the Terrorist attacks of Madrid in March 2004, the Terrorist attack in London in July 2005, the Militant attacks which have occurred in Nigeria in February 2006 and the OPEC Cut Agreement in November 2006. From August 2007 onwards we had the start of the financial sub-prime crisis and with this a new regime shift among the series relationship. Besides this in February 2009 the world faced a new announcement of production cut within the OPEC.

Finally, we present the results (figure 3) for the conditional mean excess returns (first plot) and smoothed regime probability plots for states 1 and 2 (second plot) for three randomly selected sectors considering the world respective sector index. As evidenced by the smooth probability plots the sectors for which we have higher regimes shifts, by order of importance are the oil and gas sector and that of consumer goods. As stated previously these higher correlations and regime changes for the oil and gas sector was somehow expected given the straight relation between the industries in this sector and oil price returns. With respect to the consumer goods sector we can say that oil and related products are used in all phases of food production. Due to this it is expected stronger regimes shifts and impacts of oil returns over consumer goods because they increase production and transportation costs. Also, it is feasible to say that the reaction of consumer goods index is both related to increases in marginal costs associated and to possible shifts in consumer expenditures (future demand reductions due to cuts in consumer expenditures is an important factor while determining industry sensitivities to oil price changes; Arouri, 2011).

Figure 3 – Conditional means and smoothed probability plots of the MS(2) VAR(1) model: world index sector returns and oil price changes



NOTE: All periods of events identified previously in figure 2 can be easily extended into figure 3.

All the other sectors used in this study revealed to have similar behaviors' than those represented by the Industrials and Utilities sector in terms of regime switching, but obviously some of them are more affected than others, meaning that show more regime shifts than the other ones given that some of these are also more closely related to oil and oil related products. However, a lot more remains to be done and it would be useful to test for other nonlinear models in order to state if the MSVAR model is the better to describe these asymmetric and nonlinear responses that do exist between the variables under analysis. Moreover, it would be interesting to extend the sample period and associate these structural regime shifts to other socio-economic-political events, which have historically been reported.

5. Conclusions

This paper investigates the nonlinear relationship among stock regional and sector market indices and oil price returns from 1992 until 2012 using monthly data, given that there is evidence of an asymmetric relationship between oil price and financial activity. We use the Markov switching VAR to detect the possibility of data structural changes which were confirmed by using the Bai and Perron (1998) structural break tests for the sample of regions and sectors considered. Results seem to indicate that return series are well fitted by the MSVAR model and a common regime switching behavior can be extracted for several sectors as oil and gas, utilities, consumer goods and industrials, which corresponds to the period starting from the world global financial crisis in 2007. Results point for two regime behavior shifts among the world general stock index return which have been clearly identified, periods which coincide with some important economic features and socio-political conditions that prevailed in the World, independently of the sector under analysis. However, in sectors like oil and gas and consumer goods regime shifts show to be more pronounced than in the others. In addition we also found that the MSVAR model manages to capture a satisfactory timing of the regimes that affected the stock markets regions and sectors under analysis. Finally, we conclude that there is evidence of co movement among the series because we manage to extract common regime switching behavior among them.

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Impact of fossil fuel costs on electric power prices. Empirical evidences of the Spanish case

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Abstract

In Spain, the most important process of electricity generation is still thermal conversion of fossil fuels, such as gas and coal. Thus, changes in these primary energy sources prices can directly affect electricity price as the costs of generating electricity are likely to be passed to the electricity prices through the wholesale electricity market.

The objective of this paper is to analyse how important are fossil fuel sources in explaining the variations in Spanish wholesale electricity prices.

Under Spanish electricity industry deregulation, price formation was delegated to the law of supply and demand in the wholesale electricity market. Therefore, in order to determine the electricity price we present a simultaneous equations statistical model to identify the demand and supply functions.

We propose a Maximum Entropy Econometric approach to estimate the model when information is limited. The obtained results suggest that coal and natural gas prices play an important role in determining wholesale electricity prices in Spain.

Keywords: Electricity market; Wholesale electricity price; Emissions Trading System; Fossil fuels; Entropy.

JEL classification codes: Q40, L51.

1. Introduction

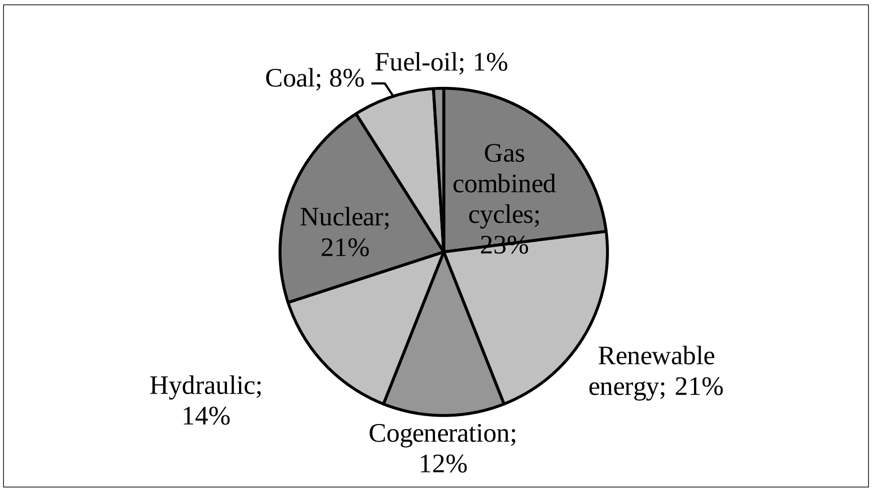
One of the key concepts in the Spanish electricity industry liberalization process has been the creation of a wholesale electricity market to determine electricity prices.

In this market, electricity generation selling companies determine the offered amount according to their short-term marginal cost, which is the variable cost of producing one extra unit of electricity (including the fuel, the emissions, and the operation and maintenance costs). The supply curve is constructed according to the "merit order" of plants of different technologies in generation markets, ranking capacity from the cheapest to the most expensive (in terms of marginal costs).

In parallel, electricity consumers establish the demanded amount. Finally, supply and demand settle at the same marginal kWh cost of electricity.

In Spain, although a substantial amount of electricity demand is covered from the electricity generated from hydro, renewables and nuclear technologies, the dominant production process covering the demand is still thermal conversion of fossil fuels, such as gas and coal as is showed in Figure 1.

Figure 1. Supply of demand by electricity production technology in Spain



Source: Own elaboration form Spanish Electricity Network (2010)

Thus, changes in these primary energy sources prices- natural gas, petroleum and coal- can directly affect electricity price as the costs of generating electricity are likely to be passed to the electricity prices through the wholesale electricity market (Nakawiroa *et al.*, 2008). The objective of the paper is to analyze the influence of those fossil fuels on Spanish wholesale electricity prices.

Furthermore, under the European Emission Trading System created in 2005, Spanish generator Companies incorporate their emission allowance costs in their sale offers to this market with the consequent increase of the wholesale electricity prices (Kim *et al.*, 2010). It has been shown in Germany (Weight, 2009) or Denmark (Nielsen *et al*., 2011). In this paper, we also analyze the effect of emission allowance costs on Spanish wholesale electricity prices

As we have shown, under Spanish electricity industry deregulation price formation was delegated to the law of supply and demand in the wholesale electricity market. Therefore, in order to determine the electricity price we present a simultaneous equations model to identify and estimate the demand and supply functions.

The simultaneous equations statistical model (SESM) has been applied extensively in econometric-statistical studies including two stage least squares (Theil, 1971), three stage least squares (Zellner and Theil, 1962), limited information maximum likelihood (Fuller, 1967) and full information maximum likelihood (Koopmans, 1950; Hausman, 1974).

However, the sample data related to the price that the European market assigns to carbon emission allowance is relatively recent since prior to 2005 there is no data available on this quantity. Therefore, the empirical analysis relies on yearly data collected from 2005 to 2010. In this situation of presence of small samples, traditional approaches may provide parameter estimates with high variance and/or bias, or provide no solution at all. As an alternative to traditional methods, we propose a Maximum Entropy Econometric approach. The approach consists of developing a non-linear inversion procedure (Golan, 2002) which requires the application of the tools provided by the Information Theory (Shannon, 1948; Jaynes 1957a, Jaynes 1957b).

The generalized maximum entropy approach were proposed for the linear SESM in different ways (Golan, 2002; Golan *et al*., 1997; Marsha *et al*., 2004) analyzed its sampling properties in small and large sample situations including the case of contaminated error models.

Thus, the objective of the paper is to analyze the influence of those fossil fuels on Spanish wholesale electricity prices by estimating simultaneous equations model using a Maximum Entropy Econometric approach.

This paper is organized as follows. In section 2 illustrates the proposed maximum entropy Econometric formulation. In section 3 we present the simultaneous equations model specification for the wholesale electricity market and the estimated model over the period 2005-2010. Conclusions and remarks are given in Section 4.

2. Maximum entropy estimation procedure

We introduce a general model specification for the SESM model and the procedure to its estimation by using a maximum entropy econometric approach when information is limited.

To provide a format for analyzing the simultaneous equations statistical model (SESM) we follow formalization of Golan (2002). Thus, consider the ith equation of a set of N simultaneous equations: $y_i = Y_i\alpha_i + E_i\beta_i + u_i = X_i\delta_i + u_i$, where y_i (matrix T_x1) and Y_i represent the endogenous-jointly determined variables in the ith equation and E_i represents the exogenous-predetermined variables in the ith equation.

Let X_i be a T_xm_i representing the endogenous Y_i and exogenous-predetermined E_i variables that appear in the ith equation with non-zero coefficients. Further, $\delta_i = (\alpha_i^{'}, \beta_i^{'})$ is a m_i dimensional vector of unknown and unobservable parameters corresponding to the endogenous and exogenous variables in the ith equation and u_i is a T-dimensional random vector for the ith equation. The variables y_i, Y_i, E_i are observed and δ_i and u_i are unobservable. The complete system of N equations may be written as:

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{pmatrix} = \begin{pmatrix} X_1 & & & \\ & X_2 & & \\ & & \ddots & \\ & & & X_N \end{pmatrix} \begin{pmatrix} \delta_1 \\ \delta_2 \\ \vdots \\ \delta_N \end{pmatrix} + \begin{pmatrix} u_1 \\ u_2 \\ \vdots \\ u_N \end{pmatrix}$$

or compactly as $y = X\delta + u$ where y and u are a NT-dimensional random vectors. Given the SESM, the problem consist in estimating the unknown and unobservable parameters δ_i or δ.

The Maximum Entropy Econometric approach allows to recover the estimates of $\delta_1^i, \delta_2^i, ..., \delta_m^i$ in the corresponding parameterized model without making distributional assumptions. The approach consists of developing a non-linear inversion procedure (Golan, 2002) which requires the application of the tools provided by the Information Theory (Shannon, 1948; Jaynes 1957a, Jaynes 1957b).

Consider a regression-based method $y_i = X_i\delta_i + u_i$ in a situation of limited sample data. A probability distribution should be used in order to represent partial and limited information regarding the individual observations so they are consistent with the observed sample data. Therefore, following Golan et al (1996) it is possible to define an inverse general problem for recovering δ_i defined as: $y_i = X_i\delta_i + u_i = X_iP_i + u_i$, where $P_i{:}(p_1^i, \ldots, p_m^i)'$ is a m-dimensional vector of unknown terms related to the probability distribution. The main objective is to estimate a probability distribution P_i given the limited information and minimal distributional assumptions and therefore recover δ_i as $\hat{P}_i = \hat{\delta}_i$.

However, as the number of observations (T) is smaller than the number of independent variables (m_i), in order to recover P by using traditional procedures of mathematical inversion, there is more than one vector P making the solution feasible. Therefore the problem is ill-posed and there is no basis for picking a particular solution vector for P from the feasible set. Thus, by asking for a particular set of probabilities considered as most likely, it seems reasonable to favor the one that could have been generated in the greatest number of ways given the available data.

The definition of the entropy measure H(P) and the formulation of the Entropy Maximization problem can help to estimate a unique P distribution since the principle of Maximum Entropy provides a basis for transforming the sample information into a probability distribution that reflects the uncertainty about the individual outcomes.

The measures of entropy H(P) quantify the uncertainty associated with a random experiment. In particular, given a random variable X with values x_i and probability distribution $P=(p_1,...,p_n)$ with $p_i \geq 0$ (i=1..., n) and $\sum_{i=1}^{n} p_i = 1$, Shannon's measure of entropy (Shannon, 1948) is defined as: $H_S(P)=H_S(p_1,...,p_n)=-\sum_{i=1}^{n} p_i \log p_i$.

The value of the entropy is maximum when all the values x_i have the same probability (and then P is a uniform distribution). This situation would be justified by the Laplace Indifference Principle, according to which the uniform distribution is the most suitable representation of the knowledge when the random variable is completely unknown. Nevertheless, sometimes the ignorance of the probability distribution of X is not absolute and there is some partial information on the distribution such as the mean, variance, moments or some characteristics which can be formulated as equality constraints. In such a case, it is possible to estimate the probability distribution through the application of the Maximum Entropy principle (Jaynes 1957a, Jaynes 1957b) choosing the distribution for which the available information is just sufficient to obtain the probability assignment: $\hat{P}=\{\hat{p}_1,\ldots,\hat{p}_n\}$

Working towards a criterion for recovering the parameters of the regression model in the general inverse problem $y_i = X_i\delta_i + u_i = X_i P_i + u_i$, if there is no evidence that a specific independent variable is more significant than others, the related probability distribution (P) would be the uniform (according to Laplace Indifference Principle). However, the principle of maximum entropy provides a basis for using the sample information in a probability distribution P that reflects the uncertainty about the individual independent variable. Therefore, the problem consists of estimating a nonnegative distribution P by maximizing the value of the entropy $H(P)$ subject to the available information. By solving the optimization problem the estimated probability distribution $\hat{P}$ is obtained.

A general inverse problem $y_i = X_i\delta_i + u_i = X_i P_i + u_i$ it is considered where the goal is to determine the unknown and unobservable frequencies $P_i=(p_1^i,...,p_m^i)'$, representing the data generating process. Then, within the possible sets of probabilities fulfilling $\sum_{I=1}^{m} p_I^i = 1, p_I^i \geq 0$, a single vector must be chosen. Through the application of the principle of maximum entropy $H(P)$ is maximized under the restrictions of information consistency $y_i = X_i P_i + u_i$, and the adding up-normalization constraint for P: $P'\ell = 1$.

However, under this first specification of the model $y_i = X_i\delta_i + u_i = X_iP_i + u_i$ the regression coefficients estimated may be limiting and unrealistic as they are interpretive as probabilities. There may be different levels of uncertainty underlying each unknown so it is possible to generalize the maximum entropy problem to permit a discrete probability distribution to be specified and obtained for each regression coefficient δ_i. Then, for each δ_i, it is assumed there exists a discrete probability distribution that is defined over a parameter space $\square^K$ by a set of equally distanced discrete points $Z^i = \left[z_1^i,\ldots,z_K^i\right]'$ with corresponding probabilities $P_i = \left[p_{i1},\ldots,p_{iK}\right]'$ and with $K \geq 2$. Thus, δ_i is viewed as the mean value of some well-defined random variable Z: $\delta_i = E_{P_i}\left[Z_i\right]$

If the vector of disturbances, u, is assumed to be a random vector with finite location and scale parameters, it is possible to represent the uncertainty about it by treating each u_t^i (t=1, ..., T) as a finite and discrete random variable with $J \geq 2$ possible outcomes.

Thus, it is assumed that each u_t^i is limited by a set of equally distanced discrete points V= [v_{t1}^i,.., v_{tJ}^i] with corresponding probabilities $W_i = \left[w_{i1},\ldots,w_{iJ}\right]'$. Thus, u_t^i is viewed as the mean value of some well-defined random variable V.

Given the reparametrization, the maximum entropy formulation for recovering the unknown δ_i parameter vector for the ith equation is given by:

Maximize: $$H(P_i,W_i) = H(P_i) + H(W_i) = -P_i^{'}\ln P_i - W_i^{'}\ln W_i$$

Subject to: $$\left.\begin{array}{l} y_i = X_iZ_ip_i + V_iw_i \\ (I_{m_i} \otimes \ell_k)p_i = 1_{m_i} \\ (I_T \otimes \ell_j)w_i = 1_T \end{array}\right\}$$

ℓ being a K-dimensional vector of ones, ℓ_N a N-dimensional vector of ones and $\otimes$ the Kronecker product. The solution of the optimization program give us $\hat{P}$ and thus $\hat{\delta}_i = E_{\hat{P}_i}\left[Z_i\right]$

3. The wholesale electricity price estimated

The objective of the paper is to analyze the influence of those fossil fuels on Spanish wholesale electricity prices by estimating simultaneous equations model using a Maximum Entropy Econometric approach. Therefore, in this section present the linear specification of the simultaneous equations statistical model and its estimation with Spanish data over 2005-2010.

3.1. Simultaneous equations statistical model specification

As we have seen in section 1, under wholesale electricity market, price formation was delegated to the law of supply and demand.

Supply curve is mainly determined by generation cost of producing electricity (including the fuel and emissions) so the long-term electricity supply function could be established as: P=f (Q, PG, PC, PP, PCO2), where P is the *wholesale electricity price*, Q *is electricity quantity*, PG, PP and PC are *gas price, petroleum price* and *coal price* respectively (as they constitute over 90% of the short-run marginal costs of their respective generating technologies) and PCO2 is the *CO_2 emission prices.*

Regarding the electricity demand, it is mainly determined by price, general economic activity and energy efficiency (Henley and Peirson, 1997, Lin, 2003, Fezzi and Bunn, 2010).

The general *economic activity* makes reference to the effects of economic growth on electricity energy consumption. In another way, the impact of the increase and transformation of the productive systems and the social habits of the country in electricity demand. An increase of the economic activity produce an increased household income involving greater electricity demand due to the increase of household equipment. Moreover, electricity is a necessary input in the production.

Moreover, the *energy efficiency improvement* (using as a proxy *energy insensitivity)* is also an important determinant to explain the demand of electricity. In that sense and *energy efficiency improvement* could decrease electricity demand.

We would like to point out that although weather factor is an important variable explaining electricity demand, it does not have a major impact on annual electricity consumption due to the small share of residential demand in the total electricity consumption in Spain.

The long-term electricity demand function could be established as: Q=f (P, EA, EI), where Q is *electricity quantity*, P is the *wholesale electricity price*, EA is *economic activity* and EI is *energy insensitivity*.

Regarding the functional form of the SESM, although there is no consensus in the literature about the most appropriate functional form, most of the studies adopt a linear or logarithmic form. Thus, assuming constant elasticities the simultaneous equations statistical model could be specify as:

$$\left.\begin{aligned} \ln(Q) &= \delta_0^d + \delta_1^d \ln(P) + \delta_2^d \ln(EA) + \delta_3^d \ln(EI) + u^d \\ \ln(P) &= \delta_0^s + \delta_1^s \ln(Q) + \delta_2^s \ln(PG) + \delta_3^s \ln(PC) + \delta_4^s \ln(PP) + \delta_5^s \ln(PCO2) + u^s \end{aligned}\right\}$$

This system describes the aggregate demand and supply functions submitted into the wholesale electricity market. The variables Q and P are jointly endogeneous and require non-standard statistical treatment. Both curves are specified in a double-log form and therefore can be empirically estimated as a system of linear equations.

3.2. Empirical estimation and results

In order to estimate the simultaneous equations model described above for the Spanish Wholesale electricity market, the following data is used:

-P (*Wholesale Electricity prices,* euros/MWh) obtained from the Iberian Energy Market Operator (Operador del Mercado Ibérico de Energía, OMEL) and

- Q (*Wholesale Electricity quantity,* MWh) obtained from the Spanish Electricity Network (Red Eléctrica Española)

-EA (*Economic Activity*, Millions of euro per capita): As a proxy of the *Economic Activity*, we consider the Gross Domestic Product per capita at constant price from Eurostat (Millions of euro, chain-linked volumes, reference year 2005, at 2005 exchange rates)

-EI (*Energy intensity of the economy*, kgoe- kilogram of oil equivalent per 1000 euro): This variable Obtained from Eurostat is defined as Gross inland consumption of energy divided by GDP (chain-linked volumes - reference year 2005).

-PG *(Price of Gas*, euros/Gigajoule): This variable obtained from Eurostat measures the price of gas for medium size industries in Spain.

-PC *(Price of Coal,* euros/ton): This variable is measure by using the McCloskey index obtained from the McCloskey Coal Report.

-PP (*Price of Crude Oil (petroleum),* euros/barrel): The variable obtained from World Bank measure the price of the Brent Crude Oil (light blend 38 API, fob U.K.).

-PCO2 (*CO_2 Allowance Emission price*, euros/ton). This variable is obtained from the electronic business system of the European CO_2 allowance emissions market (Sistema Electrónico de Negocio de Derechos de Emisión de CO_2, SENDECO).

The traditional simultaneous equations model (SEM) estimation [1-5] is applied extensively in econometric-statistical studies. However, the sample data related to the price that the market assigns to carbon emission allowance is relatively recent since prior to 2005 there is no data available on this quantity. Therefore, the empirical analysis relies on yearly data collected from 2005 to 2010 (T=6). In this situation of scarce information when trying to estimate the wholesale electricity price model through traditional procedures a dimensionality problem exists. In the presence of small samples traditional approaches provide no solution at all. As an alternative a Maximum Entropy Econometric approach is used to estimate the model.

We must first reparameterize the model, recasting the errors and parameters in terms of discrete probability distributions.

Firstly, it is necessary to establish an a priori range for the possible values that may be assumed by u error in the model, which may be employed to assume certain characteristics of its distribution: V. Since this decision is arbitrary, a support vector for the errors V=(-v, -v/2, 0, v/2, v) for v>0 is assigned. It guarantees error´s symmetry around zero. The decision regarding the amplitude of the range of values which it may assume is arbitrary. According with Golan el al. (1997) it is possible to use the *three standard deviation rule* (Pukelsheim 1994) as estimation for V= (-3s, -3s/2, 0, 3s/2, 3s) where s is the sample variance of y.

Moreover, a priori range for the possible values that may be assumed by δ in the model is also established. The restrictions imposed on the parameter space through Z should reflect the prior knowledge about the unknown parameters. In the absence of compelling economic theory, these bounds are set wide enough to be non-binding. However, if a priori information or economic theory can be called upon, these upper or lower bounds can be specified to restrict the coefficient to be either non-positive or non-negative. If δ_i is restricted to be non-negative, then $z_1^i = 0$ with $z_k^i > 0$ for all k > 1. Similarly, if δ_i is restricted to be non-positive, then $z_K^i = 0$ and $z_k^i < 0$ for all k <K. In our model, δ_2^d, δ_3^d, δ_1^s, δ_2^s, δ_3^s, δ_4^s, δ_5^s are constrained to be non-negative and δ_1^d are constrained to be non-positive, taking in all cases a vector support with three values. The considered vector supports are reported in table 1.

Table 1. Parameter support vectors

Variable	**Vector support**		
δ_i	z_1^i	z_2^i	z_3^i
Constant	-100	0	100
Electricity price	-80	-40	0
Economic activity	0	60	120
Energy Intensitivity	0	30	60
Electricity quantity	0	30	60
Price of gas	0	50	100
Price of coal	0	10	20
Price Petroleum	0	10	20
Price of CO_2 emissions	0	5	10

Table 2 and Table 3 show the estimated δ for the wholesale electricity price demand and supply functions under the reparameterized system by using the GAMS software (*General Algebraic Modeling System*).

In order to evaluate the overall estimated model we report the information index. Using the Maximum entropy econometric approach, one investigates how "far" the data pull the estimates away from a state of complete ignorance (uniform distribution). In order to measure the reduction in the initial uncertainty, the information index entropy measure R is defined (Soofi, 1990, 1992; Golan, 1994) and where $R \in [0,1]$. Higher is the value of R better is the estimated model. The reported estimated coefficients for the model correspond with highest R obtained.

Table 2. Estimated electricity demand model by Maximum entropy econometric approach

Variables	$\hat{\delta}_i$	$S(\hat{p}_i)$
Constant	20.113	0.972
Electricity price	-0.400	0.050
Economic activity	1.339	0.098
Energy Intensitivity	0.713	0.103
Support vector for the errors (-v, -v/2, 0, v/2, v)	v=	0.4
Estimated information index	R=	0. 7

Table 3. Estimated electricity supply model by Maximum entropy econometric approach

Variables	$\hat{\delta}_i$	$S(\hat{p}_i)$
Constant	-16.655	0.981
Electricity quantity	0.947	0.128
Price of gas	0.150	0.014
Price of coal	0.316	0.038
Price of petroleum	0.041	0.021
Price of CO_2 emissions	0.114	0.099
Support vector for the errors (-v, -v/2, 0, v/2, v)	v=	0.7
Estimated information index	R=	0.725

We also report the obtained values for the normalized entropy measure $S(\hat{p}_i)$, which allows to evaluate the obtained parameter estimations. As it ranges between 0 and 1 -where lower values indicate that a variable makes a real contribution to the model- the obtained values in our models indicate that all considered variables are appropriate to explain the model.

The estimated information index obtained indicates an important reduction of the uncertainty by using the maximization entropy approach. In fact there is a reduction of the uncertainty of 70% in both models.

Regarding the demand function, the results show low demand elasticity. As expected, variability on electricity prices is not always passed to end consumers. Moreover, an increase of 1% in GDP involves greater electricity demand by increasing a 1.339%.

With regard to the supply function, the findings yield that the prices related to the most primary energies such as gas and carbon allows us to explain electricity prices as $S(\hat{p}_i)$ is near zero. In fact, an increase of one percent in the price of gas, coal and petroleum produces an increase of 0.15%, 0.31% and 0.04% respectively in the wholesale electricity price by holding all the other relevant factors constant.

In addition, an increase of one percent in the price of CO_2 emissions produces an increase of 0.11% in the wholesale electricity price by holding all the other relevant factors constant.

4. Conclusion

This paper examines the relations between Spanish wholesale electricity prices and fossil fuels prices – coal, natural gas and crude oil by using a maximum econometric approach. Instead of focusing only on electricity price dynamics in a single equation framework, we consider price and quantity interactions in a simultaneous system of equations based on the electricity wholesale market operation- where price formation is delegated to the law of supply and demand.

The electricity supply curve is mainly determined by the short-term marginal cost (including the fuel and the emissions) of the different technologies in electricity generation markets. In Spain, the dominant production process covering the electricity demand is still thermal conversion of fossil fuels; therefore, the marginal costs that determine the electricity prices are basically those related to coal, gas and crude oil prices, but also emission cost. The electricity demand curve, it is mainly determined by price, general economic activity and energy efficiency improvement.

The empirical estimation of the simultaneous equations model for Spanish wholesale electricity market has been carried on over the period 2005-2010.

The obtained results indicate that economic activity involves greater electricity demand as electricity is a necessary input in the production in a modern economy. As expected, the estimated demand price elasticity is very low indicating that variability on electricity prices is not always passed to end consumers.

Regarding the electricity supply, an increase in the fossil fuel costs and emission prices leads to higher electricity prices. In fact, an increase of one percent in the price of gas produces an increase of 0.15% in the wholesale electricity price by holding all the other relevant factors and an increase of one percent in the price of coal produces an increase of 0.3% in the electricity price.

Our results confirm the importance on gas prices on the Spanish wholesale electricity price as other authors has pointed out by using different sets of historical data and different methodologies (Furió and Chuliá, 2010; Mounthino *et al*., 2011). Moreover, as electricity production by gas combined cycle power plants has significantly increased in Spain, the additional gas demand results in higher prices for gas, which also results in higher prices for electricity as Möst and Perlwitz (2009) have been shown in the European Union. In order to reduce high gas dependence in power generation an increase in the efficiency of gas-fired power plants, energy source diversification and the development of new processes could be appropriate. The development of renewable energy industries has become a way to decrease the use of fossil fuels and CO_2 emission in electricity generation.

We would like to point out that Spain has a high dependence on imported fossil fuels as crude oil and natural gas used are imported 100% and coal almost 65%; Therefore the link between electricity prices and international energy commodities prices introduces some risk to energy generation related to volatility of international market prices

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The Impact of EU ETS on the Spanish Electricity Prices

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Abstract

This paper addresses the impact of the CO_2 opportunity cost on the wholesale electricity price in the context of the Spanish electricity market for the period corresponding to the Phase II of the European Union Emission Trading Scheme (EU ETS). In the econometric analysis we specify a Vector Error-Correction Model (VECM) to estimate both long-run equilibrium relations and short-run interactions between the electricity price and the fuel (natural gas and coal) and carbon prices. The model is estimated using daily market prices and the four commodities prices are modeled as jointly endogenous variables. Moreover we include a set of exogenous variables in order to account for the electricity demand conditions (temperature) and the electricity generation mix (electricity generated by technology, bided/matched over 95% of the marginal price). The results for the Spanish electricity market suggest that the dynamic pass-through of carbon prices into electricity prices is strongly significant and we estimated a long-run elasticity (equilibrium relation) that is in line with studies that have been conducted for other markets. The results show evidence that power producers have been passed on the opportunity costs of freely allocated emissions allowances to electricity prices, enabling power companies to get windfall profits.

JEL codes: Q41, Q48, C32, Q51, L94

Keywords: EU ETS; Spanish electricity market; MIBEL; Cost pass-through; Windfall profits; Cointegration; Vector Error Correction Model

1. Introduction

The European Union (EU) has implemented a cap-and-trade system - Emission Trading Scheme (EU ETS) on January 2005 as a tool to reach the emissions targets set forth Kyoto Protocol. In this regard, it is design to operate in two phases, the first from 2005 to 2007, while the second spans the period 2008 to 2012. Each of these phases corresponds to a National Allocation Plan (NAP) which specifies the total number of emissions allowances allocated (grandfathered[1]) to the individual installations covered by the scheme. Transactions of such allocated allowances are then made possible through an EU emissions allowances (EUA) market that provides a price for the CO_2. The scheme covers several industry sectors of which electricity sector is the largest one. Therefore, the performance of EU ETS depends on environmental effectiveness (inducing electricity industry to cut CO_2 emissions) and economic efficiency (ensure that the cuts would be made by those firms that could achieve the most efficient abatement costs). Furthermore, the EU ETS might also have a considerable distributive and welfare implications, impacting on consumer's surplus and firm`s profits and competitiveness. Either the performance of the EU ETS or its distributive and welfare implications depends on what extent the CO_2 emission allowances prices are passed through into electricity prices. This study focuses on this latter issue, analyzing the impact of EUA prices on electricity pricing in the short and long run.

Economic theory explains why, under a cap-and-trade system, the price of emissions ought to be treated as a marginal cost. As a producer holds allowances, the electricity production, and CO_2 emitting, competes with the possibility to sell those allowances in the market. This so-called CO_2 opportunity cost equals the CO_2 market price. While electricity producers may full recognize the opportunity costs of CO_2 allowances in their marginal production costs, these costs might not be fully passed through to electricity prices. (Sijm, et al., 2005) and (Gullì, 2008) give a set of reasons why the pass-through rate (PTR) of CO_2 costs into electricity prices may different than 100%, including among other reasons demand responses (price elasticity), level of power demand, market structure (degree of market concentration), technology mix (fuel used in production), available generation capacity. In this paper we empirically study the dynamic interaction between carbon prices, electricity prices and fuel prices (natural gas and coal) for the Spanish electricity market, a division of Iberian Electricity Market (MIBEL), for the Phase II of EU ETS (January 2008 to December 2011).

This paper builds on previous work by the authors (Freitas and Silva, 2012a) and (Freitas and Silva, 2012b). According to our knowledge, we think this study introduces some innovation in the state of the art (empirical research in measuring pass-through of CO_2 costs into commodities or products prices) in respect to the treatment given to the exogenous variables that aims to reflect the marginal power production unit present in the electricity system.

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[1] Free allocation of CO_2 allowances on the basis of historical emissions.

2. Literature Review

The interaction between carbon prices and electricity prices has been examined in several other studies. A more extensive literature review regarding the EU ETS impact in the European power sector can be found in (Freitas and Silva, 2012a) and (Freitas and Silva, 2012b). Most of published analyses conduct in order to estimate the PRT of CO_2 cost into electricity prices have not considered the mutual interactions between electricity price, fuel prices (natural gas, coal, fuel, oil) and carbon prices. One the first studies taking into account those interdependencies was provided by (Fezzi and Bunn, 2009) where the authors, using multivariate analysis, modeled the prices of all variables as a joint system. Developing a vector error correction model (VECM), with the electricity, gas and carbon prices as endogenous variables and temperature as an exogenous regressor, the authors estimated the dynamic pass-through of CO_2 price into electricity price for Germany and UK. Other studies have been following that econometric approach, where this article also belongs. (Honkatukia, et al., 2006) developed a similar model for the NordPool market considering the electricity, gas, coal and carbon prices as endogenous variables. (Fell, 2010), also for the NordPool and with the same prices variables, added to the VECM the temperature and the reservoir water level as exogenous regressor. (Chemarin, et al., 2008) estimated with a VECM for the France power market considering the electricity, gas, oil and carbon as prices as endogenous and a two different weather variables: the temperature, affecting the demand side of electricity market, and rainfall influencing the electricity production of a country with regards of its energy mix. (Thoenes, 2011) with the same econometric approach, analyses the relationship between electricity, fuels and carbon prices for the German market.

Other works has been conducted in order to examine the long-run relation and short-run dynamics between electricity prices and fossil fuel prices. (Mohammadi, 2009) analyses the relation between the electricity prices and coal, natural gas and crude oil for the USA market, (Mjelde and Bessler, 2009) for the same market added the uranium price to the analysis, (Ferkingstad, et al., 2011) studied the Northern European electricity market case and (Moutinho, et al., 2011) the Spanish case.

3. Spanish Electricity Market Background

The Spanish energy sector was liberalized in late 1990s and the Spanish electricity wholesale market was established in 1998. The design for the market was partially based on other liberalized electricity markets (namely those in United Kingdom, Scandinavia, and some U.S. markets) (Pacheco, 2010). An important reform implemented in the Iberian wholesale electricity markets was the launch of MIBEL on July 2007.The joint Portuguese-Spanish electricity market allows participants to trade power on either side of the Portugal/Spain border. The daily spot market (the drive of the current study) is managed by OMEL (Operator responsible for the Electricity Spot Market). The wholesale electricity spot price formation in OMEL uses “market splitting” procedure to solve cross-border congestion management- one single Iberian price area, if there is no congestion in the interconnection between Spain and Portugal and with distinct price areas, if there is congestion in the interconnection between both countries (Silva and Soares, 2008).

Table 1 show total installed capacity and production by technology at the end of 2010. Five firms have been operating in the Spanish power generation market as competitors: Endesa, Iberdrola, Unión Fenosa, Hidroelectrica del Cantábrico and Electra del Viesgo.

Table 1. Electricity Production and Generation Capacity by Technology

	Installed Capacity (MW)		**Electricity Production (GWh)**	
Thermal Fuel/gas	2.860	2,9%	1.825	0,7%
Thermal Coal	11.380	11,5%	22.097	7,9%
CCGT (Natural Gas)	25.235	25,5%	64.604	23,1%
Hydroelectric	17.561	17,7%	38.653	13,8%
Nuclear	7.777	7,9%	61.990	22,1%
Renewables	27.238	27,5%	61.866	22,1%
Others	6.992	7,1%	29.036	10,4%
Total	99.043	100,0%	280.071	100,0%

Source: REE – Red Eléctrica de España: "El Sistema Eléctrico Español".

The influence of carbon on the price of electricity may not be constant across time. Even the unlikely event of full pass-through of CO_2 costs, the CO_2 emissions associated with electricity generation will remain a function of generation fuel expended. This in turn induces the increase in the marginal cost of electricity generation due to CO_2 market dependency upon the technology adopted in generation. Assuming that Spanish e electricity market is competitive with electricity pricing based on the cost of marginal generator, the changes in electricity prices due to carbon emissions prices will depend on the generation technology of the marginal producer. If the electricity market in question has generation technologies at the margin that vary over time, such as the Spanish electricity system, then the electricity price response to carbon price changes will be variable across time. This presents an additional challenge to the estimation of the electricity responsiveness to CO_2 prices changes. In order to overcome this difficulty, we included in the econometric model a set of variables, which we hoped to serve as a proxy of the marginal producer (electricity generated by technology, bided/matched over 95% of the marginal price). Climate variables, such as temperature, rainfall or brightness may also influence the relationship between electricity and carbon prices (Engle, et al., 1986). As in (Freitas and Silva, 2012a) and

(Freitas and Silva, 2012b) we chose to incorporate in the model only the effects of climate variables on the demand side (air temperature) to the extent that we hope the supply side effects would be captured by the energy mix variables mentioned above.

The basic assumption in our econometric analyses is that changes in electricity prices can be explained by variations in fuel and carbon costs of the price-setting technology. Hence, is assumed that other costs (capital, operational or maintenance costs) are constant, and that the market structure did not vary over the period of the study. Therefore, changes in prices cannot be attributed to changes in technology, market power, generation capacity or other factors.

4. Data

This study covers the period corresponding to the Phase II of EU ETS, running from January 01, 2008, to December 31, 2011. We use daily data for working days[2]. The electricity series, from OMEL, is the day-ahead price (€/MWh) for the peak load regime. The peak price is the hourly average of spot prices quoted from 8:00h to 20:00h. The natural gas price (€/MWh gas) is the spot price from the TTF (Title Transfer Facility) trading hub[3]. The coal price (€/ton.) is the spot index API#2 (CIF ARA[4]). The EUA price series (€/ton.) is the future price quoted at EEX – European Energy Exchange (Leipzig, Germany)[5]. We transformed the price variables into their natural logarithms to reduce variability, and thus obtaining directly the elasticity values from the parameter estimates.

In order to consider the non-linear relationship between electricity demand and air temperature, which as shown by (Engle, et al., 1986) is non-linear ("V" shaped function) as it is used for both heating or cooling purposes, as other studies ((Fezzi and Bunn, 2010), (Fezzi and Bunn, 2009) and (Fell, 2010), including for the Spanish case (Valor, et al., 2001) and (Labandeira, et al., 2012)), we modeled temperature as a deviation from a threshold. Thus, we defined two climate variables: *HDD* (heating degree days), which represents the deviations of mean temperature below the threshold of cold (increasing of electricity demand is mainly for heating purposes) and *CDD* (cooling degree days) which represents the deviations above the threshold of heat (increasing of electricity demand is mainly for cooling purposes)[6]. We used the thresholds proposed by (Labandeira, et al., 2012) for the Spanish case, considering the level of 13 ºC for *HDD* and 23ºC for *CDD*.

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[2] Weekend and national holidays are excluded from this study because demand patterns are substantially different from working days.

[3] TTF in Netherlands is one of the most important trading hubs in Europe; physical natural gas delivery at notional trading point, the Dutch Title Transfer Facility.

[4] Delivered to the Amsterdam/Rotterdam/Antwerp region.

[5] We selected the future price because this is the only price series of EUA 2nd Phase that starts at January 1st, 2008. However we tested prices from other markets (futures and spot), namely ECX – European Climate Exchange (London, UK) and BlueNext (Paris, France) and we did not find significant differences.

[6] HDD = max (T^*– T_t; 0) and CDD = max (T_t–T^{**}; 0), with T_t representing the mean daily temperature, T^* the cold threshold and T^{**} heat threshold

To control the model for the marginal technology in the market, we defined four variables according to the merit order present in the Spanish power generation mix: renewables, hydroelectric, thermal coal and CCGT are the usual marginal technologies[7]. Each variable "mix_t^m" is defined as the ratio between the power generated by the technology "*m*" bided/matched over 95% of the marginal price and the total amount of power in the market bided/matched over 95% of the marginal price. For instance, the variable mix_t^{coal} = 0,25 means that, on day *t*, 25% of all electricity bided/matched over 95% of the marginal price was produced by coal-fired power plants. These variables, as the air temperature variables, are treated in the econometric model as exogenous variables.

Table 2. Summary Statistics

	Main Variables - Prices						**Control Variables**					
	Electricity			**Inputs**			**Temp.**		**Production Technologies**			
	Peak	Base	Off-peak	Carbon	Gas	Coal	CDD	HDD	Renew	Hydro	CCGT	Coal
units	*€/MWh*	*€/MWh*	*€/MWh*	*€/Ton.*	*€/MWh*	*€/Ton.*	*ºC*	*ºC*	*%*	*%*	*%*	*%*
Mean	52,20	48,01	43,83	15,92	19,31	76,78	1,41	2,28	0,03	0,19	0,58	0,17
Median	50,72	46,93	42,92	14,80	21,40	78,62	-	-	0,01	0,14	0,64	0,11
Min.	3,47	4,62	5,78	6,90	7,00	42,46	-	-	0,00	0,00	0,00	0,00
Max.	93,67	82,13	72,98	29,27	31,49	141,91	8,64	13,43	0,70	0,87	0,97	0,83
Std. Dev.	14,60	13,47	12,72	4,55	5,89	22,32	2,28	3,10	0,11	0,16	0,27	0,18
Var.Coef.	0,28	0,28	0,29	0,29	0,31	0,29	1,62	1,36	3,25	0,89	0,46	1,07
Skewness	0,33	0,17	-0,03	0,93	-0,37	0,51	1,32	1,19	4,74	1,60	-0,67	1,39
Kurtosis	-0,16	-0,29	-0,29	0,26	-1,01	-0,08	0,31	0,38	21,60	2,77	-0,61	1,44

Source: Electricity prices - OMEL; Inputs (fuel prices and EUA price) - Thomson Reuters/DataStream; Air temperatures - European Climate Assessment & Dataset (ECA&D), Production technologies: OMEL.

[7] We excluded the thermal fuel because it has represented the marginal technology at very few situations. Moreover, as we will see latter, in the econometric model it is not statistical significant.

5. Model Description

Empirical research in measuring pass-through of CO_2 costs into commodities or products prices, including the electricity price, typically applies one of two modeling techniques: univariate approach, with a single equation regression, or multivariate approach. Recent studies have confirmed that dynamic interactions may play a fundamental role in the price formation process of electricity wholesale markets (Knitell and Roberts, 2005) and multivariate analysis of simultaneous equations is the only technique that avoids the endogeneity problems by treating all variables (electricity price, fuel prices and EUA prices) to be endogenous. Multivariate analysis has been developed using either the VAR models or cointegrated VAR (CVAR) models. As noted in (Engle and Granger, 1987), there are strong beliefs that economic data are non-stationary, meaning any particular price measure over time will not be tied to its historical mean. So, modeling that kind of data by a levels VAR model appears to be inadequate, because of spurious regression risk, thus requiring one of the two solutions: i) modeling a VAR in first differences which may impose the risk of loss relevant information about long-term relationships; ii) specifying a CVAR, if the variables show a very interesting property, namely the cointegration. The latter alternative, if it is possible, has the advantage of allowing the simultaneous analysis of the long-run interactions and the short-term adjustments to the equilibrium relationship.

The cointegration concept, introduced by (Engle and Granger, 1987), means that individual economic variables may be non-stationary and wander through time, but a linear combination of them may converges to a stationary process. Such a process, if present, may reflect the long-run equilibrium relationship, and is referred to as the cointegration equation. According to (Engle and Granger, 1987), cointegrated variables must have an error correction representation in which an error correction term (ECT) must be incorporated into the model. Accordingly, a VECM is formulated to reintroduce the information lost in the differencing process, thereby allowing for long-run equilibrium as well as short-run dynamics. Several procedures have been proposed for testing the null hypothesis that two or more non-stationary time series are not cointegrated, meaning there exist no linear combinations of the series that are stationary. One approach is to use likelihood ratio tests based on estimation a VAR. This approach was first proposed by (Johansen, 1988), (Johansen and Juselius, 1990) and was been extended later by (Harbo, et al., 1998) and (Pesaran, et al., 2000) to includes exogenous variables in the model, which in our case is particularly useful because it allows an adequate treatment of the marginal technology and temperatures variables.

Given the order of integration of the variables used, a general VECM specification can be formulated as:

$$\Delta \mathrm{P}_{\mathrm{t}} = \alpha \beta' \mathrm{P}_{\mathrm{t}-1} + \sum_{\mathrm{i}=1}^{\mathrm{k}-1} \Gamma_{\mathrm{i}} \Delta \mathrm{P}_{\mathrm{t}-\mathrm{i}} + \Phi \mathrm{Z}_{\mathrm{t}} + \mu_t + \varepsilon_t \quad ; \qquad \varepsilon_t \sim Niid(0, \Sigma)$$

- Where P_t is a (4x1) vector of prices (endogenous variables) measured at time t: $P_t = [P_t^{peak}, P_t^{carb}, P_t^{gas}, P_t^{coal}]$ - P_t^{peak} is the natural logarithm of electricity price, P_t^{carb} is the natural logarithm of CO_2

emission allowances price, P_t^{gas} is the natural logarithm of natural gas price and P_t^{coal} is the natural logarithm of coal price. α and β are (4xr)[8] matrix, whereas β and α represent the cointegrating vectors and the matrix with the estimations on the speed of adjustments to the equilibrium, respectively.

- Where Γ_i is a (4x4) matrix with the estimations of short-run parameters relating price changes lagged i periods.

- Where Φ is a (4x6) matrix of coefficients associated with the (6x1) vector Z_t that represents the exogenous variables: $Z_t = [mix_t^{renew}, mix_t^{hydro}, mix_t^{ccgt}, mix_t^{coal}, CDD, HDD]$ - mix_t^{renew} is the % of electricity bided/matched over 95% of the marginal price on day *t* produced by renewables, mix_t^{hydro} is the % of electricity bided/matched over 95% of the marginal price on day *t* produced by hydroelectric power plants, mix_t^{ccgt} is the % of electricity bided/matched over 95% of the marginal price on day *t* produced by CCGT power plants, mix_t^{coal} is the % of electricity bided/matched over 95% of the marginal price on day *t* produced by coal-fired power plants, and the air temperature variables (HDD and CDD) as defined previously.

- Where μ_t is a (4x1) vector of constant[9] and ε_t is a (4x1) vector of innovations.

Estimation typically proceeds in two stages: first, a sequence of tests is run to determine *r*, the cointegration rank. Then, for a given rank the parameters are estimated. The row rank of β determines the number of cointegration vectors. Usually two tests on the eigenvalues are used to determine *r*: Trace Test and λ_{max} Statistics.

6. Empirical Results

We start our estimation procedure by testing the non-stationarity for all price series. We tested the null hypotheses of a unit root (UR) trough the Augmented Dickey-Fuller Test (ADF test). The tests are conducted using the natural logarithms of the price series (electricity, EUA, natural gas and coal). As shown in Table 3, all series fail to reject the null of a UR for all specifications tested at a 5% level except for electricity price (ADF Test with only a constant). However, the Unit Root Test with Breaks, which allow accounting for the possibility of level shift (Lanne, et al., 2002), confirm the non-stationarity of the electricity prices. On the contrary, we have evidence that the differenced series are stationary. These results provide evidence for the hypotheses that all prices are non-stationary in levels, but have stationary first differences.

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[8] Where *r* is the number of cointegrating vectors.

[9] Actually $\Pi = \alpha\, \beta'$ may be of order (4x5) or (4x4) depending on whether the constant is inside or outside (restricted or unrestricted) of the cointegration space.

Table 3. Unit Root Tests

	ADF Test					Unit Root Test With Breaks		
Natural Logarithm of Prices - Levels								
	Lags	Constant		Const.&Trend.			Lags	Constant
		Stat.	p-value	Stat.	p-value			Stat.
Ppeak	6	-2,925	0,04	-2,860	0,18	Ppeak	6	-1,170
Pcarb	0	-0,487	0,89	-1,306	0,89	Pcarb	0	0,264
Pgas	0	-1,996	0,29	-2,011	0,59	Pgas	0	-1,987
Pcoal	0	-1,116	0,71	-1,119	0,92	Pcoal	0	-1,044
Natural Logarithm of Prices - First Differences								
Series	Lags	Constant		No Constant				
		Stat.	p-value	Stat.	p-value			
Δ *Ppeak*	5	-18,491	0,00	-18,498	0,00			
Δ *Pcarb*	0	-29,456	0,00	-29,409	0,00			
Δ *Pgas*	0	-32,672	0,00	-32,688	0,00			
Δ *Pcoal*	0	-30,741	0,00	-30,756	0,00			

Notes: Null hypotheses of a unit root (the series is non-stationary) for ADF test and Unit Root With Breaks test. Critical values and p-values for ADF test are given in (MacKinnon, 1996). Critical values for UR With Breaks test are given in (Lanne, et al., 2002): -2,58; -2,88 and -3,48 for 10%, 5% and 1% significant level respectively. Number of lags chosen by SIC minimization (maximum of 20 lags) for ADF and UR tests.

The first step in modeling procedure is to determine the lag relationship among the price series in the levels VAR. The AIC (Akaike Info Criterion), SIC (Schwarz Info Criterion) and HQC (Hannan and Quinn Criterion) loss metrics suggest the appropriate VAR lag length is two[10] *K=2*, indicate that the inclusion of exogenous variables (both the generation mix variables and weather variables) improves the fit of the VAR to the data and suggest not including lags in the exogenous variables.

The tests of cointegration were implemented with the technique based on the reduced rank regression introduced in (Johansen, 1991). Since the VAR model contains exogenous variables, the (Osterwald-Lenum, 1992) and (Johansen, 1995) asymptotic critical values are no longer valid, and we therefore used the asymptotic critical values provided in (Mackinnon, et al., 1999), which results from improvements made to the work in (Pesaran, et al., 2000). The decision of whether the constant is within or outside of the cointegration space was based on the three metrics, and the results recommend restricting the intercept to lie in the cointegration space.

[10] As the VAR is specified in first differences, the number of lags lag in the VECM should be one (*k-1*).

Table 4. Cointegration Tests

H_O:		Trace Test			λ_{max} - Max Eigen Value Test		
r =	p-r =	Statistics	Critical Values	p-values	Statistics	Critical Values	p-values
0	4	158,67	109,82	0,00	113,18	47,63	0,00
1	3	45,49	78,33	0,93	34,21	40,98	0,22
2	2	11,29	50,57	1,00	8,18	34,00	1,00
3	1	3,11	26,14	1,00	3,11	26,14	1,00

Notes: 5% significant level for critical values is. p-values calculated using the software in (Mackinnon, et al., 1999). Model with restricted constant (Case II), two lags in endogenous variables and 6 exogenous variables.

The results for both Trace Test and λ_{max} Statistics, presented in Table 4, clearly indicate the existence of one cointegrated vector. So, we proceed under the result of a single long-run relationship among the variables.

With the cointegration rank and optimum number of lags determined, the parameters of model can be estimated. The results reported in Table 5 for the cointegrated vector β, which is normalized on P_{t-1}^{peak}, show that all estimates parameters have the correct sign and they are all significant (at 10% significance level) according to the Likelihood Ration Test as showed in (Johansen, 1995). Since the coefficients can be interpreted as price elasticities, therefore, a EUA price rise of 1%, would, in equilibrium, be associated with an electricity price rise of 0,27% (0,25% in the natural gas price and 0,27% in coal price). In addition, it appears from the parameter estimates for the adjustment coefficients α (EC_{t-1}), for 5% significance, only the electricity price series reject the null, meaning that the long-run relationships in the data are important only for the electricity price. These results are expected since EUA, natural gas and coal are commodities traded global and thus may be driven more by forces outsider the Spanish energy market. As one can see, the evidence of weak exogeneity is not so strong in the case of coal prices.

Analyzing the short-run parameters in the VAR, only the lagged electricity price is significant. In the case of the exogenous variables, we could confirm that the marginal technology is important for the short run dynamics of electricity price. There is also strong evidence that the weather variables are important for electricity price changes in the short-run, when the demand of electricity reflects either heating (*HDD*) or cooling (*CDD*) purposes.

Table 5. VECM Parameter Estimates

Cointegration Relationship				
P_t^{peak}	P_t^{carb}	P_t^{gas}	P_t^{coal}	*Const.*
1,000 ***	-0,268 ***	-0,253 **	-0,272 *	-2,397 ***
	(0,080)	(0,107)	(0,136)	(0,530)

Short Run Dynamics				
	ΔP_t^{peak}	ΔP_t^{carb}	ΔP_t^{gas}	ΔP_t^{coal}
EC_{t-1}	-0,194 ***	-	-	-0,007 *
ΔP_{t-1}^{peak}	-0,332 ***	0,016 **	-	-
ΔP_{t-1}^{carb}	-	0,074 **	0,110 **	0,104 ***
ΔP_{t-1}^{gas}	-	-0,031 *	-	0,030 *
ΔP_{t-1}^{coal}	-	-0,113 ***	-	-
mix_t^{renew}	-0,622 ***	-	-	-
mix_t^{hydro}	-0,169 ***	-	-	-
mix_t^{ccgt}	-0,237 ***	-	-	-
mix_t^{coal}	-0,229 ***	-	-	-
CDD	0,002 **	-	-	-
HDD	0,002 **	-	-	-

Notes: EC_{t-1} refers to the adjustment coefficients (α). We only present the significant coefficients. Standard errors in parentheses. *** Significant at 1% level; ** Significant at 5% level; * Significant at 10% level.

*Table 6. Diagnostic Tests on Residu**als***

Diagnostic Tests on Residuals		
Serial Correlation [H_0: uncorrelated]		
Ljung-Box Q' (5)	6,811	[0,235]
Heterocedasticity [H_0: homokedastic]		
ARCH (5)	91,413	[0,000]
Normality (H_0: normal distributed)		
Doornik-Hansen (8)	5.339,7	[0,000]

Notes: p-values in parentheses.

Table 7. Residuals Correlation Matrix

ΔP^{peak}	1	0,026	0,005	-0,038
ΔP^{carb}	-	1	0,108	-0,039
ΔP^{gas}	-	-	1	0,065
ΔP^{coal}	-	-	-	1

Although residuals analysis (Table 6) shows evidence of autoregressive conditional heterocedasticity (ARCH) and non-normality this is not likely to be a major problem in our cointegration analysis since (Gonzalo, 1994) showed that the properties of asymptotically optimal inferences present on maximum likelihood estimators hold in finite samples even without the normality assumption.

7. Conclusion

This study uses a VECM approach to conclude on the relationship between electricity prices and CO_2 emissions allowances prices for the Spanish electricity market (a division of MIBEL) in the context of the Phase II of EU ETS (2008-2011). We developed an econometric model that encompasses long-run and equilibrium and short-run effects in the dynamic interactions between electricity, carbon, gas and coal prices. We control the effect of the input prices in electricity price by using two sets of exogenous variables: one reflecting the demand for electricity conditions (temperatures) and the other reflecting the marginal technology present in the system (weight of each technology present in the production mix on the total electricity bided/matched over 95% of the marginal price). Using daily data, we show that carbon price plays an important role in formulating the equilibrium price of electricity and, as the other fuels, is essential exogenous in the long run. The long-run elasticity of electricity price to carbon price shocks, here the CO_2 Cost Pass-Through, is 27%, meaning that, in the long-run, a 1% shock in carbon prices impact, on average, into a 0,27% shock in electricity prices. Our results compare with 93% in (Honkatukia, et al., 2006) for the NordPool market, 32% in (Fezzi and Bunn, 2009) for the UK market, [11% - 13%] in (Fell, 2010) for the NordPool market and 36% in (Thoenes, 2011) for the German market. In addition, the results we found are below the simulations ([60%-63%] in (Sijm, et al., 2008) and [60%-100%] in (Lise, et al., 2010)) and the empirical estimates, for the period 2005-2006, ([52%-111%] in (Sijm, et al., 2008)) for the Spanish market.

Concluding, the results we have estimated for the Spanish wholesale electricity market, in line with studies for other different European electricity markets, show evidence of a significant link between carbon prices and electricity prices demonstrating that power producers have been passed on the opportunity costs of freely allocated emissions allowances to electricity prices, enabling power companies to get windfall profits. According to these conclusions the competitiveness of the power producers may not be affected if the companies have to pay for emissions allowances, which therefore would result in a distributive impact on consumer's surplus and firm`s profits. Therefore, this results support the changing in allocation rule of emissions allowances to the electricity sector, from grandfathering to auctioning, proposed by the European Commission for the next phase of the EU ETS starting on 2013.

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Copulas and CoVaR, with applications for the energy market

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Abstract

The paper presents a novel methodology for the estimation of systemic market risk. For this, we extend the conditional value-at-risk methodology proposed by Adrian and Brunnermeier (2011) by applying copulas. First, the theoretical foundations behind the analysis are put forward. Next, the generic framework is provided. Different Archimedean copulas are calibrated to historical market data of the most important electric energy futures. Empirical implementations highlight the strength of the methodology as we show that taking into account the complete correlation structure allows for a much better estimation of market risk. Using power derivatives, the paper bridges the gap between the energy markets and the advancements in quantitative risk management.
Keywords: Copula, Conditional Value-at-Risk, Energy Market, Systemic Market Risk.
JEL Classification: C10, C31, C53, G32

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Contents

1 Impetus

Introduction

Modern portfolio theory argues that, as long as returns are multivariate normally distributed, then what influences agents' behavior are the first and second moments of the return distribution. As a matter of fact, most applications assume multivariate normality (either by conditioning returns on common factors, or through the asymptotic behavior of an infinitesimally granular portfolio). However, empirical studies generally fail not to reject this assumption for individual assets.

Since one is generally interested in the risk of individual positions, we propose a novel methodology able of taking into account the complete correlation structure between assets. As a result, the risk inherent in individual assets can be extracted by inferring information through other market variables. Indeed, using copulas allows reaching exactly the aforementioned target.

A striking fact is that, regardless of the advances in risk management practices in the financial industry, apparently little attention has been given to the non-financial sector, The energy market, and more precisely the electric energy market, is exemplar for this phenomenon. Indeed, rather few studies bridge the gap between financial risk management and the energy market[1]. This restriction is amplified when taking into account the price patterns observed in the electricity market. Indeed, as mentioned by Aggarwal et al. (2009) [2] energy prices face a mean and variance that is driven by seasonality and calendar effects. Moreover, they are influenced by the properties of electricity, namely non-storability, inelastic short-term demand and an oligopolistic generator market.

Hence, our motivation for presenting, comparing and empirically assessing a new methodology to market risk measurement by referring to electric energy derivatives.

Related literature

Ané and Kharoubi (2003) [5] incorporate copulas for the construction of multivariate distribution and density functions. Thereby, they are able to set up multivariate models that are still flexible enough to be applicable to risk management. Moreover, they allow incorporating subjective judgments of the random variables' distributions. They propose applying parametric as well as non-parametric copulas to asset returns. Fitting the parametric copulas is done via log-likelihood estimations. In order to fit non-parametric copulas they propose the approach introduced in Deheuvels (1979 [24] & 1981 [25]). After running Monte Carlo simulations on different two-stock-index portfolios, the authors

[1] Some relevant studies include: Chiu et al. (2010) [15] who apply different conditional approaches for the estimation of value-at-risk for Brent and WTI crude oil prices. Huang et al. (2008) [39] who apply GARCH-type models for different energy commodities. Cabedo and Moya (2003) [12] focus on the oil market whereas Giot and Laurent (2003) [35] compare the RiskMetrics approach to a Student-type one.

come to the conclusion that up to 20% of the deviations between the model and the historical value-at-risk are due to a misspecification of the dependence structure between the asset returns.

In the same line of thought, Cherubini and Luciano (2001) [14] apply the Archimedean copula family and historical distributions to estimate tail probabilities and the market risk trade-offs. They conclude that copulas allow for an efficient smoothening of multivariate distribution functions.

Barbieri et al. (2009) [8] apply a factor model to estimate 5% value-at-risk, on a one-day as well as multiple-day basis. They compare the daily factor returns method and the scaled BIM[2] covariance matrix method to the EWMA approach. As highlighted by the authors, EWMA is applicable as a benchmark value-at-risk model for the proposed factor models as long as one is comparing low turnover portfolios. Otherwise (as they highlight) EWMA is not a pragmatic approach to assess the risk of a portfolio. Moreover, comparing the factor models to the EWMA model, which focuses exclusively on volatility, allows analysing whether factor models are better in forecasting value-at-risk. The comparison is done with the confidence regions proposed by Kupiec (1995) [45] as well as the bias statistics. They come to the conclusion that the daily factor returns model is equally accurate to the EWMA approach and the covariance approach. Moreover, the daily factor returns model has the advantage to be as accurate as EWMA and to provide the benefits of longer horizon factor models.

Embrechts et al. (2001) [31] use copulas to evaluate the risk of different types of positions. They do not only concentrate on the market risk of a single position. Instead, they apply copula theory to the estimation of the value-at-risk of a portfolio. Moreover, they highlight the ease of use when using copulas to estimate insurance risk. They show that copulas are a powerful tool to estimate joint risks and that they offer a wide range of possible applications.

Rank and Siegl (2002) [49] remind the readers that the "concept of correlation entails several pitfalls" and thus propose the use of copulas for the calculation of the value-at-risk. Throughout their paper they apply 17 Archimedean copulas for the computation of the value-at-risk of a USD and GBP portfolio. Their benchmarks are the historical simulation and the variance-covariance method as presented in Deutsch and Eller (2004) [28]. They test their results for different portfolio weights and different confidence intervals. Their conclusion is that copulas are highly suitable for the calculation of the value-at-risk of a portfolio.

Very recently, Boubaker and Sghaier [10] apply copulas in order to investigate how the presence of long memory affects the dependence structure among assets. They compute the efficient frontier of stock market and exchange rate returns in an expected shortfall environment. The authors conclude that the true dependence structure has a major effect on the efficient frontier.

[2] Barra Integrated Model.

Outline

The remainder of the paper proceeds as follows: Section 2 presents the data that is used for the in-sample calibration and out-of-sample testing. The focus of Section 4 is on the outline of the mathematical and practical aspects of copula theory that are relevant for the subsequent discussions. The emphasis is on the concepts and main properties of copulas, as well as their most prominent examples and families. In Section 5, we compare copulas and quantile regressions for the estimation of conditional value-at-risk and develop the generic cases that allow for a straightforward application. We conclude in Section 6.

2 Data

Presentation

The data consists of daily energy end of day prices downloaded from the Thomson Reuters Database. The data covers the most liquidly traded electricity contracts for continental Europe (i.e. German and French base and peak power for 2013 and 2014). The (in-sample) calibration period ranges from 23$^{\text{rd}}$ March 2007 to 31$^{\text{st}}$ December 2011. The out-of-sample back-testing period ranges from 1$^{\text{st}}$ January 2012 to 27$^{\text{th}}$ July 2012[3]. All non-trading days as well as days with missing data were not taken into account.

Characteristics

We test whether electric energy price returns are subject to the well-known stylized facts of asset price returns[4]. Tables 2 and 3 present the most important summary statistics. The tables highlight that the energy log-returns are obviously not normally distributed. To test for normality, we apply the Shapiro-Wilk (1965) [52] test. The non-reported Shapiro-Wilk test rejects the null hypothesis of normality at any conventional confidence level. The skewness of the distributions indicates that the returns experience relatively more upward movements than downward movements. The leptokurtic feature is very pronounced, as the levels of excess kurtosis show.

From Figure 1 one can infer that electric energy daily log-returns experience generally little autocorrelation. However, there appears to be a general pattern with regard to the strength and the sign of the autocorrelation.

[3]Note that the reason for choosing futures contracts is neither random nor accidental. Indeed, our goal is to structure the analysis in a way that its results become comparable to non-energy assets (e.g. shares). In this sense, using spot energy contracts would not make much sense. Indeed, once the spot contracts matures, physical delivery has to be performed. Given that electric energy cannot be stored in general, delivery implies immediate consumption. Moreover, electric spot energy may face negative prices. As a matter of fact, spot energy contracts are not comparable to equity. Thus, referring to futures contracts allows for a much better comparison to non-energy contracts.

[4]See for instance Christoffersen (2003) [18] and McNeil et al. (2005) [46].

As a matter of fact, one can conclude that electric energy futures' daily log-returns feature the same stylized facts as "conventional" asset returns.

3 Risk measures

In the following, we present the two main metrics for the assessment of risk that will be employed throughout the paper, namely value-at-risk and conditional value-at-risk[5]. For the assessment of market risk, value-at-risk is without doubt the most prominent one.

Definition 1 [Value-at-risk] *For a given risk factor X with random increments ΔX and a given time horizon $[0, \Delta t]$, the value-at-risk at confidence level $\alpha \in (0,1)$ is defined as the highest value l in $\mathbb{R}$ such that the probability that the loss $(-\Delta X)$ on the position is greater than l does not exceed α. Formally:*

$$\boxed{\mathrm{VaR}_{\alpha,\Delta t} := \sup\{l \mid \Pr(\Delta X \leq l) \leq \alpha\}}$$

In the same line of thought, Adrian and Brunnermeier (2011) [1] define conditional value-at-risk as follows:

Definition 2 [Conditional value-at-risk] *Conditional value-at-risk at confidence level α and for a given time horizon $[0, \Delta t]$ is the value-at-risk of the risk factor X_j conditional on some event $\mathcal{F}(X_i)$ of the risk factor X_i. That is, conditional value-at-risk is implicitly defined by the α-quantile of the conditional probability distribution. Formally:*

$$\boxed{\mathrm{CoVaR}_{\alpha,\Delta t}^{j|\mathcal{F}(X_i)} := \sup\{l \mid \Pr(\Delta X_j \leq l \mid \mathcal{F}(X_i)) \leq \alpha\}}$$

For the calculation of the conditional value-at-risk, the conditioning event $\mathcal{F}(X_i)$ may be any feasible event. But there are two very convenient conditioning events: One being that the position X_i has attained its value-at-risk. This means that we condition on $\mathcal{F}(X_i)\colon \Delta X_i = \mathrm{VaR}^i_{\alpha,\Delta t}$. Thus, we are in a position to estimate the systemic impact of X_i on X_j. Another way is to think of $\mathcal{F}(X_i)$ as being the latest observed value of ΔX_i, $\mathcal{F}(X_i) : \Delta X_i = \Delta x_i$. Thus, we extract the currently available information about X_j inherent in X_i.

4 Copulas

The focus of the following paragraphs is on the main properties of copulas that are useful for our study[6].

[5] Definitions as well as detailed investigations about the properties of the latter two are provided, amongst others, by Adrian and Brunnermeier (2011) [1], Crouhy et al. (2001) [20], McNeil et al. (2005) [46] and Szegö (2004) [54].

[6] Works discussing the properties of copulas, that we refer to, include Brigo and Mercurio (2006) [11], McNeil et al. (2005) [46], Nelsen (2006) [47], Rank (2007) [48] and Rank and Siegl (2002) [49].

Theory

Definition 3 [Copula] *An n-dimensional copula*

$$C\colon [0,1]^n \to [0,1]$$

is a cumulative distribution function with uniform marginal cumulative distribution functions.

Hence, a copula is an n-dimensional cumulative distribution function (CDF) such that for any vector of uniformly distributed random variables in the unit hypercube, denoted $\mathbf{U} = [U_1, \ldots, U_n]^\intercal$, the copula is:

$$\boxed{C(u_1, \ldots, u_n) = \Pr(U_1 \le u_1, \ldots, U_n \le u_n)} \tag{1}$$

An important theorem stating that it is possible to derive a joint cumulative distribution function out of the marginal cumulative distribution functions is known as Sklar's (1959) [53] theorem.

Theorem 1 [Sklar's theorem] *For any joint n-dimensional cumulative distribution function $F(x_1, \ldots, x_n)$ with marginal cumulative distribution functions $F_1, \ldots, F_n$, there is an n-dimensional copula C such that for any $x_i \in \overline{\mathbb{R}}, i = 1, \ldots, n$, we have:*

$$F(x_1, \ldots, x_n) = C(F_1(x_1), \ldots, F_n(x_n))$$

Where $\overline{\mathbb{R}}$ denotes the extended real line $\overline{\mathbb{R}} := [-\infty, \infty]$. Supposing that the marginal CDFs F_i are invertible, Equation (1) can be rewritten as:

$$\boxed{C(u_1, \ldots, u_n) = F\big(F_1^{-1}(u_1), \ldots, F_n^{-1}(u_n)\big)} \tag{2}$$

Consequently, we are able to derive the n-dimensional copula C of $X_1, \ldots, X_n$. Moreover, according to Equations (1) and (2) we are able to derive that $\Pr(X_1 \le x_1, \ldots, X_n \le x_n) = C(F_1(x_1), \ldots, F_n(x_n))$.

An important application of the copula (that will come in handy later) is the conditional distribution that can be extracted from it. The conditional distribution of U_n can be written in the following way[7]:

[Conditional cumulative distribution function using copulas] *For n uniformly distributed random variables $U_1, \ldots, U_n$ with a continuous n-dimensional copula C, let $U_i = u_i, i = 1, \ldots, n-1$, then the conditional cumulative distribution function of U_n is*

$$\boxed{\begin{aligned}&\Pr(U_n \le u_n \mid U_1 = u_1, \ldots, U_{n-1} = u_{n-1}) = \\ &\qquad\qquad \frac{\partial^{n-1} C(u_1, \ldots, u_n)}{\partial u_1 \cdots \partial u_{n-1}} \Bigg/ \frac{\partial^{n-1} C(u_1, \ldots, u_{n-1})}{\partial u_1 \cdots \partial u_{n-1}}\end{aligned}} \tag{3}$$

[7]See for instance Embrechts et al. (2001) [31]

Archimdedean copulas

Archimedean copulas are a very popular class of copulas for their ease of construction, their properties and since a variety of copula families are in fact Archimedean.

Definition 4 [**Archimedean copula**] *Let* $\varphi : \mathbb{I} \times \Theta \to [0, \infty]$ *be a continuous and strictly decreasing function such that* $\varphi(1) = 0$. *Let* $\varphi^{[-1]}$ *be its pseudo-inverse and* $\boldsymbol{\theta}$ *a parameter vector such that* $\boldsymbol{\theta} \in \Theta$. *Then*

$$\boxed{C^A(u_1, \ldots, u_n; \varphi, \boldsymbol{\theta}) := \varphi^{[-1]}(\varphi(u_1; \boldsymbol{\theta}), \ldots, \varphi(u_n; \boldsymbol{\theta}))}$$

is an Archimedean copula if and only if φ *is convex.*

Definition 5 [**Archimedean copula generator function**] *A continuous, strictly decreasing and convex function* $\varphi : \mathbb{I} \times \Theta \to [0, \infty]$ *such that* $\varphi(1) = 0$ *is known as Archimedean copula generator.* φ *is a strict generator if* $\lim_{t \to 0^+} \varphi(t) = \infty$.

Archimedean copulas are very powerful tools for statistical modeling as they allow incorporating a variety of dependence structures.In the Appendix Archimedean copulas with properties we give a short overview with some of the most important properties of the different Archimedean copulas.

5 Applications

Quantile regression

To build a working ground, we start with a generic case where we have three random variables X, Z and ε. The three random variables are supposed to be linked according to an invertible functional $\xi(\Delta Z, \varepsilon)$ which represents the factor model linking ΔX with ΔZ and ε. $\Delta X, \Delta Z$ and ε have the following cumulative distribution functions: $F_{\Delta X}, F_{\Delta Z}$ and F_ε respectively. Furthermore, we suppose that ε is an error term independent of ΔZ.

The conditional value-at-risk, according to the Definition 2, can be calculated by solving for CoVaR_{α_X} in the following relationship:

$$\Pr(\Delta X \leq \text{CoVaR}_{\alpha_X} \mid \Delta Z = \text{VaR}_{\alpha_Z}) = \alpha_X$$

Assuming that the conditionin event is $\Delta Z = \Delta z$ we finally get:

$$\boxed{\text{CoVaR}_{\alpha_X} = \xi\big(\Delta z, F_\varepsilon^{-1}(\alpha_X)\big)}$$

Next, we perform an analysis similar in methodology to that adopted by Adrian and Brunnermeier (2011) [1][8]. We extend the analysis proposed by Adrian and

[8]The advantage of using a quantile regression in this context is straightforward. Since we are only interested in correctly estimating the joint movements in the tails of the distribution, running a standard OLS would not yield a satisfying result since it is rather designed to estimate the conditional mean.

Brunnermeier (2011) [1] in the sense that we test whether the quantile regression allows for a correct specification of the conditional value-at-risk of X[9]. To analyse whether the conditional value-at-risk computed using the set-up from above is correct, we check whether it satisfies conditional coverage[10].

The quantile regressions are run on combinations of the 12 types of contracts as privded in the Section 2, for both the 1% and the 5% conditional value-at-risk. The resulting 112 quantile regressions are tested out-of-sample. The observed ratio of outliers as well as the quantile regression coefficients are summarised in Table 4. We clearly see that among the quantile regressions all but one allow us not to reject the null hypothesis for any conventional confidence level. This means that, apparently, quantile regressions seem to be somewhat incorrect in estimating conditional value-at-risk.

As a result, the following paragraphs are dedicated to testing whether the accuracy of the predictions increase if we apply a copula framework.

Copula application

Suppose (again) that we have two random variables X and Z which have the following cumulative distribution functions: $F_{\Delta X}$ and $F_{\Delta Z}$ respectively. We call H the joint cumulative distribution function of ΔX and ΔZ. Let us denote C the differentiable copula that links ΔX and ΔZ.

According to Equation (3) and assuming that C is differentiable in the second coordinate we have:

$$\Pr(\Delta X \leq \Delta x \mid \Delta Z = \Delta z) = \left.\frac{\partial C(u,v)}{\partial v}\right|_{u=F_{\Delta X}(\Delta x),\, v=F_{\Delta Z}(\Delta z)}$$

To simplify notations, we will refer to $\partial C(u,v)/\partial v|_{u=F_{\Delta X}(\Delta x),\, v=F_{\Delta Z}(\Delta z)}$ as the conditional cumulative distribution of ΔX given $\Delta Z = \Delta z$, denoted $C_{(\Delta X|\Delta Z)}$ $(F_{\Delta X}(\Delta x), F_{\Delta Z}(\Delta z))$. Without loss of generality, we suppose that $C_{(\Delta X|\Delta Z)}$ is invertible in the first coordinate. Following Definition 2 of the conditional value-at-risk we are able to calculate $\mathrm{CoVaR}_{\alpha_X}$ by applying Sklar's theorem and equation (3) for the conditional cumulative distribution of ΔX given ΔZ:

$$\boxed{\mathrm{CoVaR}_{\alpha_X} = F^{-1}_{\Delta X}\left(C^{-1}_{(U|V)}(\alpha_X, \alpha_Z)\right)} \tag{4}$$

Since a crucial exercise of fitting the data to the copulas is the correct specification of the marginal distributions, the following section is dedicated to the specification of them.

[9]Indeed, as far as we know, Adrian and Brunnermeier (2011) [1] do not provide whether they tested if the computation of the conditional value-at-risk using quantile regressions is an accurate specification. In order to circumvent this lack of clarity we explicitly test for the accuracy of the quantile regression framework.

[10]More precisely, we apply the tests of Kupiec (1995) [45] for unconditional coverage and Christoffersen (1998) [17] for independence. In the Appendix under Kupiec's test for unconditional coverage and Christoffersen's test for conditional covergage we provide a short reminder of the two tests.

Regarding the distributional assumptions of ΔX and ΔY we refer to the three most common set-ups: the normal distribution, the three-parameter Student t-distribution as well as the empirical distribution function[11]. Hence, the empirical application is based on 11 Archimedean copulas[12] and the three different distribution functions.

The procedure utilized is the following: the parameters for the parametric marginal distribution functions are estimated in the in-sample period using maximum likelihood estimation (MLE). The returns are then transformed to the copula scale using the probability integral transformation. Next, the eight different electric energy futures contracts are grouped in two-asset-portfolios. The eleven bi-variate copulas are fitted to the uniformly distributed returns using MLE, too. Once all the parameters are estimated, we compute the conditional value-at-risk in the out-of-sample period referring to the set-up proposed in equation (4). We assume that the conditioning event (here the observed return Δz) is known. Once the conditional value-at-risk is calculated, the value-at-risk exceptions are tested for conditional coverage.

Tables 5 to 37 report the output of the conditional value-at-risk backtesting in the out-of-sample period (statistical significance is indicated with asterisks). We observe that copulas allow for a better specification, compared to quantile regressions. It can be seen that the copula approach is more than 10 times more probable to yield statistically significant results than the quantile regression framework. Of course, the statistical significance is not unrelated either to the marginal distribution function as well as to the copula.

Table 38 reports the summary of the copula approach. As we can see, and rather unsurprisingly, some copulas perform better than others do. The leading copula is copula number 16, especially when using the empirical marginal distribution function. The reason why copula 16 outperforms the other copulas is related to the fact that this copula builds up mass quickly in the lower quadrant of its distribution – and is consequently better suited for the estimation of events in exactly that region.

Unsurprisingly, we observe that the three best performing copulas, are those with the highest level of lower tail dependence.

Another fact that is often observed, and this study shall not be an exception, is that the t-distribution need not necessarily outperform less sophisticated approaches. Indeed, as we observe in Table 38, the combination of t-distribution

[11] As already pointed out by Choros et al. (2009) [16] and shown by Joe (2001) [41], IFM is computationally more efficient than the simultaneous estimation of the distribution and the copula parameters. Consequently, the calibration of the models is divided in two stages: In a first phase, we estimate the parameters for the distribution functions. Once those parameters are approximated, the parameters for the copulas are estimated. Since Weiß (2010) [56] highlights that maximum likelihood estimation is the most attractive alternative for estimating the distributional parameters, we shall apply it for our analysis.

[12] For the reader's convenience, we are referring to the numbering of the copulas as provided in Nelsen (2006, pp. 116 – 119) [47]. Accordingly, the copulas that are applied have the following numbers: 3, 4, 5, 6, 9, 10, 12, 13, 14, 16 and 17. Some copulas are omitted because their singular component does not allow for a straightforward calibration. This restriction will be tackled in a subsequent paper.

and Archimedean copulas does not provide superior results to the normal distribution.

6 Conclusion

Given the challenges regarding the statistical significance of the conditional value-at-risk when using quantile regressions, the aim of the current paper is to present an alternative – i.e. the introduction of copulas. Furthermore, we want to provide a methodology that is both simple to adopt, flexible in use and statistically significant. The generic cases that we develop help us for subsequent parts since they provide the general set-up for the conditional value-at-risk computation. Based on a static maximum likelihood estimation of the marginal distributions' and the copulas' parameters, we show that copulas provide superior results than quantile regressions in the out-of-sample back-test. Our results foster the fact that the statistical significance depends both on the estimated marginal distribution functions as well as on the copula.

Consequently, future research may turn around analysing the statistical significance of our copula methodology in a dynamic set-up. We expect the results to improve. However it would be interesting to know the relationship between increased computational complexity and statistical significance. Moreover, it would be of interest to analyse the effect of moving to an entirely non-parametrical framework. Furthermore, a deepened understanding of the relationship between statistical significance of our conditional value-at-risk methodology and the coefficients of tail dependence would be insightful.

7 Appendix

Properties of conditional value-at-risk

As Adrian and Brunnermeier (2011) [1] show, conditional value-at-risk has the following 7 properties:

- **Cloning property:** Conditional value-at-risk (in return space) of a position is the same as the conditional value-at-risk of its n clones.
- **Causality:** The marginal contribution of a position, measured by

$$\mathrm{CoVaR}_{\alpha,\Delta t}^{j,X_i=\mathrm{VaR}_i} - \mathrm{CoVaR}_{\alpha,\Delta t}^{j,X_i=\mathrm{median}_i}$$

  does not distinguish whether the contribution of an institution is causal or simply driven by a common factor.
- **Tail distribution:** Conditional value-at-risk focuses on the events in the tail of the distributions. Consequently, it is more extreme than the usual unconditional value-at-risk. Given that conditional value-at-risk conditions on crisis states, it takes into account the shifts in the mean, increase in volatility as well as changes in skewness and kurtosis.
- **Conditioning:** Conditional value-at-risk conditions on the event $\mathcal{F}(X_i)$ which is most of the time assumed to be $\left\{X_i = \mathrm{VaR}_{\alpha,\Delta t}^{i}\right\}$ and which occurs with probability α. In this sense, the probability that $\mathcal{F}(X_i)$ occurs is dependent on the level of risk of position i.
- **Directionality:** $\mathrm{CoVaR}_{\alpha,\Delta t}^{j,X_i=\mathrm{VaR}_i}$ is not necessarily $\mathrm{CoVaR}_{\alpha,\Delta t}^{i,X_j=\mathrm{VaR}_j}$.
- **Exposure conditional value-at-risk:** Exposure conditional value-at-risk, denoted by $\mathrm{CoVaR}_{\alpha,\Delta t}^{j,X_{\mathrm{system}}=\mathrm{VaR}_{\mathrm{system}}}$ is equal to the conditional value-at-risk of position j given that the economy is in a bad state.
- **CoES:** Conditional value-at-risk is adoptable to other measures of conditional risk. Thus, it can be applied to conditional expected shortfall, given by:

$$\mathbb{E}\Big(X_{\mathrm{system}} \mid X_{\mathrm{system}} \leq \mathrm{CoVaR}_{\alpha,\Delta t}^{X_i=\mathrm{VaR}_i}\Big)$$

Electric energy futures contracts

Electric energy futures (when traded on energy exchanges) are contracts distinguished (amongst others) by the delivery period, the load profile and the place of delivery (see for instance the documentation of the European Energy Exchange [29]):

- The delivery periods are most commonly weeks, months, quarters, seasons and years.

- The load profile is either base load, peak load or off-peak. Base load is a constant delivery rate each day of the week for the whole 24 hours. Peak load is a constant delivery from Monday to Friday starting each day at 8 am and ending at 8 pm. Off-peak is the difference between base load and peak load.

- The place of delivery is the balancing area within the transmission system of the delivery of power on which the futures contracts are based.

Thus, a German base year contract is a futures contract for physical delivery of electric energy each hour of each day during a calendar year, deliverable in the German balancing zone.

There are also so-called "-ahead" contracts. These contracts are, as the name suggests, contracts stipulating delivery for the following delivery period (e.g. a year-ahead contract stipulates delivery for the following calendar year).

Three-parameter Student t-distribution function

The three-parameter Student t-distribution function is the location-scale equivalent of the usual Student t-distribution. The three-parameter version contains, next to the degrees of freedom (v) also a location (or mean) parameter (μ) as well as a scale (or dispersion) parameter (σ). It is equivalently defined as the **??**, but in one dimension. The corresponding probability density function is then

$$f(x; v, \mu, \sigma) = \frac{\Gamma\left(\frac{v+1}{2}\right)}{\Gamma\left(\frac{v}{2}\right)\sqrt{\pi v}\sigma}\left(1 + \frac{1}{v}\left(\frac{x-\mu}{\sigma}\right)^2\right)^{-\frac{v+1}{2}}$$

Where Γ is the gamma function.

Archimedean copulas with properties

Table 1 highlight some of the most important Archimedean copulas, with their copula function, the generator function, the range of θ, lower and upper tail dependence. The corresponding conditional inverses as well as the density functions may be obtained by the corresponding author, on demand. The table was taken from Nelsen (2006) [47].

Table 1: Archimedean copulas with generator function and coefficients of tail dependence

#	$C(u,v;\theta)$	$\varphi(t;\theta)$	Θ	λ_l	λ_u
1	$\left(\max\{u^{-\theta}+v^{-\theta}-1,0\}\right)^{-\frac{1}{\theta}}$	$\frac{1}{\theta}\left(t^{-\theta}-1\right)$	$[-1,\infty)\backslash\{0\}$	$2^{-\frac{1}{\theta}}$	0
2	$\max\left\{1-\left((1-u)^{\theta}+(1-v)^{\theta}\right)^{\frac{1}{\theta}},0\right\}$	$(1-t)^{\theta}$	$[1,\infty)$	0	$2-2^{\frac{1}{\theta}}$
3	$\frac{uv}{1-\theta(1-u)(1-v)}$	$\ln\left(\frac{1-\theta(1-\theta)}{t}\right)$	$[-1,1)$	0	0
4	$\exp\left(-\left((-\ln(u))^{\theta}+(-\ln(v))^{\theta}\right)^{\frac{1}{\theta}}\right)$	$(-\ln(t))^{\theta}$	$[1;\infty)$	0	$2-2^{\frac{1}{\theta}}$
5	$-\frac{1}{\theta}\ln\left(1+\frac{\left(e^{-\theta u}-1\right)\left(e^{-\theta v}-1\right)}{e^{-\theta}-1}\right)$	$-\ln\left(\frac{e^{-\theta t}-1}{e^{-\theta}-1}\right)$	$\mathbb{R}\backslash\{0\}$	0	0
6	$1-\left((1-u)^{\theta}+(1-v)^{\theta}-(1-u)^{\theta}(1-v)^{\theta}\right)^{\frac{1}{\theta}}$	$-\ln\left(1-(1-t)^{\theta}\right)$	$[1,\infty)$	0	$2-2^{\frac{1}{\theta}}$
7	$\max\{\theta uv+(1-\theta)(u+v-1),0\}$	$-\ln(\theta t+(1-\theta))$	$(0,1]$	0	0
8	$\max\left\{\frac{\theta^2 uv-(1-u)(1-v)}{\theta^2-(\theta-1)^2(1-u)(1-v)},0\right\}$	$\frac{1-t}{1+(\theta-1)t}$	$[1,\infty)$	0	0
9	$uv\exp(-\theta\ln(u)\ln(v))$	$\ln(1-\theta\ln(t))$	$(0,1]$	0	0
10	$\frac{uv}{(1+(1-u^{\theta})(1-v^{\theta}))^{\frac{1}{\theta}}}$	$\ln\left(2t^{-\theta}-1\right)$	$(0,1]$	0	0
11	$\left(\max\{u^{\theta}v^{\theta}-2(1-u^{\theta})(1-v^{\theta}),0\}\right)^{\frac{1}{\theta}}$	$\ln\left(2-t^{-\theta}-1\right)$	$\left(0,\frac{1}{2}\right]$	0	0
12	$\left(1+\left((u^{-1}-1)^{\theta}(v^{-1}-1)^{\theta}\right)^{\frac{1}{\theta}}\right)^{-1}$	$\left(\frac{1}{t}-1\right)^{\theta}$	$[1,\infty)$	$2^{-\frac{1}{\theta}}$	$2-2^{-\frac{1}{\theta}}$

13	$\exp\left(1-\left((1-\ln(u))^\theta+(1-\ln(v))^\theta-1\right)^{\frac{1}{\theta}}\right)$	$(1-\ln(t))^\theta-1$	$(0,\infty)$	0	0
14	$\left(1+\left(\left(u^{-\frac{1}{\theta}}-1\right)^\theta+\left(v^{-\frac{1}{\theta}}-1\right)^\theta\right)^{\frac{1}{\theta}}\right)^{-\theta}$	$\left(t^{-\frac{1}{\theta}}-1\right)^\theta$	$[1,\infty)$	$\frac{1}{2}$	$2-2^{-\frac{1}{\theta}}$
15	$\left(\max\left\{1-\left(\left(1-u^{\frac{1}{\theta}}\right)^\theta+\left(1-v^{\frac{1}{\theta}}\right)^\theta\right)^{\frac{1}{\theta}},0\right\}\right)^\theta$	$\left(1-t^{\frac{1}{\theta}}\right)^\theta$	$[1,\infty)$	0	$2-2^{-\frac{1}{\theta}}$
16	$\frac{1}{2}\left(S+\sqrt{S^2+4\theta}\right)$ $S=u+v-1-\theta\left(\frac{1}{u}+\frac{1}{v}-1\right)$	$\left(\frac{\theta}{t}+1\right)(1-t)$	$[0,\infty)$	$\frac{1}{2}$	0
17	$\left(1+\frac{\left((1+u)^{-\theta}-1\right)\left((1+v)^{-\theta}-1\right)-1}{2^{-\theta}-1}\right)^{-\frac{1}{\theta}}-1$	$-\ln\left(\frac{(1+t)^{-\theta}-1}{2^{-\theta}-1}\right)$	$\mathbb{R}\backslash\{0\}$	0	0
18	$\max\left\{1+\frac{\theta}{\ln\left(e^{\frac{\theta}{u-1}}+e^{\frac{\theta}{v-1}}-e^\theta\right)},0\right\}$	$e^{\frac{\theta}{t-1}}$	$[2,\infty)$	0	1
19	$\frac{\theta}{\ln\left(e^{\frac{\theta}{u}}+e^{\frac{\theta}{v}}-e^\theta\right)}$	$e^{\frac{\theta}{t}}-e^\theta$	$(0,\infty)$	1	0
20	$\left(\ln\left(e^{u^{-\theta}}+e^{v^{-\theta}}-e\right)\right)^{-\frac{1}{\theta}}$	$e^{t^{-\theta}}-e$	$(0,\infty)$	1	0
21	$1-\left(1-\left(\max\left\{(1-(1-u)^\theta)^{\frac{1}{\theta}}+(1-(1-v)^\theta)^{\frac{1}{\theta}}-1,0\right\}\right)^\theta\right)^{\frac{1}{\theta}}$	$1-(1-(1-t)^\theta)^{\frac{1}{\theta}}$	$[1,\infty)$	0	$2-2^{-\frac{1}{\theta}}$
22	$\max\left\{(1-(1-u^\theta)\sqrt{1-(1-v^\theta)^2}-(1-v^\theta)\sqrt{1-(1-u^\theta)^2},0\right\}$	$\arcsin(1-t^\theta)$	$(0,1]$	0	0

Kupiec's test for unconditional coverage

Kupiec (1995) [45] discusses a number of tests to verify the null hypothesis that the observed ratio of value-at-risk exceptions is equal to the targeted confidence level α. The most prominent and widely used test, not least because of the attention granted to it by regulators, is the test for conditional coverage (also known as probability of failure test). Under the null hypothesis, the number of exceptions (N) follows a binomial distribution ($N \sim \mathrm{B}(T, \alpha)$), where T is the total number of observations. The probability of observing exactly n exceptions in a sample of size T is thus given by

$$\Pr(N = n) = f(n; \alpha, T) = \binom{T}{n} \alpha^n (1 - \alpha)^{T-n}$$

Unconditional coverage is measured by the ratio of exceptions to observations:

$$\hat{\alpha} := \frac{n}{T}$$

Thus, under the null hypothesis: H0: $\hat{\alpha} = \alpha$. The likelihood ratio test statistic for unconditional coverage proposed is

$$\mathrm{LR}_{\mathrm{UC}} := -2 \ln\!\Big(\alpha^n (1 - \alpha)^{T-n}\Big) + 2 \ln\!\Big(\hat{\alpha}^n (1 - \hat{\alpha})^{T-n}\Big)$$

The likelihood ratio test statistic is asymptotically chi-squared distributed with one degree of freedom. Thus, at confidence level α under the null hypothesis, the model cannot be rejected if $\mathrm{LR}_{\mathrm{UC}} < \chi^2(\alpha; 1)$.

Christoffersen's test for conditional covergage

Christoffersen (1998) [17] proposes a test for conditional coverage is composed of two complementary components. The first one is Kupiec's test for unconditional coverage. The second is his test for independence.

Test for independence

Christoffersen's test for independence examines whether the sequence of value-at-risk exceptions is serially independent or not. Suppose that we have a position X with observed first order differences ΔX. Let us define the indicator variable $\mathbb{1}_t$ at time t and for position X's value-at-risk interval forecast $(-\infty, \mathrm{VaR}_{\alpha,\Delta \mathrm{t}})$ as follows:

$$\mathbb{1}_t := \begin{cases} 1 & : \text{if } \Delta X_t \in (-\infty, \mathrm{VaR}_{\alpha,\Delta \mathrm{t}}) \\ 0 & : \text{if } \Delta X_t \notin (-\infty, \mathrm{VaR}_{\alpha,\Delta \mathrm{t}}) \end{cases}$$

Please note that for notational purposes we drop the subscript t for $\mathrm{VaR}_{\alpha,\Delta t}$. Indeed, $\mathrm{VaR}_{\alpha,\Delta t}$ need not be time invariant, and so doesn't the value-at-risk interval forecast.

With this definition in mind, we obtain the value-at-risk exceptions sequence $\{\mathbb{1}_t\}$. Independence of the value-at-risk exceptions is tested against a binary first-order Markov chain with transition probability matrix Π_1 given as:

$$\Pi_1 = \begin{bmatrix} 1-\pi_{01} & \pi_{01} \\ 1-\pi_{11} & \pi_{11} \end{bmatrix}$$

Where $\pi_{ij} = \Pr(\mathbb{1}_t = j \mid \mathbb{1}_{t-1} = i)$. Defining n_{ij} as being the number of observations with value i followed by j, the corresponding likelihood function is thus given by:

$$\mathrm{L}(\Pi_1; \mathbb{1}_1, \ldots, \mathbb{1}_T) = (1-\pi_{01})^{n_{00}} \pi_{01}^{n_{01}} (1-\pi_{11})^{n_{10}} \pi_{11}^{n_{11}}$$

Based on the exceptions sequence, we get the observed transition matrix $\hat{\Pi}_1$:

$$\hat{\Pi}_1 = \begin{bmatrix} \frac{n_{00}}{n_{00}+n_{01}} & \frac{n_{01}}{n_{00}+n_{01}} \\ \frac{n_{10}}{n_{10}+n_{11}} & \frac{n_{11}}{n_{10}+n_{11}} \end{bmatrix}$$

Denoting Π_2 the transition matrix of an independent sequence, given by

$$\Pi_2 = \begin{bmatrix} 1-\pi_2 & \pi_2 \\ 1-\pi_2 & \pi_2 \end{bmatrix},$$

we are able to obtain the likelihood function under the null hypothesis:

$$\mathrm{L}(\Pi_2; \mathbb{1}_1, \ldots, \mathbb{1}_T) = (1-\pi_2)^{n_{00}+n_{10}} \pi_2^{n_{01}+n_{11}}$$

The corresponding maximum likelihood estimate is $\hat{\Pi}_2 = \hat{\pi}_2 = (n_{01}+n11)/(n_{00}+$ $+n_{10}+n_{01}+n_{11})$. The likelihood ratio test statistic for independence is

$$\mathrm{LR}_{\mathrm{ind}} := -2\ln(\mathrm{L}(\hat{\Pi}_2; \mathbb{1}_1, \ldots, \mathbb{1}_T)) + 2\ln(\mathrm{L}(\hat{\Pi}_1; \mathbb{1}_1, \ldots, \mathbb{1}_T))$$

The likelihood ratio test statistic is asymptotically chi-squared distributed with one degree of freedom. Thus, at confidence level α under the null hypothesis, the model cannot be rejected if $\mathrm{LR}_{\mathrm{ind}} < \chi^2(\alpha; 1)$.

Test for conditional coverage

Conditional coverage is met if we have both unconditional coverage and independence. Thus, we shall test the null hypothesis of the unconditional coverage test against the alternative of the independence test. Formally, the likelihood ratio test statistic for conditional coverage is

$$\mathrm{LR}_{\mathrm{CC}} := -2\ln(\alpha^n (1-\alpha)^{T-n}) + 2\ln(\mathrm{L}(\hat{\Pi}_1; \mathbb{1}_1, \ldots, \mathbb{1}_T))$$

The likelihood ratio test statistic is asymptotically chi-squared distributed with two degrees of freedom. Thus, at confidence level α under the null hypothesis, the model cannot be rejected if $\mathrm{LR}_{\mathrm{ind}} < \chi^2(\alpha; 1)$.

In addition, Christoffersen (1998) [17] shows that, when conditioning on the first observation, the three ratio test statistics for unconditional coverage, independence and conditional coverage are related by the following relation:

$$\mathrm{LR}_{\mathrm{CC}} = \mathrm{LR}_{\mathrm{UC}} + \mathrm{LR}_{\mathrm{ind}}$$

Tables

Table 2: German and French electric energy 2013 return summary statistics

Statistics	German Base	German Peak	French Base	French Peak
Observations	1151	1061	1245	971
Mean	-0.0135	-0.0306	-0.0165	-0.0060
Std. dev.	0.9596	1.0450	1.0381	1.2528
Skewness	0.1854	0.5871	0.1473	1.7950
Kurtosis	3.8881	7.5697	4.0533	19.8276
1^{st} percentile	-2.6545	-2.5676	-2.7161	-3.1145
Median	-0.0542	-0.0957	0.0179	-0.0753
99^{th} percentile	2.6493	3.3629	2.7023	3.0172

Table 3: German and French electric energy 2014 return summary statistics

Statistics	German Base	German Peak	French Base	French Peak
Observations	994	947	682	565
Mean	-0.0237	-0.0336	-0.0237	-0.0123
Std. dev.	1.0400	1.0999	1.1337	1.2255
Skewness	0.0297	0.7795	0.1228	0.0463
Kurtosis	5.2361	8.4235	4.5286	2.0465
1^{st} percentile	-3.1347	-3.0618	-3.0685	-3.2646
Median	-0.0784	-0.0849	-0.0357	-0.0749
99^{th} percentile	2.8622	3.4336	3.4290	3.0246

Table 4: Bivariate quantile regression value-at-risk back-test (with quantile regression parameters)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000 -2.1065 0.6668	0.0000 -1.0744 0.6405	0.0000 -2.2852 0.7688	0.0000 -1.0257 0.7677
F1BYF3 & F1BYF4	0.0000 -1.4589 0.6903	0.0000 -0.6220 0.8695	0.0000 -1.3928 1.1465	0.0000 -0.7247 0.9800
F1BYF3 & F1PYF4	0.0000 -2.3909 0.4545	0.7143 -1.1420 0.6323	0.0000 -2.3308 0.7800	0.0000 -1.2951 0.8413
F1BYF3 & F2BYF3	0.0000 -2.2859 0.3366	1.4706 -1.1015 0.3919	0.0000 -2.1280 0.6700	1.4706 -1.2260 0.8142
F1BYF3 & F2PYF3	0.0000 -2.9856 0.0028	2.6786 -1.6896 0.0014	0.0000 -3.3274 0.5339	0.8929 -1.7074 0.6267
F1BYF3 & F2BYF4	0.0000 -3.1675 0.0046	0.7634 -1.8468 0.0031	0.7634 -2.2462 0.5993	0.7634 -1.3449 0.7678
F1BYF3 & F2PYF4	0.0000 -3.3603 0.0047	0.9901 -1.9821 0.0032	0.0000 -3.0881 0.6538	0.9901 -1.8251 0.6789
F1PYF3 & F1BYF4	0.0000 -2.3332 0.6405	0.0000 -1.0877 0.7031	0.0000 -2.7148 0.6332	0.0000 -1.2259 0.5816
F1PYF3 & F1PYF4	0.0000 -1.5274 0.8250	1.4184 -0.8313 0.8245	0.0000 -1.9834 0.7085	0.0000 -0.9434 0.8218
F1PYF3 & F2BYF3	0.0000 -2.4073 0.6484	0.7246 -1.1487 0.6597	0.7246 -2.1787 0.5508	0.7246 -1.4991 0.5329
F1PYF3 & F2PYF3	0.0000 -3.2485 0.0034	1.7699 -1.6514 0.0016	0.0000 -2.9357 0.7455	0.0000 -1.7117 0.5703

F1PYF3 & F2BYF4	0.0000 -3.9788 0.0047	0.7576 -1.8303 0.0022	0.7576 -2.1547 0.5915	0.7576 -1.6794 0.5881
F1PYF3 & F2PYF4	0.0000 -4.5222 0.0052	0.9804 -1.8575 0.0022	0.0000 -2.5145 0.6852	0.9804 -1.7694 0.5786
F1BYF4 & F1PYF4	0.0000 -2.7112 0.5018	0.7246 -1.3465 0.5448	0.0000 -2.4352 0.6403	0.0000 -1.2766 0.7435
F1BYF4 & F2BYF3	0.0000 -2.6207 0.3649	2.2388 -1.3081 0.2758	0.7463 -2.3025 0.5589	0.7463 -1.4662 0.6511
F1BYF4 & F2PYF3	0.0000 -3.3403 0.3641	0.0000 -1.8937 0.5741	0.0000 -3.4478 0.0052	2.7523 -1.5922 -0.0035
F1BYF4 & F2BYF4	0.0000 -3.5566 0.0054	2.3256 -1.7222 0.0032	0.7752 -2.2641 0.6161	0.7752 -1.4389 0.6993
F1BYF4 & F2PYF4	0.0000 -3.6995 0.0054	1.0000 -1.9770 0.0035	0.0000 -2.9737 0.5645	0.0000 -1.9101 0.5248
F1PYF4 & F2BYF3	0.0000 -2.3930 0.6299	0.7353 -1.3654 0.7750	0.7353 -2.4907 0.4298	0.7353 -1.7261 0.4741
F1PYF4 & F2PYF3	0.0000 -3.0932 0.6077	0.0000 -1.9903 0.5554	0.0000 -3.6988 0.0039	0.0000 -1.8967 0.0019
F1PYF4 & F2BYF4	0.0000 -3.8237 0.0054	0.7692 -1.7990 0.0031	0.7692 -2.6979 0.4726	0.7692 -1.7813 0.5338
F1PYF4 & F2PYF4	0.0000 -4.0899 0.0056	0.0000 -1.9347 0.0032	0.0000 -3.0932 0.6077	0.9901 -1.8490 0.5082
F2BYF3 & F2PYF3	0.9091* -3.0818 0.0039	3.6364 -1.8158 0.0025	0.0000 -2.6712 1.0431	2.7273 -1.6599 1.0443
F2BYF3 & F2BYF4	0.7813 -1.3321 0.7635	2.3438 -0.8506 0.8440	0.0000 -1.3379 0.9984	3.1250 -0.7784 0.9991

F2BYF3 & F2PYF4	0.0000 -2.8294 0.9527	4.0000 -1.7194 0.8770	0.0000 -2.8307 1.0429	3.0000 -1.9209 1.044
F2PYF3 & F2BYF4	0.0000 -2.5692 0.6060	0.0000 -1.7109 0.6291	0.0000 -2.4525 0.9531	0.9434 -1.661 0.9540
F2PYF3 & F2PYF4	0.0000 -2.6889 0.9970	3.5294 -1.1451 0.7411	0.0000 -2.0174 0.9978	1.5625 -1.2416 0.9986
F2BYF4 & F2PYF4	0.0000 -2.4774 0.9531	2.0833 -1.7077 0.9539	0.0000 -3.1683 1.0282	1.0417 -1.8678 1.0267

The results in table 4 present the observed proportion of value-at-risk events (in percent) as well as the intercept and the slope of the quantile regressions. Figures with one asterisk satisfy Kupiec's (1995) [45] test for unconditional coverage at the 10% level. For space purposes, we replaced the contract names by their respective Reuters Instrument Code (RIC). The RIC reads as follows: F1BYF3 for German (F1) Base (B) Year (Y) 2013 (F3) and F2PYF4 for French (F2) Peak (P) Year (Y) 2014 (F4).

Table 5: Bivariate copula value-at-risk back-test (copula number 3 with normal distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.7092	1.4184	2.8369
F1BYF3 & F2BYF3	0.0000	0.0000	3.6765	8.0882
F1BYF3 & F2PYF3	0.0000	1.7857	0.0000	4.4643
F1BYF3 & F1BYF4	0.0000	0.0000	2.1583	6.4748
F1BYF3 & F1PYF4	0.0000	0.7143	0.0000	3.5714
F1BYF3 & F2BYF4	0.0000	0.7634	2.2901	3.0534
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	5.9406
F1PYF3 & F2BYF3	0.0000	0.0000	0.7246	1.4493
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	0.0000	0.7576	0.7576
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	1.9608
F2BYF3 & F2PYF3	0.9091*	5.4545	0.0000	0.9091
F2BYF3 & F1BYF4	0.7463	0.7463	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.2059	0.0000	0.0000
F2BYF3 & F2BYF4	0.0000	0.7813	0.0000	0.0000
F2BYF3 & F2PYF4	2.0000	5.0000***	0.0000	1.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.8929
F2PYF3 & F2BYF4	0.0000	0.0000	0.9434**	1.8868
F2PYF3 & F2PYF4	0.0000	0.0000	0.0000	0.0000
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.7752	0.7752
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.0000	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	1.9802
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	1.0417

Table 6: Bivariate copula value-at-risk back-test (copula number 4 with normal distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.0000	2.8369	10.6383
F1BYF3 & F2BYF3	0.0000	0.0000	6.6176	12.5000

F1BYF3 & F2PYF3	0.0000	0.8929	0.8929	1.7857
F1BYF3 & F1BYF4	0.0000	0.0000	12.9496	25.8993
F1BYF3 & F1PYF4	0.0000	0.7143	1.4286	5.7143
F1BYF3 & F2BYF4	0.0000	0.0000	3.8168	9.1603
F1BYF3 & F2PYF4	0.0000	1.9802	0.9901***	1.9802
F1PYF3 & F2BYF3	0.0000	0.0000	0.7246	0.7246
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F1PYF4	0.0000	1.4184	0.0000	0.7092
F1PYF3 & F2BYF4	0.0000	0.0000	0.7576	0.7576
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	0.0000
F2BYF3 & F2PYF3	0.9091*	2.7273	0.0000	0.0000
F2BYF3 & F1BYF4	0.7463	0.7463	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	1.4706	0.0000	0.0000
F2BYF3 & F2BYF4	0.7813	3.1250	1.5625	3.9063
F2BYF3 & F2PYF4	1.0000***	3.0000	0.0000	0.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.9174
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F2BYF4	0.0000	0.0000	0.9434**	0.9434
F2PYF3 & F2PYF4	1.1765	8.2353	0.0000	3.5294
F1BYF4 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.7752	0.7752
F1BYF4 & F2PYF4	0.0000	0.0000	0.0000	0.0000
F1PYF4 & F2BYF4	0.0000	0.0000	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.0000
F2BYF4 & F2PYF4	1.0417**	2.0833	0.0000	0.0000

Table 7: Bivariate copula value-at-risk back-test (copula number 5 with normal distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.0000	9.9291	21.2766
F1BYF3 & F2BYF3	0.0000	0.7353	9.5588	19.8529
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	8.0357
F1BYF3 & F1BYF4	0.0000	0.0000	23.7410	39.5683
F1BYF3 & F1PYF4	0.7143	0.7143	5.0000	15.0000
F1BYF3 & F2BYF4	0.0000	0.0000	5.3435	14.5038
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	8.9109
F1PYF3 & F2BYF3	0.0000	0.7246	0.7246	1.4493

F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.8850
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	0.0000
F1PYF3 & F1PYF4	0.7092	2.1277	0.0000	2.1277
F1PYF3 & F2BYF4	0.0000	1.5152	0.7576	0.7576
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	0.9804
F2BYF3 & F2PYF3	0.9091*	4.5455	0.0000	3.6364
F2BYF3 & F1BYF4	0.7463	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	1.4706	0.0000	0.7353
F2BYF3 & F2BYF4	0.7813	6.2500	1.5625	5.4688
F2BYF3 & F2PYF4	1.0000***	6.0000	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	0.9174	0.0000	0.0000
F2PYF3 & F1PYF4	0.0000	0.8929	0.0000	0.0000
F2PYF3 & F2BYF4	0.0000	0.9434	0.9434**	0.9434
F2PYF3 & F2PYF4	4.7059	14.1176	2.3529	11.7647
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.0000	1.5504
F1BYF4 & F2PYF4	0.0000	1.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.9901
F2BYF4 & F2PYF4	1.0417**	2.0833	0.0000	1.0417

Table 8: Bivariate copula value-at-risk back-test (copula number 6 with normal distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.7092	1.4184	6.3830
F1BYF3 & F2BYF3	0.0000	0.7353	2.2059	10.2941
F1BYF3 & F2PYF3	0.0000	1.7857	0.8929	0.8929*
F1BYF3 & F1BYF4	0.0000	0.0000	9.3525	17.9856
F1BYF3 & F1PYF4	0.0000	1.4286	0.7143	2.1429
F1BYF3 & F2BYF4	0.0000	0.7634	1.5267	3.8168
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	1.9802
F1PYF3 & F2BYF3	0.0000	0.7246	0.7246	1.4493
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	0.7194
F1PYF3 & F1PYF4	0.7092	1.4184	0.0000	0.7092
F1PYF3 & F2BYF4	0.0000	0.7576	0.7576	1.5152
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	0.0000
F2BYF3 & F2PYF3	0.9091*	2.7273	0.0000	0.0000

F2BYF3 & F1BYF4	0.7463	1.4925	0.0000	0.7463
F2BYF3 & F1PYF4	0.7353	1.4706	0.0000	0.0000
F2BYF3 & F2BYF4	0.7813	3.1250	1.5625	4.6875
F2BYF3 & F2PYF4	1.0000***	3.0000	0.0000	0.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.9174
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F2BYF4	0.0000	0.0000	0.9434**	1.8868
F2PYF3 & F2PYF4	1.1765	5.8824	0.0000	1.1765
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.7752	1.5504
F1BYF4 & F2PYF4	0.0000	2.0000	0.0000	0.0000
F1PYF4 & F2BYF4	0.0000	0.0000	0.7692	1.5385
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.0000
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	0.0000

Table 9: Bivariate copula value-at-risk back-test (copula number 9 with normal distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.8369	0.0000	0.7092
F1BYF3 & F2BYF3	0.0000	2.9412	0.7353	2.9412
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	0.0000
F1BYF3 & F1BYF4	0.0000	2.8777	0.0000	2.1583
F1BYF3 & F1PYF4	0.0000	2.8571	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	3.0534	0.7634	2.2901
F1BYF3 & F2PYF4	0.0000	3.9604	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.7246	2.8986
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	2.1583
F1PYF3 & F1PYF4	0.0000	0.7092	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	0.7576	0.7576	2.2727
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	0.9804
F2BYF3 & F2PYF3	0.9091*	3.6364	0.0000	0.0000
F2BYF3 & F1BYF4	0.7463	2.9851	0.0000	2.2388
F2BYF3 & F1PYF4	0.7353	2.9412	0.0000	0.0000
F2BYF3 & F2BYF4	0.7813	3.1250	0.7813	2.3438
F2BYF3 & F2PYF4	1.0000***	4.0000	0.0000	1.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000

F2PYF3 & F2BYF4	0.0000	0.0000	0.9434**	2.8302
F2PYF3 & F2PYF4	0.0000	0.0000	0.0000	1.1765
F1BYF4 & F1PYF4	0.0000	2.1739	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	2.3256	0.7752	2.3256
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.0000	0.7692	2.3077
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.9901
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	1.0417

Table 10: Bivariate copula value-at-risk back-test (copula number 10 with normal distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.8369	0.0000	0.7092
F1BYF3 & F2BYF3	0.0000	2.9412	0.7353	2.9412
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	0.0000
F1BYF3 & F1BYF4	0.0000	2.8777	0.0000	2.1583
F1BYF3 & F1PYF4	0.0000	2.8571	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	3.0534	0.7634	2.2901
F1BYF3 & F2PYF4	0.0000	3.9604	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.7246	2.8986
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	2.1583
F1PYF3 & F1PYF4	0.0000	0.7092	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	0.7576	0.7576	2.2727
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	0.9804
F2BYF3 & F2PYF3	0.9091*	3.6364	0.0000	0.0000
F2BYF3 & F1BYF4	0.7463	2.9851	0.0000	2.2388
F2BYF3 & F1PYF4	0.7353	2.9412	0.0000	0.0000
F2BYF3 & F2BYF4	0.7813	3.1250	0.7813	2.3438
F2BYF3 & F2PYF4	1.0000***	4.0000	0.0000	1.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F2BYF4	0.0000	0.0000	0.9434**	2.8302
F2PYF3 & F2PYF4	0.0000	0.0000	0.0000	1.1765
F1BYF4 & F1PYF4	0.0000	2.1739	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	2.3256	0.7752	2.3256
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.0000	0.7692	2.3077

F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.9901
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	1.0417

Table 11: Bivariate copula value-at-risk back-test (copula number 12 with normal distribution)

	1^{st} on 2^{nd}		**2^{nd} on 1^{st}**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	1.4184	3.5461	10.6383
F1BYF3 & F2BYF3	0.0000	0.0000	7.3529	13.9706
F1BYF3 & F2PYF3	0.0000	7.1429	0.0000	6.2500
F1BYF3 & F1BYF4	0.0000	0.0000	12.9496	23.0216
F1BYF3 & F1PYF4	0.7143	2.1429	1.4286	7.8571
F1BYF3 & F2BYF4	0.0000	0.7634	3.0534	6.8702
F1BYF3 & F2PYF4	0.0000	2.9703	0.9901***	7.9208
F1PYF3 & F2BYF3	0.0000	0.0000	0.7246	3.6232
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.885
F1PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.7194
F1PYF3 & F1PYF4	0.0000	1.4184	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	0.7576	0.7576	0.7576
F1PYF3 & F2PYF4	0.0000	1.9608	0.0000	2.9412
F2BYF3 & F2PYF3	2.7273	5.4545	0.0000	2.7273
F2BYF3 & F1BYF4	0.7463	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.9412	0.0000	0.7353
F2BYF3 & F2BYF4	0.7813	6.2500	0.0000	3.9063
F2BYF3 & F2PYF4	2.0000	6.0000	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	0.9174	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	0.8929
F2PYF3 & F2BYF4	0.0000	1.8868	0.9434**	4.7170
F2PYF3 & F2PYF4	2.3529	12.9412	0.0000	10.5882
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.7752	0.7752
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	2.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	2.9703
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	2.0833

Table 12: Bivariate copula value-at-risk back-test (copula number 13 with normal distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	1.4184	3.5461	14.8936
F1BYF3 & F2BYF3	0.0000	0.0000	8.0882	16.1765
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	5.3571
F1BYF3 & F1BYF4	0.0000	0.7194	16.5468	33.0935
F1BYF3 & F1PYF4	0.7143	1.4286	2.8571	10.0000
F1BYF3 & F2BYF4	0.0000	1.5267	3.0534	10.6870
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	6.9307
F1PYF3 & F2BYF3	0.0000	0.0000	0.7246	2.8986
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	0.7194
F1PYF3 & F1PYF4	0.7092	2.8369	0.0000	0.7092
F1PYF3 & F2BYF4	0.0000	1.5152	0.7576	0.7576
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	1.9608
F2BYF3 & F2PYF3	0.9091*	6.3636	0.0000	2.7273
F2BYF3 & F1BYF4	0.7463	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.9412	0.0000	0.7353
F2BYF3 & F2BYF4	3.1250	7.8125	0.0000	5.4688
F2BYF3 & F2PYF4	2.0000	5.0000***	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	1.8349
F2PYF3 & F1PYF4	0.0000	0.8929	0.0000	0.8929
F2PYF3 & F2BYF4	0.0000	1.8868	0.9434**	2.8302
F2PYF3 & F2PYF4	3.5294	15.2941	3.5294	14.1176
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.7752	0.7752
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	1.9802
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	1.0417

Table 13: Bivariate copula value-at-risk back-test (copula number 14 with normal distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	1.4184	4.2553	12.0567
F1BYF3 & F2BYF3	0.0000	0.0000	8.0882	14.7059

F1BYF3 & F2PYF3	0.0000	7.1429	0.0000	6.2500
F1BYF3 & F1BYF4	0.0000	0.0000	13.6691	24.4604
F1BYF3 & F1PYF4	0.7143	2.1429	2.1429	7.8571
F1BYF3 & F2BYF4	0.0000	0.7634	3.8168	8.3969
F1BYF3 & F2PYF4	0.0000	2.9703	0.9901***	7.9208
F1PYF3 & F2BYF3	0.0000	0.0000	0.7246	3.6232
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.7194
F1PYF3 & F1PYF4	0.0000	1.4184	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	0.7576	0.7576	0.7576
F1PYF3 & F2PYF4	0.0000	1.9608	0.0000	2.9412
F2BYF3 & F2PYF3	2.7273	5.4545	0.0000	2.7273
F2BYF3 & F1BYF4	0.7463	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.9412	0.0000	0.7353
F2BYF3 & F2BYF4	0.7813	3.9063	0.7813	3.9063
F2BYF3 & F2PYF4	2.0000	6.0000	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	0.9174	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	0.8929
F2PYF3 & F2BYF4	0.0000	0.0000	0.9434**	4.7170
F2PYF3 & F2PYF4	2.3529	9.4118	0.0000	4.7059*
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.7752	0.7752
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	2.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	1.9802
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	1.0417

Table 14: Bivariate copula value-at-risk back-test (copula number 16 with normal distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	1.4184	1.4184	2.8369
F1BYF3 & F2BYF3	0.0000	0.0000	3.6765	8.0882
F1BYF3 & F2PYF3	0.0000	6.2500	0.0000	5.3571
F1BYF3 & F1BYF4	0.0000	0.0000	2.1583	6.4748
F1BYF3 & F1PYF4	0.7143	2.1429	0.7143	3.5714
F1BYF3 & F2BYF4	0.0000	0.7634	2.2901	3.0534
F1BYF3 & F2PYF4	0.0000	2.9703	0.9901***	7.9208
F1PYF3 & F2BYF3	0.0000	0.0000	0.7246	2.1739

F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.7194
F1PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	0.0000	0.7576	0.7576
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	2.9412
F2BYF3 & F2PYF3	1.8182	5.4545	0.0000	0.9091
F2BYF3 & F1BYF4	0.7463	0.7463	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.9412	0.0000	0.7353
F2BYF3 & F2BYF4	0.0000	0.7813	0.0000	0.0000
F2BYF3 & F2PYF4	2.0000	6.0000	0.0000	2.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	0.8929	0.0000	0.8929
F2PYF3 & F2BYF4	0.0000	0.0000	0.9434**	3.7736
F2PYF3 & F2PYF4	0.0000	0.0000	0.0000	0.0000
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.7752	0.7752
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	2.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	1.9802
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	1.0417

Table 15: Bivariate copula value-at-risk back-test (copula number 17 with normal distribution)

	1^{st} on 2^{nd}		**2^{nd} on 1^{st}**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.7092	8.5106	20.5674
F1BYF3 & F2BYF3	0.0000	0.0000	8.8235	19.8529
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	8.0357
F1BYF3 & F1BYF4	0.0000	0.0000	21.5827	36.6906
F1BYF3 & F1PYF4	0.7143	1.4286	5.0000	14.2857
F1BYF3 & F2BYF4	0.0000	1.5267	4.5802	16.0305
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	8.9109
F1PYF3 & F2BYF3	0.0000	0.7246	0.7246	1.4493
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	0.0000
F1PYF3 & F1PYF4	0.7092	2.8369	0.0000	1.4184
F1PYF3 & F2BYF4	0.0000	2.2727	0.7576	0.7576
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	1.9608
F2BYF3 & F2PYF3	0.9091*	7.2727	0.0000	3.6364

F2BYF3 & F1BYF4	0.7463	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.2059	0.0000	0.7353
F2BYF3 & F2BYF4	1.5625	6.2500	1.5625	4.6875
F2BYF3 & F2PYF4	2.0000	7.0000	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	0.9174	0.0000	0.0000
F2PYF3 & F1PYF4	0.0000	1.7857	0.0000	0.8929
F2PYF3 & F2BYF4	0.0000	1.8868	0.9434**	0.9434
F2PYF3 & F2PYF4	3.5294	15.2941	3.5294	11.7647
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.7752	1.5504
F1BYF4 & F2PYF4	0.0000	1.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	1.9802
F2BYF4 & F2PYF4	1.0417**	2.0833	0.0000	2.0833

Table 16: Bivariate copula value-at-risk back-test (copula number 3 with t-distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	1.4706
F1BYF3 & F2PYF3	0.0000	2.6786	0.0000	1.7857
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F1PYF4	0.7143	1.4286	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	1.5267	0.0000	0.0000
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.0000	0.7246	1.4493
F1PYF3 & F2PYF3	0.0000	0.0000	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F1PYF4	0.0000	0.7092	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	1.5152	0.0000	0.7576
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	2.9412
F2BYF3 & F2PYF3	0.0000	6.3636	0.0000	2.7273
F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	1.4706	0.0000	0.7353
F2BYF3 & F2BYF4	0.0000	1.5625	0.0000	0.0000
F2BYF3 & F2PYF4	1.0000***	5.0000***	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	0.9174	0.0000	0.0000
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	0.8929

F2PYF3 & F2BYF4	0.0000	2.8302	0.0000	2.8302
F2PYF3 & F2PYF4	0.0000	1.1765	0.0000	0.0000
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.9901	0.0000	1.9802
F2BYF4 & F2PYF4	0.0000	3.1250	0.0000	1.0417

Table 17: Bivariate copula value-at-risk back-test (copula number 4 with t-distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	0.7353
F1BYF3 & F2PYF3	0.0000	1.7857	0.0000	0.8929
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F1PYF4	0.0000	0.7143	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.0000	0.0000	0.7246
F1PYF3 & F2PYF3	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F1PYF4	0.0000	1.4184	0.0000	1.4184
F1PYF3 & F2BYF4	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	0.9804
F2BYF3 & F2PYF3	0.0000	2.7273	0.0000	2.7273
F2BYF3 & F1BYF4	0.0000	0.7463	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	0.7353	0.0000	0.7353
F2BYF3 & F2BYF4	0.0000	3.1250	1.5625	3.9063
F2BYF3 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F2BYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F2PYF4	2.3529	10.5882	1.1765	4.7059*
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF4 & F2PYF4	0.0000	0.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.0000	0.7692	0.7692

F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.9901
F2BYF4 & F2PYF4	0.0000	0.0000	0.0000	1.0417

Table 18: Bivariate copula value-at-risk back-test (copula number 5 with t-distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.7092	0.0000	0.7092
F1BYF3 & F2BYF3	0.0000	0.7353	0.0000	0.7353
F1BYF3 & F2PYF3	0.0000	2.6786	0.0000	0.8929
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F1PYF4	0.7143	0.7143	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F2PYF4	0.0000	1.9802	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.0000	1.4493
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.885
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	0.0000
F1PYF3 & F1PYF4	0.7092	2.8369	0.0000	0.7092
F1PYF3 & F2BYF4	0.0000	1.5152	0.0000	0.0000
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	1.9608
F2BYF3 & F2PYF3	0.0000	3.6364	0.0000	3.6364
F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	0.7353	0.0000	0.7353
F2BYF3 & F2BYF4	0.0000	5.4688	1.5625	4.6875
F2BYF3 & F2PYF4	0.0000	5.0000***	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	0.9174	0.0000	0.0000
F2PYF3 & F1PYF4	0.0000	1.7857	0.0000	0.0000
F2PYF3 & F2BYF4	0.0000	0.9434	0.0000	0.0000
F2PYF3 & F2PYF4	3.5294	14.1176	2.3529	9.4118
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.0000	0.7752
F1BYF4 & F2PYF4	0.0000	1.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.9901
F2BYF4 & F2PYF4	0.0000	0.0000	0.0000	2.0833

Table 19: Bivariate copula value-at-risk back-test (copula number 6 witht-distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.7092	0.0000	0.0000
F1BYF3 & F2BYF3	0.0000	0.7353	0.0000	1.4706
F1BYF3 & F2PYF3	0.0000	1.7857	0.0000	0.0000
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F1PYF4	0.0000	1.4286	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	0.7634	0.0000	0.0000
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	0.0000
F1PYF3 & F2BYF3	0.0000	0.0000	0.0000	1.4493
F1PYF3 & F2PYF3	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.7092
F1PYF3 & F2BYF4	0.0000	0.0000	0.0000	0.7576
F1PYF3 & F2PYF4	0.0000	0.0000	0.0000	0.0000
F2BYF3 & F2PYF3	0.0000	1.8182	0.0000	0.0000
F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	1.4706	0.0000	0.7353
F2BYF3 & F2BYF4	0.0000	0.7813	1.5625	4.6875
F2BYF3 & F2PYF4	0.0000	3.0000	0.0000	0.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	0.9174
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F2BYF4	0.0000	0.0000	0.0000	0.9434
F2PYF3 & F2PYF4	1.1765	5.8824	1.1765	1.1765
F1BYF4 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.0000	0.7752
F1BYF4 & F2PYF4	0.0000	1.0000	0.0000	0.0000
F1PYF4 & F2BYF4	0.0000	0.0000	0.0000	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.0000
F2BYF4 & F2PYF4	0.0000	1.0417	0.0000	0.0000

Table 20: Bivariate copula value-at-risk back-test (copula number 9 with t-distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.8369	0.0000	0.7092
F1BYF3 & F2BYF3	0.0000	2.9412	0.0000	2.9412

F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	0.0000
F1BYF3 & F1BYF4	0.0000	2.8777	0.0000	2.1583
F1BYF3 & F1PYF4	0.0000	2.8571	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	3.0534	0.0000	1.5267
F1BYF3 & F2PYF4	0.0000	3.9604	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.0000	2.8986
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	2.1583
F1PYF3 & F1PYF4	0.0000	0.7092	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	0.7576	0.0000	1.5152
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	0.9804
F2BYF3 & F2PYF3	0.0000	3.6364	0.0000	0.0000
F2BYF3 & F1BYF4	0.0000	2.9851	0.0000	2.2388
F2BYF3 & F1PYF4	0.0000	2.9412	0.0000	0.0000
F2BYF3 & F2BYF4	0.0000	3.1250	0.0000	1.5625
F2BYF3 & F2PYF4	0.0000	4.0000	0.0000	1.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F2BYF4	0.0000	0.0000	0.0000	1.8868
F2PYF3 & F2PYF4	0.0000	0.0000	0.0000	1.1765
F1BYF4 & F1PYF4	0.0000	2.1739	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	2.3256	0.0000	1.5504
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.0000	0.0000	1.5385
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.9901
F2BYF4 & F2PYF4	0.0000	2.0833	0.0000	1.0417

Table 21: Bivariate copula value-at-risk back-test (copula number 10 with t-distribution)

	1^{st} on 2^{nd}		**2^{nd} on 1^{st}**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	4.9645**	0.0000	1.4184
F1BYF3 & F2BYF3	0.0000	2.9412	0.0000	2.9412
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	0.0000
F1BYF3 & F1BYF4	0.0000	2.8777	0.0000	2.1583
F1BYF3 & F1PYF4	0.0000	2.8571	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	3.0534	0.0000	1.5267
F1BYF3 & F2PYF4	0.0000	3.9604	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.0000	2.8986

F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	2.1583
F1PYF3 & F1PYF4	0.0000	0.7092	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	0.7576	0.0000	1.5152
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	0.9804
F2BYF3 & F2PYF3	0.0000	3.6364	0.0000	0.0000
F2BYF3 & F1BYF4	0.0000	2.9851	0.0000	2.2388
F2BYF3 & F1PYF4	0.0000	2.9412	0.0000	0.0000
F2BYF3 & F2BYF4	0.0000	3.1250	0.0000	1.5625
F2BYF3 & F2PYF4	0.0000	4.0000	0.0000	1.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	0.0000
F2PYF3 & F2BYF4	0.0000	0.0000	0.0000	1.8868
F2PYF3 & F2PYF4	0.0000	0.0000	0.0000	1.1765
F1BYF4 & F1PYF4	0.0000	2.1739	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	2.3256	0.0000	1.5504
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.0000	0.0000	1.5385
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.9901
F2BYF4 & F2PYF4	0.0000	2.0833	0.0000	1.0417

Table 22: Bivariate copula value-at-risk back-test (copula number 12 with t-distribution)

	1$^{\text{st}}$ on 2$^{\text{nd}}$		**2$^{\text{nd}}$ on 1$^{\text{st}}$**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.1277	0.0000	0.0000
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	2.9412
F1BYF3 & F2PYF3	0.0000	7.1429	0.0000	1.7857
F1BYF3 & F1BYF4	0.0000	0.7194	0.0000	0.0000
F1BYF3 & F1PYF4	0.7143	2.1429	0.0000	0.7143
F1BYF3 & F2BYF4	0.0000	1.5267	0.0000	0.0000
F1BYF3 & F2PYF4	0.9901***	4.9505**	0.0000	2.9703
F1PYF3 & F2BYF3	0.0000	0.7246	0.7246	4.3478
F1PYF3 & F2PYF3	0.0000	2.6549	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	1.4388	0.0000	0.0000
F1PYF3 & F1PYF4	0.7092	2.1277	0.0000	0.7092
F1PYF3 & F2BYF4	0.0000	2.2727	0.0000	0.7576
F1PYF3 & F2PYF4	0.0000	3.9216	0.0000	2.9412
F2BYF3 & F2PYF3	0.9091*	8.1818	0.0000	2.7273

F2BYF3 & F1BYF4	0.7463	2.2388	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.9412	0.7353	0.7353
F2BYF3 & F2BYF4	2.3438	7.8125	0.0000	3.9063
F2BYF3 & F2PYF4	2.0000	9.0000	0.0000	5.0000
F2PYF3 & F1BYF4	0.0000	2.7523	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	3.5714	0.0000	1.7857
F2PYF3 & F2BYF4	0.0000	2.8302	0.0000	3.7736
F2PYF3 & F2PYF4	3.5294	15.2941	2.3529	8.2353
F1BYF4 & F1PYF4	0.7246	0.7246	0.0000	0.7246
F1BYF4 & F2BYF4	0.0000	1.5504	0.0000	0.7752
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	3.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	1.9802	0.0000	2.9703
F2BYF4 & F2PYF4	0.0000	3.1250	0.0000	4.1667

Table 23: Bivariate copula value-at-risk back-test (copula number 13 with t-distribution)

	1^{st} on 2^{nd}		**2^{nd} on 1^{st}**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.7092	0.0000	0.7092
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	2.2059
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	1.7857
F1BYF3 & F1BYF4	0.0000	0.7194	0.0000	0.0000
F1BYF3 & F1PYF4	0.7143	1.4286	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	1.5267	0.0000	0.0000
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.0000	1.4493
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	1.4388	0.0000	0.0000
F1PYF3 & F1PYF4	0.7092	3.5461	0.0000	1.4184
F1PYF3 & F2BYF4	0.0000	2.2727	0.0000	0.7576
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	2.9412
F2BYF3 & F2PYF3	0.0000	7.2727	0.0000	2.7273
F2BYF3 & F1BYF4	0.0000	2.2388	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	1.4706	0.0000	0.7353
F2BYF3 & F2BYF4	2.3438	9.3750	0.0000	3.9063
F2BYF3 & F2PYF4	1.0000	6.0000	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	1.8349	0.0000	0.0000
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	0.8929

F2PYF3 & F2BYF4	0.0000	2.8302	0.0000	1.8868
F2PYF3 & F2PYF4	5.8824	16.4706	2.3529	11.7647
F1BYF4 & F1PYF4	0.7246	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	1.5504	0.0000	0.0000
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	1.9802	0.0000	1.9802
F2BYF4 & F2PYF4	0.0000	1.0417	0.0000	2.0833

Table 24: Bivariate copula value-at-risk back-test (copula number 14 with t-distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.7092	0.0000	0.0000
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	2.2059
F1BYF3 & F2PYF3	0.0000	7.1429	0.0000	1.7857
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F1PYF4	0.7143	1.4286	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	1.5267	0.0000	0.0000
F1BYF3 & F2PYF4	0.9901***	3.9604	0.0000	2.9703
F1PYF3 & F2BYF3	0.0000	0.7246	0.7246	3.6232
F1PYF3 & F2PYF3	0.0000	1.7699	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	0.0000
F1PYF3 & F1PYF4	0.0000	2.1277	0.0000	1.4184
F1PYF3 & F2BYF4	0.0000	2.2727	0.0000	0.7576
F1PYF3 & F2PYF4	0.0000	3.9216	0.0000	2.9412
F2BYF3 & F2PYF3	0.0000	8.1818	0.0000	3.6364
F2BYF3 & F1BYF4	0.0000	2.2388	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.9412	0.7353	0.7353
F2BYF3 & F2BYF4	0.7813	4.6875	0.0000	3.9063
F2BYF3 & F2PYF4	2.0000	7.0000	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	1.8349	0.0000	3.6697
F2PYF3 & F1PYF4	0.0000	3.5714	0.0000	1.7857
F2PYF3 & F2BYF4	0.0000	2.8302	0.0000	1.8868
F2PYF3 & F2PYF4	2.3529	11.7647	1.1765	7.0588
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.0000	0.7752
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	3.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	0.7692

F1PYF4 & F2PYF4	0.0000	1.9802	0.0000	2.9703
F2BYF4 & F2PYF4	0.0000	3.1250	0.0000	4.1667

Table 25: Bivariate copula value-at-risk back-test (copula number 16 with t-distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	1.4706
F1BYF3 & F2PYF3	0.0000	6.2500	0.0000	1.7857
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F1PYF4	0.7143	1.4286	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	1.5267	0.0000	0.0000
F1BYF3 & F2PYF4	0.9901***	2.9703	0.0000	2.9703
F1PYF3 & F2BYF3	0.0000	0.0000	0.7246	2.1739
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	0.0000
F1PYF3 & F1PYF4	0.0000	0.7092	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	1.5152	0.0000	0.7576
F1PYF3 & F2PYF4	0.0000	1.9608	0.0000	2.9412
F2BYF3 & F2PYF3	0.0000	7.2727	0.0000	2.7273
F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.2059	0.0000	0.7353
F2BYF3 & F2BYF4	0.0000	1.5625	0.0000	0.0000
F2BYF3 & F2PYF4	2.0000	5.0000***	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	1.8349	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	1.7857
F2PYF3 & F2BYF4	0.0000	2.8302	0.0000	2.8302
F2PYF3 & F2PYF4	0.0000	1.1765	0.0000	0.0000
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.0000	0.0000
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	3.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	1.9802	0.0000	2.9703
F2BYF4 & F2PYF4	0.0000	3.1250	0.0000	1.0417

Table 26: Bivariate copula value-at-risk back-test (copula number 17 with t-distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.7092	0.0000	0.7092
F1BYF3 & F2BYF3	0.0000	0.7353	0.0000	0.7353
F1BYF3 & F2PYF3	0.0000	2.6786	0.0000	0.8929
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F1PYF4	0.7143	0.7143	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	1.5267	0.0000	0.0000
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.0000	1.4493
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	1.4388	0.0000	0.0000
F1PYF3 & F1PYF4	0.7092	2.8369	0.0000	0.7092
F1PYF3 & F2BYF4	0.0000	2.2727	0.0000	0.0000
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	1.9608
F2BYF3 & F2PYF3	0.0000	6.3636	0.0000	3.6364
F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	0.7353	0.0000	0.7353
F2BYF3 & F2BYF4	0.7813	6.2500	1.5625	3.9063
F2BYF3 & F2PYF4	0.0000	5.0000***	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	0.9174	0.0000	0.0000
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	0.8929
F2PYF3 & F2BYF4	0.0000	1.8868	0.0000	0.0000
F2PYF3 & F2PYF4	3.5294	15.2941	2.3529	11.7647
F1BYF4 & F1PYF4	0.0000	1.4493	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.0000	0.7752
F1BYF4 & F2PYF4	0.0000	1.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	1.9802
F2BYF4 & F2PYF4	0.0000	0.0000	0.0000	2.0833

Table 27: Bivariate copula value-at-risk back-test (copula number 3 with empirical distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	1.4706

F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	1.7857
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F1PYF4	0.7143	1.4286	0.0000	0.7143
F1BYF3 & F2BYF4	0.0000	0.7634	0.0000	0.0000
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	2.9703
F1PYF3 & F2BYF3	0.0000	0.0000	0.0000	2.1739
F1PYF3 & F2PYF3	0.0000	1.7699	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	0.0000
F1PYF3 & F1PYF4	0.0000	0.7092	0.0000	0.0000
F1PYF3 & F2BYF4	0.0000	2.2727	0.0000	0.7576
F1PYF3 & F2PYF4	0.0000	3.9216	0.0000	3.9216
F2BYF3 & F2PYF3	0.0000	4.5455	0.0000	2.7273
F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	0.7353	0.0000	0.7353
F2BYF3 & F2BYF4	0.0000	0.7813	0.0000	0.0000
F2BYF3 & F2PYF4	1.0000***	5.0000***	0.0000	5.0000***
F2PYF3 & F1BYF4	0.0000	2.7523	0.0000	0.9174
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	1.7857
F2PYF3 & F2BYF4	0.0000	2.8302	0.0000	3.7736
F2PYF3 & F2PYF4	0.0000	4.7059*	0.0000	0.0000
F1BYF4 & F1PYF4	0.0000	0.7246	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.0000	0.7752
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	3.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	0.7692
F1PYF4 & F2PYF4	0.0000	1.9802	0.0000	2.9703
F2BYF4 & F2PYF4	0.0000	5.2083*	0.0000	4.1667

Table 28: Bivariate copula value-at-risk back-test (copula number 4 with empirical distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.7092	0.0000	0.7092
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	1.4706
F1BYF3 & F2PYF3	0.0000	2.6786	0.0000	0.8929
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.7194
F1BYF3 & F1PYF4	0.7143	0.7143	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	0.0000	0.0000	1.5267
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.0000	1.4493

F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	0.0000
F1PYF3 & F1PYF4	0.7092	5.6738	1.4184	4.2553
F1PYF3 & F2BYF4	0.0000	1.5152	0.0000	0.7576
F1PYF3 & F2PYF4	0.0000	0.9804	0.0000	1.9608
F2BYF3 & F2PYF3	0.0000	2.7273	0.0000	3.6364
F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	0.7353	0.0000	0.7353
F2BYF3 & F2BYF4	0.7813	7.8125	3.9063	7.8125
F2BYF3 & F2PYF4	0.0000	5.0000***	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	0.9174	0.0000	0.0000
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	0.8929
F2PYF3 & F2BYF4	0.0000	2.8302	0.0000	2.8302
F2PYF3 & F2PYF4	4.7059	16.4706	2.3529	11.7647
F1BYF4 & F1PYF4	0.0000	1.4493	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.0000	0.0000	1.5504
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	1.5385
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	1.9802
F2BYF4 & F2PYF4	0.0000	2.0833	0.0000	2.0833

Table 29: Bivariate copula value-at-risk back-test (copula number 5 with empirical distribution)

	1$^{\text{st}}$ on 2$^{\text{nd}}$		**2$^{\text{nd}}$ on 1$^{\text{st}}$**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.1277	0.0000	1.4184
F1BYF3 & F2BYF3	0.0000	0.7353	0.0000	1.4706
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	1.7857
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.7194
F1BYF3 & F1PYF4	0.7143	2.1429	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	0.7634	0.0000	1.5267
F1BYF3 & F2PYF4	0.0000	1.9802	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.0000	2.1739
F1PYF3 & F2PYF3	0.0000	2.6549	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	2.1583	0.0000	1.4388
F1PYF3 & F1PYF4	1.4184	5.6738	0.7092	4.9645**
F1PYF3 & F2BYF4	0.0000	2.2727	0.0000	1.5152
F1PYF3 & F2PYF4	0.0000	1.9608	0.0000	3.9216
F2BYF3 & F2PYF3	0.0000	4.5455	0.0000	5.4545

F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.7463
F2BYF3 & F1PYF4	0.7353	0.7353	0.0000	0.7353
F2BYF3 & F2BYF4	1.5625	6.2500	1.5625	4.6875
F2BYF3 & F2PYF4	0.0000	6.0000	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	1.8349	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	0.8929
F2PYF3 & F2BYF4	0.0000	4.7170	0.0000	3.7736
F2PYF3 & F2PYF4	4.7059	17.6471	3.5294	9.4118
F1BYF4 & F1PYF4	0.7246	2.1739	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.0000	3.1008
F1BYF4 & F2PYF4	0.0000	1.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	2.3077
F1PYF4 & F2PYF4	0.0000	1.9802	0.0000	1.9802
F2BYF4 & F2PYF4	0.0000	2.0833	0.0000	2.0833

Table 30: Bivariate copula value-at-risk back-test (copula number 6 with empirical distribution)

	$\mathbf{1^{st}}$ **on** $\mathbf{2^{nd}}$		$\mathbf{2^{nd}}$ **on** $\mathbf{1^{st}}$	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	1.4184	0.0000	2.1277
F1BYF3 & F2BYF3	0.0000	0.7353	0.0000	2.2059
F1BYF3 & F2PYF3	0.0000	2.6786	0.0000	0.8929
F1BYF3 & F1BYF4	0.0000	0.7194	0.7194	2.1583
F1BYF3 & F1PYF4	0.0000	1.4286	0.0000	0.0000
F1BYF3 & F2BYF4	0.0000	0.7634	0.0000	0.7634
F1BYF3 & F2PYF4	0.0000	3.9604	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.7246	1.4493
F1PYF3 & F2PYF3	0.0000	0.8850	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	0.7194	0.0000	1.4388
F1PYF3 & F1PYF4	1.4184	5.6738	2.1277	5.6738
F1PYF3 & F2BYF4	0.0000	0.7576	0.0000	0.7576
F1PYF3 & F2PYF4	0.0000	2.9412	0.0000	0.9804
F2BYF3 & F2PYF3	0.9091*	2.7273	0.0000	1.8182
F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.7463
F2BYF3 & F1PYF4	0.7353	1.4706	0.0000	0.7353
F2BYF3 & F2BYF4	3.1250	7.8125	3.9063	7.0313
F2BYF3 & F2PYF4	1.0000***	3.0000	0.0000	0.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	0.8929	0.0000	0.0000

F2PYF3 & F2BYF4	0.0000	0.9434	0.0000	0.9434
F2PYF3 & F2PYF4	4.7059	11.7647	2.3529	7.0588
F1BYF4 & F1PYF4	0.0000	2.1739	0.0000	0.0000
F1BYF4 & F2BYF4	0.0000	0.7752	0.0000	0.7752
F1BYF4 & F2PYF4	0.0000	4.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	0.7692	0.7692	2.3077
F1PYF4 & F2PYF4	0.0000	0.0000	0.0000	0.9901
F2BYF4 & F2PYF4	0.0000	2.0833	0.0000	0.0000

Table 31: Bivariate copula value-at-risk back-test (copula number 9 with empirical distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.8369	0.0000	1.4184
F1BYF3 & F2BYF3	0.0000	2.9412	0.7353	2.9412
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	0.0000
F1BYF3 & F1BYF4	0.0000	2.8777	0.0000	2.1583
F1BYF3 & F1PYF4	0.0000	2.8571	0.0000	1.4286
F1BYF3 & F2BYF4	0.0000	3.0534	0.7634	2.2901
F1BYF3 & F2PYF4	0.0000	3.9604	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	1.4493	0.7246	2.8986
F1PYF3 & F2PYF3	0.0000	1.7699	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	1.4388	0.0000	2.1583
F1PYF3 & F1PYF4	0.0000	1.4184	0.0000	1.4184
F1PYF3 & F2BYF4	0.0000	1.5152	0.7576	2.2727
F1PYF3 & F2PYF4	0.0000	1.9608	0.0000	0.9804
F2BYF3 & F2PYF3	0.9091*	3.6364	0.0000	0.0000
F2BYF3 & F1BYF4	0.7463	2.9851	0.0000	2.2388
F2BYF3 & F1PYF4	0.7353	2.9412	0.0000	1.4706
F2BYF3 & F2BYF4	0.7813	3.1250	0.7813	2.3438
F2BYF3 & F2PYF4	1.0000***	4.0000	0.0000	1.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	1.7857
F2PYF3 & F2BYF4	0.0000	0.0000	0.9434**	2.8302
F2PYF3 & F2PYF4	0.0000	0.0000	0.0000	1.1765
F1BYF4 & F1PYF4	0.0000	2.1739	0.0000	1.4493
F1BYF4 & F2BYF4	0.0000	2.3256	0.7752	2.3256
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	2.3077

F1PYF4 & F2PYF4	0.0000	1.9802	0.0000	0.9901
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	1.0417

Table 32: Bivariate copula value-at-risk back-test (copula number 10 with empirical distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.8369	0.0000	1.4184
F1BYF3 & F2BYF3	0.0000	2.9412	0.7353	2.9412
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	0.0000
F1BYF3 & F1BYF4	0.0000	2.8777	0.0000	2.1583
F1BYF3 & F1PYF4	0.0000	2.8571	0.0000	1.4286
F1BYF3 & F2BYF4	0.0000	3.0534	0.7634	2.2901
F1BYF3 & F2PYF4	0.0000	3.9604	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	1.4493	0.7246	2.8986
F1PYF3 & F2PYF3	0.0000	1.7699	0.0000	0.0000
F1PYF3 & F1BYF4	0.0000	1.4388	0.0000	2.1583
F1PYF3 & F1PYF4	0.0000	1.4184	0.0000	1.4184
F1PYF3 & F2BYF4	0.7576	2.2727	0.7576	3.7879
F1PYF3 & F2PYF4	0.0000	1.9608	0.0000	0.9804
F2BYF3 & F2PYF3	0.9091*	3.6364	0.0000	0.0000
F2BYF3 & F1BYF4	0.7463	2.9851	0.0000	2.2388
F2BYF3 & F1PYF4	0.7353	2.9412	0.0000	1.4706
F2BYF3 & F2BYF4	0.7813	3.1250	0.7813	2.3438
F2BYF3 & F2PYF4	2.0000	6.0000	0.0000	2.0000
F2PYF3 & F1BYF4	0.0000	0.0000	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	0.0000	0.0000	1.7857
F2PYF3 & F2BYF4	0.0000	0.0000	0.9434**	2.8302
F2PYF3 & F2PYF4	0.0000	0.0000	0.0000	1.1765
F1BYF4 & F1PYF4	0.0000	2.1739	0.0000	1.4493
F1BYF4 & F2BYF4	0.0000	2.3256	0.7752	2.3256
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	1.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	2.3077
F1PYF4 & F2PYF4	0.0000	1.9802	0.0000	0.9901
F2BYF4 & F2PYF4	1.0417**	3.1250	0.0000	1.0417

Table 33: Bivariate copula value-at-risk back-test (copula number 12 with empirical distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.1277	0.0000	2.8369
F1BYF3 & F2BYF3	0.0000	0.0000	0.7353	2.9412
F1BYF3 & F2PYF3	0.0000	6.2500	0.0000	2.6786
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F1PYF4	0.7143	3.5714	0.0000	0.7143
F1BYF3 & F2BYF4	0.0000	0.7634	0.0000	1.5267
F1BYF3 & F2PYF4	0.9901***	5.9406	0.9901***	5.9406
F1PYF3 & F2BYF3	0.0000	2.8986	0.7246	3.6232
F1PYF3 & F2PYF3	0.0000	5.3097	0.0000	1.7699
F1PYF3 & F1BYF4	0.7194	1.4388	0.0000	0.7194
F1PYF3 & F1PYF4	1.4184	4.9645**	0.0000	2.8369
F1PYF3 & F2BYF4	0.7576	3.7879	0.7576	1.5152
F1PYF3 & F2PYF4	0.0000	3.9216	1.9608	5.8824
F2BYF3 & F2PYF3	0.0000	7.2727	0.9091*	3.6364
F2BYF3 & F1BYF4	0.7463	2.2388	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.2059	0.7353	0.7353
F2BYF3 & F2BYF4	1.5625	10.9375	1.5625	5.4688
F2BYF3 & F2PYF4	2.0000	7.0000	1.0000***	6.0000
F2PYF3 & F1BYF4	0.0000	2.7523	0.0000	5.5046
F2PYF3 & F1PYF4	0.8929*	4.4643	0.8929*	3.5714
F2PYF3 & F2BYF4	0.0000	4.7170	0.0000	4.717
F2PYF3 & F2PYF4	5.8824	17.6471	3.5294	11.7647
F1BYF4 & F1PYF4	0.7246	2.8986	0.0000	2.1739
F1BYF4 & F2BYF4	0.0000	0.7752	0.0000	1.5504
F1BYF4 & F2PYF4	1.0000***	3.0000	1.0000***	6.0000
F1PYF4 & F2BYF4	0.7692	1.5385	0.7692	1.5385
F1PYF4 & F2PYF4	0.0000	1.9802	1.9802	6.9307
F2BYF4 & F2PYF4	0.0000	6.2500	1.0417**	6.2500

Table 34: Bivariate copula value-at-risk back-test (copula number 13 with empirical distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.8369	0.0000	2.1277
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	2.9412

F1BYF3 & F2PYF3	0.0000	4.4643	0.0000	1.7857
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.7194
F1BYF3 & F1PYF4	0.7143	2.8571	0.0000	0.7143
F1BYF3 & F2BYF4	0.0000	1.5267	0.0000	0.7634
F1BYF3 & F2PYF4	0.0000	2.9703	0.0000	2.9703
F1PYF3 & F2BYF3	0.0000	0.7246	0.0000	2.8986
F1PYF3 & F2PYF3	0.0000	3.5398	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	1.4388	0.0000	1.4388
F1PYF3 & F1PYF4	1.4184	4.9645	0.0000	2.1277
F1PYF3 & F2BYF4	0.0000	3.0303	0.0000	1.5152
F1PYF3 & F2PYF4	0.0000	3.9216	0.0000	4.9020
F2BYF3 & F2PYF3	0.0000	6.3636	0.9091	3.6364
F2BYF3 & F1BYF4	0.0000	2.2388	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	0.7353	0.7353	0.7353
F2BYF3 & F2BYF4	1.5625	9.3750	1.5625	3.9063
F2BYF3 & F2PYF4	1.0000	7.0000	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	2.7523	0.0000	1.8349
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	1.7857
F2PYF3 & F2BYF4	0.0000	3.7736	0.0000	4.7170
F2PYF3 & F2PYF4	8.2353	18.8235	4.7059	11.7647
F1BYF4 & F1PYF4	0.7246	2.1739	0.0000	1.4493
F1BYF4 & F2BYF4	0.0000	0.7752	0.0000	1.5504
F1BYF4 & F2PYF4	0.0000	3.0000	0.0000	3.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	1.5385
F1PYF4 & F2PYF4	0.0000	1.9802	0.9901	3.9604
F2BYF4 & F2PYF4	0.0000	4.1667	0.0000	6.2500

Table 35: Bivariate copula value-at-risk back-test (copula number 14 with empirical distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	1.4184	0.0000	2.1277
F1BYF3 & F2BYF3	0.0000	0.0000	0.0000	2.2059
F1BYF3 & F2PYF3	0.0000	6.2500	0.0000	2.6786
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.7194
F1BYF3 & F1PYF4	0.7143	2.8571	0.0000	0.7143
F1BYF3 & F2BYF4	0.0000	0.7634	0.0000	1.5267
F1BYF3 & F2PYF4	0.9901***	5.9406	0.9901***	5.9406
F1PYF3 & F2BYF3	0.0000	2.1739	0.7246	2.8986

F1PYF3 & F2PYF3	0.0000	4.4248	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	1.4388	0.0000	0.7194
F1PYF3 & F1PYF4	0.7092	4.9645**	0.0000	3.5461
F1PYF3 & F2BYF4	0.0000	3.0303	0.0000	1.5152
F1PYF3 & F2PYF4	0.0000	3.9216	1.9608	5.8824
F2BYF3 & F2PYF3	0.0000	7.2727	0.9091*	3.6364
F2BYF3 & F1BYF4	0.0000	2.2388	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	2.2059	0.7353	0.7353
F2BYF3 & F2BYF4	0.7813	8.5938	3.1250	5.4688
F2BYF3 & F2PYF4	2.0000	7.0000	1.0000***	6.0000
F2PYF3 & F1BYF4	0.0000	2.7523	0.0000	5.5046
F2PYF3 & F1PYF4	0.8929*	4.4643	0.8929*	4.4643
F2PYF3 & F2BYF4	0.0000	3.7736	0.0000	4.7170
F2PYF3 & F2PYF4	3.5294	16.4706	1.1765	11.7647
F1BYF4 & F1PYF4	0.7246	2.1739	0.0000	1.4493
F1BYF4 & F2BYF4	0.0000	0.7752	0.0000	1.5504
F1BYF4 & F2PYF4	1.0000***	3.0000	1.0000***	6.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	1.5385
F1PYF4 & F2PYF4	0.0000	1.9802	0.9901***	6.9307
F2BYF4 & F2PYF4	0.0000	6.2500	1.0417**	6.2500

Table 36: Bivariate copula value-at-risk back-test (copula number 16 with empirical distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	0.0000	0.0000	0.0000
F1BYF3 & F2BYF3	0.0000	0.0000	0.7353	2.2059
F1BYF3 & F2PYF3	0.8929*	7.1429	0.0000	2.6786
F1BYF3 & F1BYF4	0.0000	0.0000	0.7194	0.7194
F1BYF3 & F1PYF4	0.7143	1.4286	0.0000	0.7143
F1BYF3 & F2BYF4	0.0000	0.7634	0.0000	0.7634
F1BYF3 & F2PYF4	0.9901***	3.9604	0.9901***	3.9604
F1PYF3 & F2BYF3	0.0000	1.4493	0.7246	2.1739
F1PYF3 & F2PYF3	0.8850*	4.4248	0.0000	1.7699
F1PYF3 & F1BYF4	0.7194	1.4388	0.7194	0.7194
F1PYF3 & F1PYF4	0.0000	0.7092	0.7092	0.7092
F1PYF3 & F2BYF4	0.0000	2.2727	0.7576	1.5152
F1PYF3 & F2PYF4	0.0000	3.9216	0.9804**	4.9020**
F2BYF3 & F2PYF3	0.0000	5.4545	0.9091*	3.6364

F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	1.4706	0.0000	0.7353
F2BYF3 & F2BYF4	0.0000	0.7813	0.0000	0.0000
F2BYF3 & F2PYF4	2.0000	5.0000***	0.0000	6.0000
F2PYF3 & F1BYF4	0.0000	2.7523	0.0000	4.5872
F2PYF3 & F1PYF4	0.8929*	4.4643	0.8929*	2.6786
F2PYF3 & F2BYF4	0.0000	2.8302	0.0000	3.7736
F2PYF3 & F2PYF4	0.0000	4.7059*	0.0000	0.0000
F1BYF4 & F1PYF4	0.7246	0.7246	0.0000	0.7246
F1BYF4 & F2BYF4	0.0000	0.7752	0.0000	0.7752
F1BYF4 & F2PYF4	1.0000***	3.0000	1.0000***	5.0000
F1PYF4 & F2BYF4	0.0000	1.5385	1.5385	1.5385
F1PYF4 & F2PYF4	0.0000	1.9802	0.9901***	5.9406
F2BYF4 & F2PYF4	0.0000	5.2083*	0.0000	4.1667

Table 37: Bivariate copula value-at-risk back-test (copula number 17 with empirical distribution)

	1st on 2nd		**2nd on 1st**	
Contract	1%	5%	1%	5%
F1BYF3 & F1PYF3	0.0000	2.8369	0.0000	1.4184
F1BYF3 & F2BYF3	0.0000	0.7353	0.0000	1.4706
F1BYF3 & F2PYF3	0.0000	3.5714	0.0000	1.7857
F1BYF3 & F1BYF4	0.0000	0.0000	0.0000	0.7194
F1BYF3 & F1PYF4	0.7143	2.1429	0.0000	0.7143
F1BYF3 & F2BYF4	0.0000	1.5267	0.0000	1.5267
F1BYF3 & F2PYF4	0.0000	1.9802	0.0000	0.9901
F1PYF3 & F2BYF3	0.0000	0.7246	0.0000	2.8986
F1PYF3 & F2PYF3	0.0000	3.5398	0.0000	1.7699
F1PYF3 & F1BYF4	0.0000	2.1583	0.0000	2.1583
F1PYF3 & F1PYF4	1.4184	5.6738	0.7092	2.8369
F1PYF3 & F2BYF4	0.0000	3.7879	0.0000	2.2727
F1PYF3 & F2PYF4	0.0000	2.9412	0.0000	4.9020**
F2BYF3 & F2PYF3	0.0000	5.4545	0.0000	5.4545
F2BYF3 & F1BYF4	0.0000	1.4925	0.0000	0.0000
F2BYF3 & F1PYF4	0.7353	0.7353	0.7353	0.7353
F2BYF3 & F2BYF4	0.7813	7.0313	1.5625	4.6875
F2BYF3 & F2PYF4	0.0000	6.0000	0.0000	4.0000
F2PYF3 & F1BYF4	0.0000	1.8349	0.0000	2.7523
F2PYF3 & F1PYF4	0.0000	2.6786	0.0000	1.7857

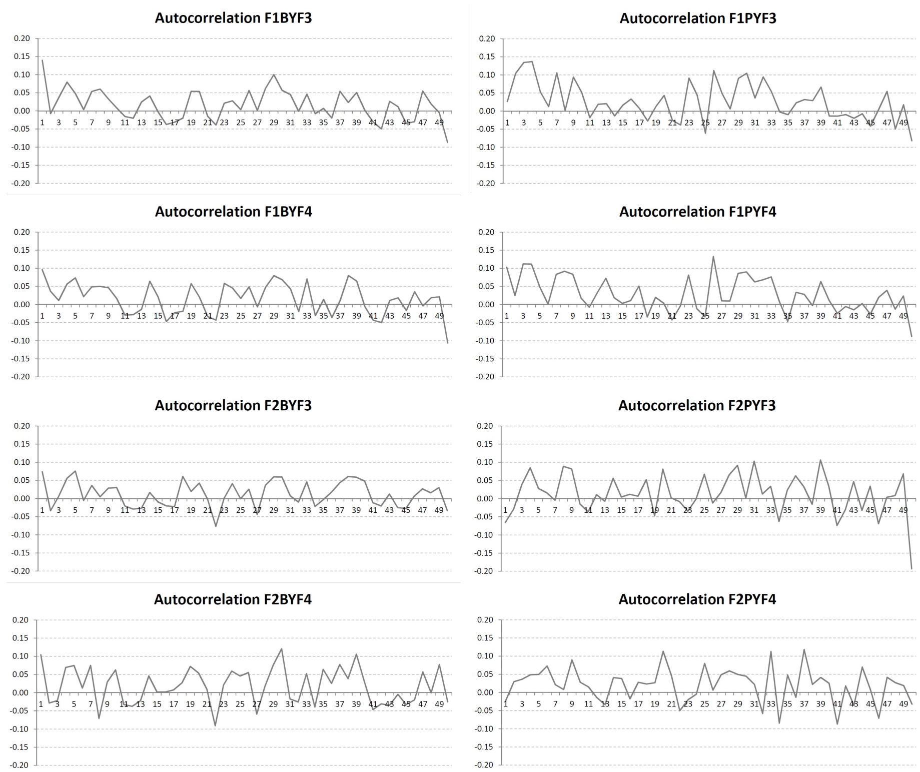
F2PYF3 & F2BYF4	0.0000	4.7170	0.0000	4.7170
F2PYF3 & F2PYF4	5.8824	17.6471	4.7059	10.5882
F1BYF4 & F1PYF4	0.7246	2.1739	0.0000	0.7246
F1BYF4 & F2BYF4	0.0000	0.7752	0.0000	3.1008
F1BYF4 & F2PYF4	0.0000	2.0000	0.0000	2.0000
F1PYF4 & F2BYF4	0.0000	1.5385	0.7692	2.3077
F1PYF4 & F2PYF4	0.0000	1.9802	0.0000	2.9703
F2BYF4 & F2PYF4	0.0000	3.1250	0.0000	5.2083*

Table 38: Bivariate copula value-at-risk back-test summary (copula application)

Copula	Normal margin	t-margin	Empirical margin	Sum
3	4	2	5	11
4	6	1	1	8
5	4	1	1	6
6	5	0	2	7
9	4	0	4	8
10	4	1	3	8
12	3	3	10	16
13	4	1	5	10
14	4	1	11	16
16	3	2	16	21
17	3	1	2	6
Sum	44	13	60	117

Figures

Figure 1: Autocorrelogramms



The results in figure 1 present the autocorrelations of our eight contracts as a function of the lag. We replaced the contract names by their respective Reuters Instrument Code (RIC). The RIC reads as follows: F1BYF3 for German (F1) Base (B) Year (Y) 2013 (F3) and F2PYF4 for French (F2) Peak (P) Year (Y) 2014 (F4).

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DAY 10 - 11:30		
Room 639 - Markets and Drivers of Renewable Energy		
The looming impact of higher shares of Renewables on electricity market prices	Reinhard Haas[1]	[1]EEG TU Wien
Renewable energy sources: economic, environmental and technical aspects	Susana Silva[1]; Isabel Soares[2]; Óscar Afonso[2]	[1]Universidade Lusíada and CEFUP; [2]FEP and CEFUP
CO2 reduction potentials and costs of biomass-based aleternative energy carriers in Austria	Amela Ajanovic[1]; Reinhard Haas[1]	[1]Vienna University of Technology
Entry strategies in the face of incumbents dominant position: the case of advanced renewable energy technologies	Margarida Fontes[1]; Cristina Sousa[2]; Silvana Pimenta[3]	[1]LNEG - Laboratório Nacional de Energia e Geologia; [2]DINAMIA´CET and ISCTE-IUL; [3]ISCTE-IUL

The looming impact of higher shares of renewables on electricity market prices

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Abstract

In several European countries with Germany leading a remarkable increase in capacities and corresponding electricity generation from wind and photovoltaic power plants took place in recent years. The core objective of this paper is to investigate the possible effects of such a further uptake of renewables on the European electricity markets. The major effects of these developments on the electricity markets will be: (i) a much higher price volatility from hour-to-hour and day-to-day; (ii) increasing relevance of intra-day markets; (iii) higher costs and prices for fossil capacities (due to higher shares of investment depreciation costs); (iv) increasing relevance of storages and "smart" grids, (vi) higher market shares for balancing markets; (vii) continuously increasing complexity of managing supply, storages and demand over time.

JEL classification codes: Q42, Q48

Conference topic: Markets and drivers of Renewable Energy

1. Introduction

The current energy supply is mainly relying on fossil fuels. Alternative energy carriers (AEC) – based on renewables, CO_2-poor or CO_2-free sources of energy - are of central importance for the transition towards a sustainable energy system and economy. One of the major reasons for a forced introduction of AEC is that they are expected to reduce GHG emissions significantly.

For a long time generating electricity from renewable energy sources (RES) has been considered as environmentally benign technologies with a huge potential yet very high costs for electricity generation ([1], [2], [3]). In recent years due to comprehensive support programmes in several countries and a significant drop in system costs – e.g of PV systems– with Germany leading – a remarkable increase in capacities and corresponding electricity generation from "new" RES took place, see Fig. 7. These increase in RES capacities had in recent years since 2009 on some days significant impacts on the spot market prices at the German electricity exchange EEX, see Fig. 9.

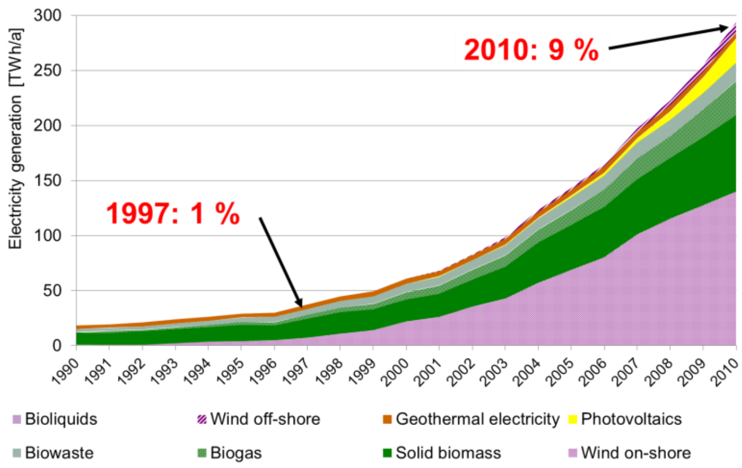

Figure 1. Development of "New RES-E capacities" in Europe in recent years

In the next years in Europe at least a continuous further growth of PV capacities can be expected. In Germany only it is expected that total installed PV capacity will increase from about 20 GW (installed by the end of 2011) to at least 50 GW by 2020. This is half of total fossil and nuclear capacity in Germany in 2011.

Recently, these increasing shares of RES-E – especially wind and PV – have especially in Germany and the affiliated part of the European electricity market led to several calls for new political interferences. Among these the most important are: (i) Calls for the implementation of capacity markets to ensure supply security; (ii) unjustified high subsidies which squeeze these RES-E capacities in the system without any market incentives; (iii) they further lead to high cost burdens for electricity customers (households but also industry); (iv) calls for new market structures because due to the high share of RES-E which are not subject to market conditions but to government interventions, e.g. due to FIT; (v) High expected additional costs for grid extension and storages which are necessary to compensate for the higher volatility of the RES-E due to their higher shares. These will even further increase the burden for customers.

The core objective of this paper is to investigate the possible effects of such a further uptake of RES-E on the prices in European electricity markets. Because Western Europe is currently already influenced by this effect we explain the likely consequences for the example of the EUR-4 electricity market (Austria, Germany, France, Switzerland).

Three major effects of how larger shares of volatile renewables impact electricity market prices are examined:

(i) the direct impact of renewables at specific times of the year when renewables shift the supply curve of conventional electricity virtually out of the market leading to temporarily very low market prices close to Zero; (ii) the indirect impact of volatile renewables on the costs at which fossil mainly natural gas capacities are offered; (iii) change of spreads between high and low price levels.

2. The changes after the liberalization of the electricity markets

In former regulated electricity markets prices came about by setting a tariff which was calculated by dividing the total costs of a utility by the total amount of electricity sold (with some differences between different groups of customers). The major change that took place after the liberalization of the electricity markets especially in Europe was that prices now were expected to reflect the marginal costs of electricity generation, see e.g. Haas [14]. Figure 2 depicts the basic opportunities: If excess capacities exist, prices will reflect short-term marginal costs (STMC,) if no excess capacities exist but if a market with perfect foresight exists prices will reflect long-term marginal costs (LTMC). And if short-term shortages in capacities are looming prices will be set strategically[1] .

[1] Strategic prices might also occur due to market power. However, this issue is not a focus of this paper

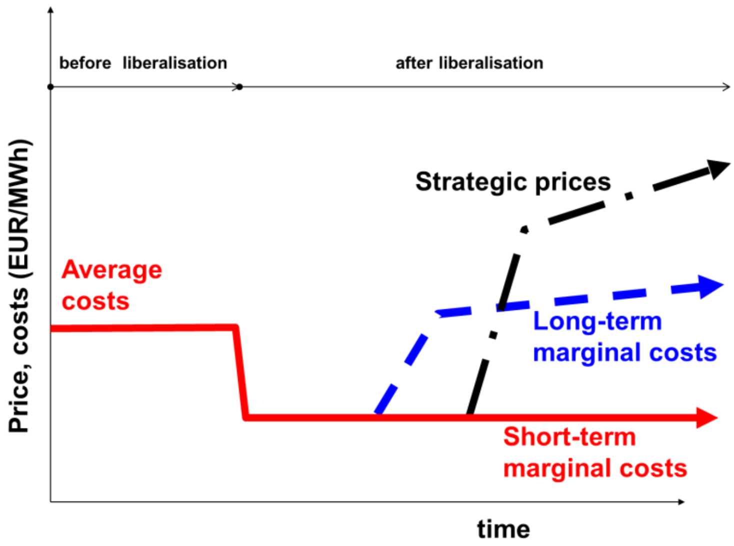

Figure 2. Basic possibilities for the price formation in liberalized electricity market

The price developments in different European electricity sub-markets from 2000-2011 is shown in Fig. 3. We can see a high volatility and considerable differences between different sub-markets. How does this price pattern come about?

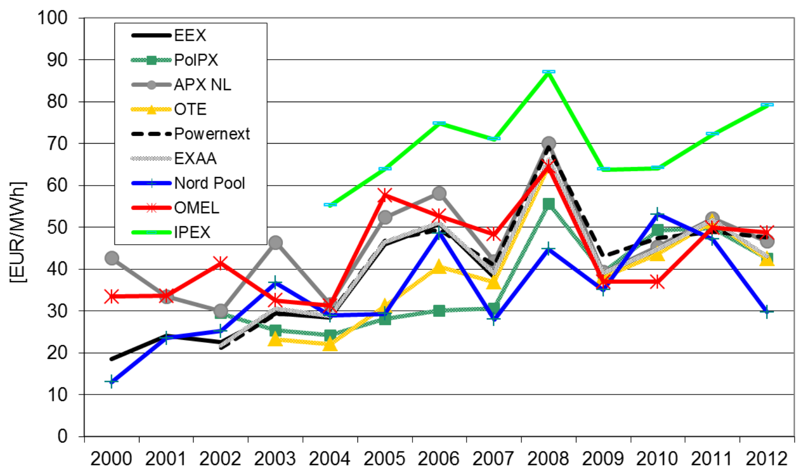

Figure 3. Price developments in different European electricity markets 2000-2012

Figure 4 shows a typical merit order supply curve for a specific point-of-time with conventional capacities (incl. large hydro).

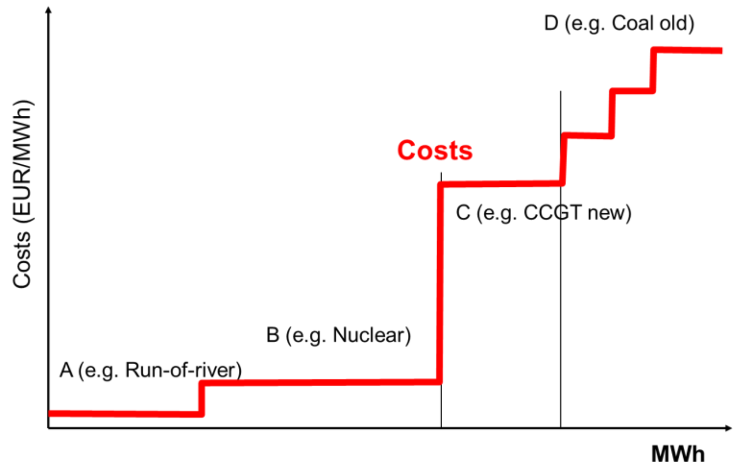

Figure 4. Typical short-term merit order supply curve for a specific point-of-time with conventional capacities (incl. large run-of-river hydro)

Figure 5 shows how prices come about in markets with conventional capacities (incl. large hydro): intersection of supply curve with demand gives electricity price at the short term system marginal costs The change in this pattern due to considering wind in addition is described in Fig. 6.

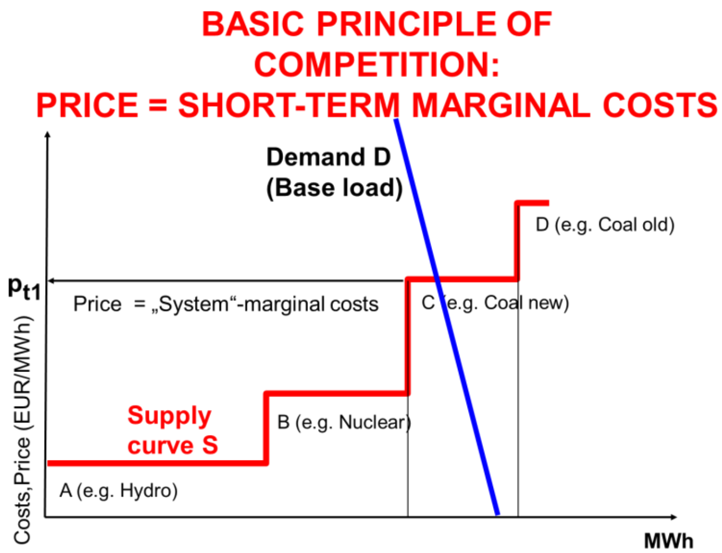

Figure 5. How prices come about in markets with conventional capacities (incl. large hydro): intersection of supply and demand gives electricity price at the short term system marginal costs

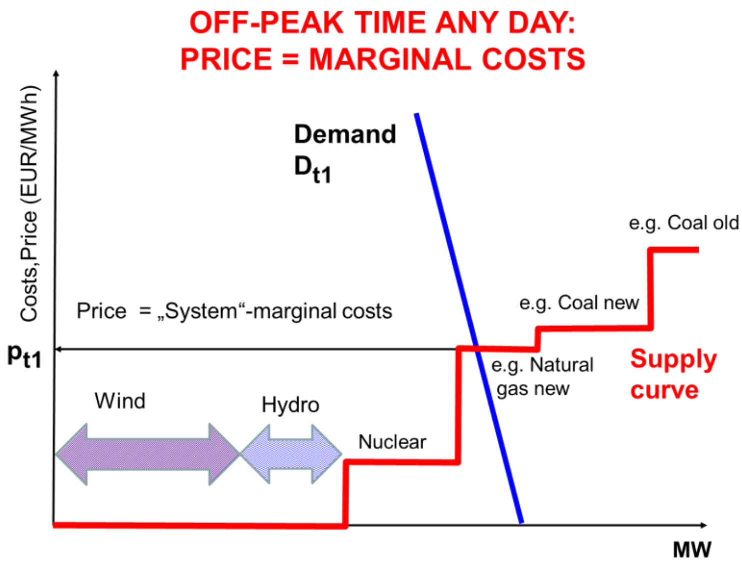

Figure 6. Merit order supply curve with additional wind capacities (incl. large hydro) at off-peak time

3. The direct impact of PV on the electricity market price

That RES have an impact on electricity prices (or in former regulated markets at least at the conceived marginal costs of electricity generation) is already known since volatile hydro power was used for electricity generation. Later in the time of starting wind booms (about 2007 to 2009, in Denmark already earlier) there was experience with temporarily high wind in the systems and sometimes even negative prices (see also [18], [19]). However, these effects due to wind happened mostly at off-peak times (at some times also due to wrong or careless wind forecasts).

What makes PV now specifically different? Figure 7 depicts an example from Germany for the impact of PV capacities on the price developments in the German electricity market on 22nd October 2011. As Fig. 7 depicts on sunny days PV- electricity generation follows the daily load profile and on these days it substitutes virtually completely the former production of hydro storages. In addition it changes the increase of prices at noon to a decrease. We can see that around noon – when prices historically were typically high –prices dropped.

Figure 8 shows the merit order supply curve with additional wind and PV capacities (incl. large hydro) at on-peak time of a nice summer day with short term marginal costs for conventional capacities.

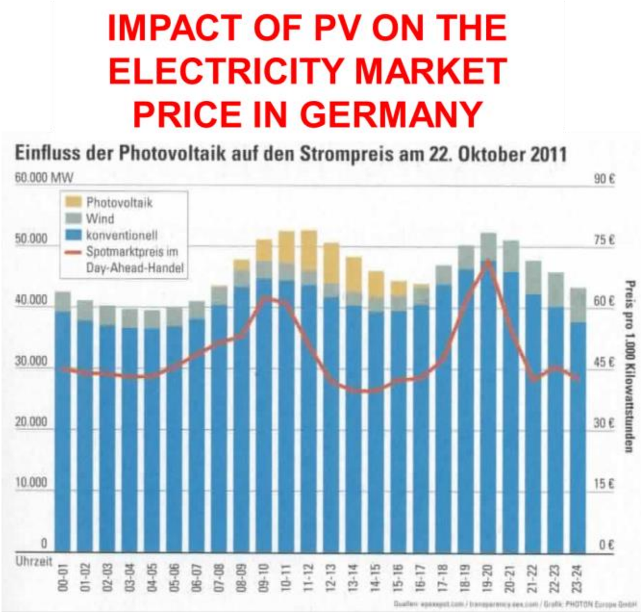

Figure 7. Example for the impact of PV capacities on the price developments in the German electricity market on 22nd October 2011

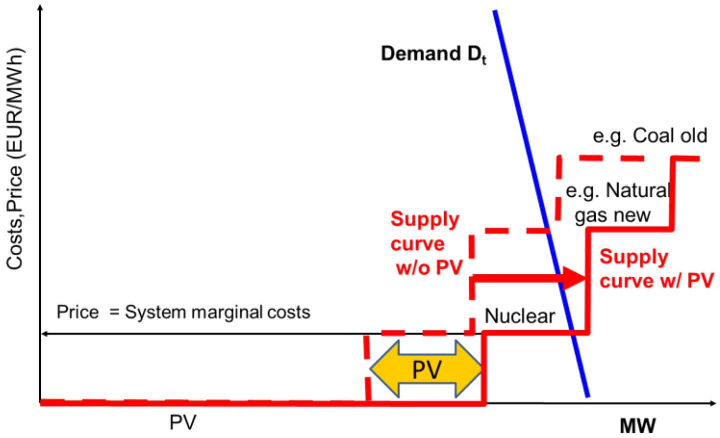

Figure 8. Merit order supply curve with and without additional PV capacities at on-peak time of a bright summer day with short term marginal costs for conventional capacities

4. Effect of temporarily higher shares of renewables on the pricing of fossil capacities

In a market with larger shares of RES the role of gas capacities will change see e.g. Auer ([6], Pantos [10], Hasoni/Hosseini [11], Carraretto [16]). Aside from the above described direct effect volatile renewables also have an indirect impact on prices in spot markets for electricity. Volatile renewables will influence the costs at which fossil – especially natural gas – capacities are offered. In Fig. 5 the supply curve is still based on the short-term marginal costs of conventional capacities only. Usually for natural gas this corresponds to about 6000 full-load hours per year. Yet, for every plant fixed costs have to be recovered in addition to the variable costs, Fig. 9. This Figure depicts the total and variable (short term) electricity generation costs of a new combined-cycled gas turbine (CCGT) depending on yearly full-load hours. As can be seen the share of fix costs is considerably higher when fullload hours are low (e.g. 1000 h/yr)2 than when full-load hours are high (e.g. 6000 h/yr).

In the past different types of fossil plants over a year – even over a day – made it possible to recover fixed costs when more expensive plants set the price. In the market that prevailed in recent years frequently old depreciated coal power plants with low efficiency and low remaining fixed costs determined the STMC. There was more room for covering the fixed costs of new CCGT than in a future system where this might not apply. Moreover, as Fig. 9 shows at 6000 hours/year operation time the fixed costs to be recovered are rather low compared to the variable costs.

This pattern is likely to change, because in markets with large shares of volatile renewables mainly highly flexible CCGT plants will survive, see e.g. Auer [6] or Carraretto [16]. But what will happen, if the full-load hours per year drop to 1000-2000 hours/year? Of course, in this case other pricing strategies (or the implementation of capacity markets) becomes relevant. Pricing with long term marginal costs (incl. the capacity costs) or even short-term strategic costs will become much more important than today. How this aspect will impact market structures and whether there is a need for changing market structures will be discussed in section 6.

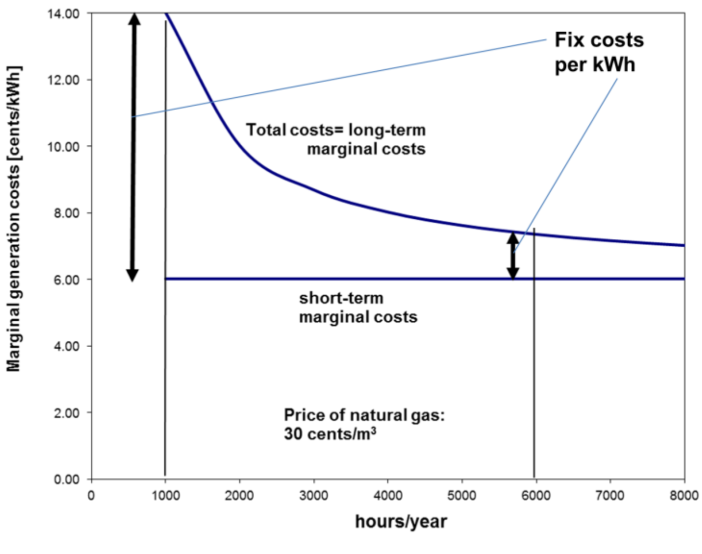

Figure 9. Total and variable (short term) electricity generation costs of a CCGT depending on yearly fulload hours

How these new pricing strategies might affect the future pricing of fossil (or biomass) power plants is shown in Fig. 10. This Figure depicts the merit order supply curve and high and low demand curve at times with low volatile renewables' availability. Three examples for supply

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[2] Of course, these fullload hours will also vary year-by-year. They will be lower a year with higher hydro power than on average and vice versa.

curves are included in this Figure: merit order supply curves for STMC vs LTMC of CCGT plants and a supply curve for strategic bidding (vertical line).

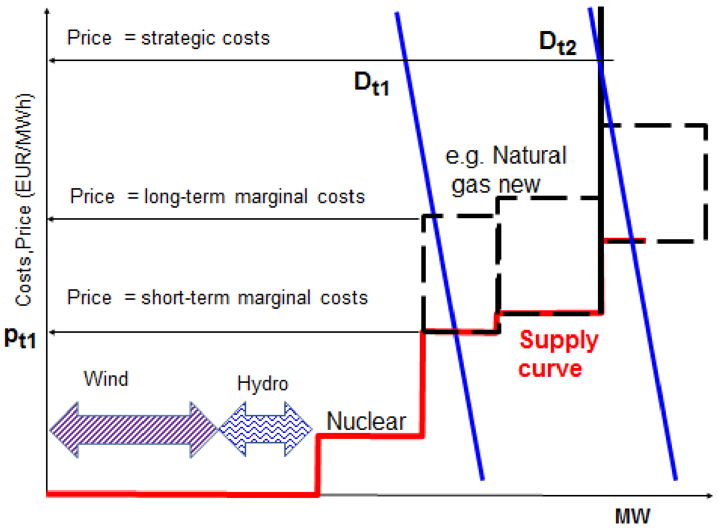

Figure 10. Merit order supply curve with additional wind capacities at off-peak time with total costs or strategic bidding for conventional capacities

5. Changes in price spreads

Of further relevance in this context is how price structures will change, mainly what will be the future “spread”. In recent years the “price spread” – the difference between the off-peak and the on-peak price for electricity – has decreased. Of core interest is how these price spreads will change in the future when larger amounts of PV and wind electricity enter the market. The consequence for electricity prices in a dynamic picture is shown in Fig. 11. It depicts exemplary the development of renewables from wind, PV and run-of-river hydro plants over a week in summer on an hourly base (based on synthetic data over an average year in Germany) in comparison to demand and resulting electricity market prices with total costs charged for conventional capacities. One can see that in this example tremendous volatilities in electricity prices – black solid line – ranging from zero to 14 cents/kWh are expected within very short-term time intervals. Of course, in practice the prices will not be Zero (but rather low) and not meet the exact LTMC but will rather be set strategically. Note, that the number 14 cents/kWh results from Fig. 9 with fullload hours of about 1000 h/yr.

If larger shares of renewables will temporarily be fed into the grid the price spread will increase. The reason is that at some times the prices will be close to Zero and at other time – when renewables are scarce – prices will be much higher due to strategic pricing of fossile capacities. These two effects on prices are depicted in Fig. 10 (solid black line). But as already mentioned, in future high prices will not necessarily appear at peak-demand times but at times with low renewables availability. The low price level will be associated with high renewables production. Among other effects this will also change the handling of hydro storages. These will in future not work mainly in the night-to-day-shift rhythm but in the context of availability or scarcity of renewables.

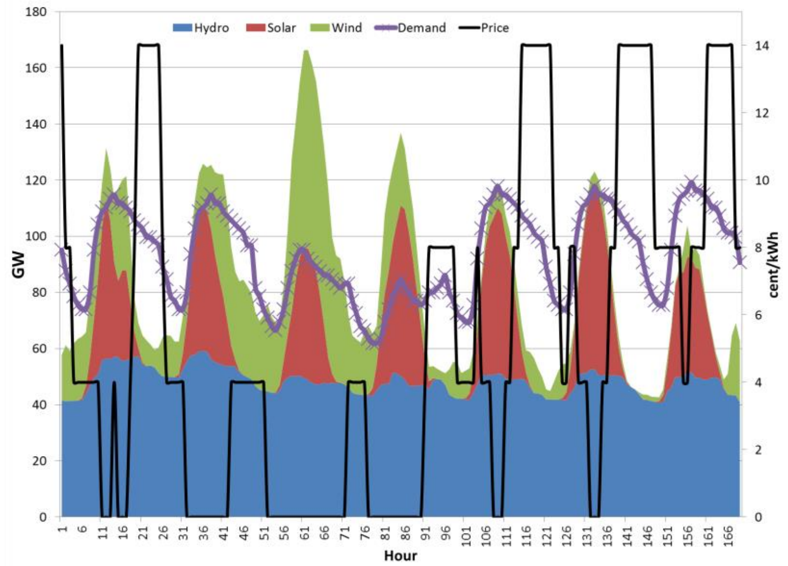

Figure 11. Development of volatile renewables from wind, PV and run-of-river hydro plants over a week in summer on an hourly base in comparison to demand and resulting electricity market prices with total costs charged for conventional capacities

The following remark is also important. For the price effect it does not make a difference whether PV electricity is fed into the grid or directly used by the customer. As the total demand profile over a day will not change (except some possible minor shifts due to individual customer behaviour) the price effects described in Fig. 11 will be in principle the same.

6. Future challenges

The above described developments and effects lead to further reflections and requests that may accompany the further uptake of PV. The most important are (see also Auer (6), Nielsen et al (8), Pantos (9), Wen (11), Lund (12), Lund (13)):

1. <u>From a rigid one-way supply system to a "breathing" system:</u>

The major change must be a paradigm change in our understanding of the whole electricity system – from generation over "smart" grids to electricity-based services finally provided. This major change in thinking is to switch from a unflexible rigid static one-way system to an over-all "breathing" system, which allows bi-directional flows, technical flexibility in the system, incl. DSM, load management from utilities and storages which also contribute to "breathing".

2. <u>Are there needs for capacity markets?</u>

The discussion of the economics of remaining fossile power plants – see Fig. 7 and Fig. 8 – leads to the question whether there is a need for so-called electricity markets. The major argument of the apologets of this idea is that only if a fixed "stand-by fee" is paid for these

mainly fossil plants, operators/owners of these plants will be retained from closing down these plants.
However, in practice it is only necessary to get rid of one simplified and anachronistic argument of the initial theoretical requests of liberalised markets: That prices must equal short-term marginal costs.

3. New market structures:
With respect to time-dependent market structures different new patterns will emerge. Regarding the role of Hedging and future contracts an argument raised recently is that in markets with high shares of RES no hedging is possible and future markets will break down. We think that actually the opposite will be true: With hedging and tradable long-term contracts these instruments will take over to a large extent the role of capacity markets. E.g long-term contracts (LTC) traded years ahead on an annual basis will serve to reserve (and ensure) LT capacity. The closer the delivery date comes the more fine-tuned will b the capacity reservation due to purchasing LTC. E.g. if good hydro power conditions are observed less capacity will be hedged than vice versa.
On the other hand there is a growing relevance of short-term markets like intraday- and secondary energy markets. In this context it is likely from our perspective that also "longer" term markets for secondary energy will emerge.

7. Conclusions

The major effects of these developments on the electricity markets will be: (i) a much higher price volatility from hour-to-hour and day-to-day; (ii) increasing relevance of intra-day markets; (iii) higher costs and prices for fossil capacities (due to higher shares of investment depreciation costs); (iv) increasing relevance of storages and "smart" grids, (v) higher incentives for PV owners in households for own use of electricity; (vi) balancing markets will gain higher market shares, which will be filled in by hydro and gas; (vii) finally the complexity of managing supply, storages and demand will increase continuously over time. (viii) Regarding the final electricity price for customers the share of costs for auxiliary services will increase remarkably compared to the pure energy production costs.

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Renewable energy sources: economic, environmental and technical aspects

Susana Silva, Isabel Soares, Óscar Afonso

Abstract

This article reviews the economic, environmental and technical characteristics of the treatment of renewable energy sources in the literature, namely in terms of the relevance and implications of each aspect considered. The analysis aims to identify how easy, likely and fast a transition to an energy system based on renewable sources would be. The aspects considered are the disaggregation for energy sources, the presence of niche markets, the discount rates considered, the form of technical change included, the contemplation of upper expansion bounds and cost reduction limits for each technology and the types of scenarios or environmental policy considered.

JEL Classification: O13, Q48, Q56, Q58

Keywords: renewable energy sources, technical aspects, environmental policy

1. Introduction

Renewable energy sources (RES) have shown to be important in dealing with environmental problems and guaranteeing the security of supply for countries dependent on fossil fuel imports. But shifting energy systems from conventional energy technologies to environmental friendly ones needs to be analyzed under cost-efficiency criteria (e.g., Hourcade *et al.*, 2006; Bataille *et al.*, 2006). For this purpose several models have been developed.

The most comprehensive ones are the Energy-Economy-Environment (E3) models which incorporate a specific system model for each of the three components and formulate effects and feedbacks among them (e.g., Capros, 1995). The taxonomy of the E3 models divides them into Bottom-Up (BU), Top-Down (TD) or Hybrid models which combine characteristics of BU and TD models. These E3 models integrate knowledge from more than one domain and provide useful information for policy making. The differentiation between BU, TD and Hybrid models has been widely studied in the literature (e.g., Löschel, 2002; Hourcade *et al.*, 2006; Jaccard *et al.*, 2003; Rivers and Jaccard, 2005; Bataille *et al.*, 2006; Böhringer and Rutherford, 2006; Böhringer, 1998; Köhler *et al.*, 2006) and is not our aim.

In this article, we aim to review some of the most important economic, environmental, and technical aspects regarding RES and for that we focus on E3 models. The characteristics of a new technology in each model are decisive to the conclusions about the technology's importance. For example, considering exogenously declining investment costs, besides being unrealistic, usually implies postponing investments until the costs of the new technology are sufficiently low. This approach neglects the possibility of cost reductions through experience accumulation resulting from early investments (e.g., Mattsson and Wene, 1997). The aspects considered in this article were chosen based on the frequency of their appearance and the importance of their consequences.

The paper is organized as follows. In section 2, we describe the main aspects considered in the literature, which include the disaggregation for RES type, the alternative energy sources included, the existence or not of niche markets, the values of the discount rates considered, the scenario bases, technical aspects of the models in particular how technical change (TC) is included, the consideration or not of upper expansion bounds for technologies and of lower bound for cost reductions and the main results of each model. Finally, section 3 concludes the article.

2. Main aspects considered in the literature

In this section we analyze the most important economic, environmental and technical aspects concerning RES and their effects in terms of models' results.

2.1. Disaggregation for RES type

One important aspect when comparing different models is their disaggregation in terms of RES. Different RES have different characteristics. For instance, solar and wind energy are non-storable, while biomass and hydro energy are storable, at least partially. The more disaggregated the energy sector, the more realistic a model can be and more technical details of each sources can be included. For instance, each source may have its own TC rate. When the distinction is only between carbon and non-carbon energy sources, RES are treated in the same way as, for instance, nuclear energy, in spite of the very different characteristics of these sources.

Some models (e.g. Capros, 1995; Capros and Mantzos, 2000; Capros *et al.*, 2001) include a wide variety of RES with a high detail levels, such as bio-fuels, thermal solar, geothermal low and high enthalpy, biomass and waste, hydrogen, solar electricity, wind and hydro. Mattsson and Wene (1997) show the importance of the high disaggregation by including as new RES photovoltaics (PV) and photovoltaic hydrogen production. This allowed a very high technical detail level and realism since PV was purely intermittent while photovoltaic hydrogen production considered energy storage. Another example is given by Seebregts *et al.* (1998) who included hydropower, solar, and wind power with their availability dependent on the year, season and even time of day. Messner (1997) additionally distinguished between solar thermal and solar PV. In Böhringer and Löschel (2006), technologies had a specific cost structure, capacity constraints and the output shares. Another type of differentiation is exemplified by Manne *et al.* (2005) and Manne and Richels (2004) who considered that for electricity generation the only existing RES in the base year was hydropower. Later, the authors considered the deployment of other RES. When the disaggregation is high it is also possible to include, for instance, different technical change rates which is decisive for technologies' growth (e.g. Barker *et al.,* 2006; Köhler *et al.,* 2006;). This issue will be discussed later.

Some models, include only one aggregated RES also called backstop technology (BT). This technology is considered abundant (faces no scarcity), is available at a constant marginal cost and allows for increasing production without increased carbon emissions. Articles which treat RES aggregately include, among others, Popp (2006), Chakravorty *et al*. (1997) (which specified PV as their BT), van der Zwaan *et al.*(2002),

Given the relatively small significance of solar energy, some models treat wind and solar energy together. This was the case of De Vries *et al.* (2001) and van Vuuren *et al.* (2004), Bosetti *et al.* (2006, 2007), and Paltsev *et al.* (2005). Other authors considered hydropower and geothermal power together (e.g., Kurosawa, 2004; Akimoto *et al.*, 2002; Sano *et al.*, 2006).

2.2. Alternative energy sources (non-RES)

A very important aspect to consider when analyzing RES is the alternative energy sources available and their characteristics, for instance, the evolution of their costs. As for RES, the higher the disaggregation for non-RES technologies, the more technical details is possible to include.

Most E3 models include as non-RES: coal, oil, gas and nuclear power (e.g., Capros and Mantzos, 2000; Capros *et al.*, 2001; Köhler *et al.*, 2006; Mattson and Wene, 1997; Seebregts *et al.*, 1998; De Vries *et al.,* 2001; van Vuuren *et al.*, 2004; Kurosawa, 2004; Paltsev *et al.*, 2005; Manne *et al.*, 1995; Manne and Richels, 2004; Böhringer and Löschel, 2006; Akimoto *et al.*, 2004 ; Sano *et al.,* 2006; Edenhofer *et al.*, 2005 and Bosetti *et al.*, 2006, 2007). For example, on Capros and Mantzos (2000) fossil fuels prices grew smoothly and electricity prices dropped due to lower marginal costs. In Köhler *et al.* (2006), each fossil technology had its own TC rate.

A very important issue is the inclusion of more modern and advanced non-RES technologies, such as combined cycle gas turbines (CCGT), fuel cells, and carbon capture and sequestration (CCS) technologies, which make the RES penetration harder. Articles considering these advanced non-RES technologies, in particular CCS ones, (e.g., Mattsson and Wene, 1997; Paltsev *et al.*, 2005; Kurosawa, 2004; Sano *et al.*, 2006; Bauer, 2005; Edenhofer *et al.*, 2005; Bosetti *et al.*, 2006, 2007; Köhler *et al.*, 2006) usually have less RES shares and/or a delay in the RES development.

Another significant aspect is the consideration of resource depletion and, in particular, its effect on the resources cost. As fossil fuels get exhausted, their prices increase and carbon-free alternatives became more competitive. Articles which consider increasing costs as resource reserves got depleted include Mattsson and Wene (1997), Paltsev *et al.* (2005), Manne *et al.* (1995), Manne and Richels (2004), Chakravorty *et al.* (1997), Kurosawa (2004), and Bosetti *et al.* (2006, 2007). It is also possible to distinguishe depleation according to the resource types (e.g., Mattsson and Wene, 1997; Chakravorty *et al.*, 1997). Some authors even show that it is only when fossil-fuels get exhausted that concerns about RES deployment appear (e.g., Chakravorty *et al.*, 1997; Bauer, 2005). Other aspects may also be included, for instance, in Paltsev *et al.* (2005) changes in resources overtime were controlled exogenously, in Manne and Richels (2004) reserves were depleted by current production but there was also the possibility of reserves augmentation through new discoveries, in Edenhofer *et al.* (2005) nuclear energy was phased out due to its unresolved problems such as the deposition of nuclear waste and nuclear proliferation.

Some models consider non-RES aggregately with a lower level of technical detail (e.g., Popp, 2006; van der Zwaan *et al.*, 2002; Barker *et al.*, 2005, 2006).

2.3. Niche markets

Gerlagh *et al.* (2004) focused their analysis in the existence of niche markets. These markets represent a very important condition to develop new technologies. In particular when there is learning-by-doing (LBD), they allow for a vital phase of the technological development where the technologies accelerate learning and start to mature. Simultaneously, they can help prevent technology “lock-in” by expanding technological possibilities. These markets can appear from firms investments to diversify their technology choices or from technology characteristics that are advantageous for specific locations or user groups. Gerlagh *et al.* (2004) provide the example of electricity generation from solar photovoltaic cells which can be competitive in a remote island. In practice, niche markets mean that the cheapest technology gains the largest market share but does not get the full market since there are specific niches for technologies with higher average costs but lower costs within the specific niche. With niche markets it is always efficient to use at least a minimum amount of each energy source, even the more expensive one.

Many authors explicitly refer the existence of niche markets (e.g., Capros, 1995; Capros and Mantzos, 2000; Capros *et al.*, 2001; De Vries *et al.,* 2001; van Vuuren *et al.*, 2004; Popp, 2006; van der Zwaan *et al.*, 2002; Barker *et al.*, 2005, 2006; Köhler *et al.*, 2006). Other authors include niche markets implicitly (having positive market shares of the relatively more expensive technologies), without refering their existence. For instance, Mattsson and Wene (1997) assumed that the large grid-connected electricity system would bear the costs of introducing emerging technologies, which were specialized niche markets.

Other models use a linear specification not guaranteeing the use of most expensive energy sources (e.g., Messner, 1997; Seebregts *et al.*, 1998; Chakravorty *et al*., 1997; Babiker *et al.*, 2001; McFarland *et al.*, 2004; Paltsev *et al.*, 2005). This represents the "winner takes it all" approach, where only the cheaper sources were used and technologies came into play only as they get economically competitive.

2.4. Discount rates

Higher discount rates favor technologies with lower up-front investments, even if operation costs are higher. Therefore, models with a higher discount rate tend to have lower RES shares. On the other hand, lower discount rates increase the use of technologies with high initial investments but lower exploration costs, because the future will be more valuable (Messner, 1997). Consequently, low discount rates favor RES technologies which tend to be capital intensive. For instance, Seebregts *et al.* (1998) showed that a more valuable future (lower discount rates) gave more importance to the learning effects and made technologies cost-effective sooner (with a 2% discount rate solar PV became cost-effective while it was not competitive with a 5% discount rate).

The range of discount rates considered is high, most commonly being in the interval from 1% to 5%, even though other values are also possible. Given the importance of the discount rate, some authors perform a sensitivity analysis to this parameter (e.g., Messner, 1997; Bosetti *et al.*, 2006; Seebregts *et al.,* 1998).

2.5. Technical aspects and Technical change

TC is one of the most important aspects when analyzing RES in the literature. These technologies, especially, wind and solar, have higher initial costs than fossil ones. If a model considers no TC this cost disadvantage will never vanish or disappear. The same happens if all technologies are treated in the same way even if there is exogenous TC. It is important not only to endogenize TC, but also to treat differently the various technologies. If RES have exogenous TC while non-RES have no TC, the cost disadvantage also decreases. The introduction of LBD with higher learning rates (*lr*)[1] for RES enables these technologies to gain market share as the capacity installed increased and costs decreased. There is a diversity of TC inclusion in the literature.

Models where technology evolves exogenously usually include the autonomous energy efficiency improvement (AEEI) (e.g. Manne *et al.*, 1995; Paltsev *et al.*, 2005). This indicator represents the decrease in the energy intensity use. Some variations are also possible, as in Böhringer and Löschel (2006) where the AEEI was influenced by price changes induced by technology specific taxes/subsidies which could be differentiated for energy sources.

Another approach used in the literature is the consideration of exogenously declining technological costs. For instance, in Kurosawa (2004) wind and solar generation costs decreased at an annual rate of 2% and 1%, respectively. For Akimoto *et al.* (2004) the cost reduction for wind power and PV was exogenously assumed to be 1.0 and 3.4 % per year, respectively.

Concerning the models with ETC, usually they consider R&D efforts which increase productivity and LBD which decreases costs. Examples of models with R&D efforts include Chakravorty *et al*. (1997) (with the same effect on all technologies) and Popp (2006). The majority of models, however, includes LBD, in particular differentiating the *lr* between new and mature technologies. Related to the *lr* we find the progress ratio (*pr*). The relationship is given by: *lr* = 1 - *pr*. Relatively immature technologies tend to benefit more from learning (have higher cost reductions) than more mature ones which means they have a higher *lr*. This gives RES the cost advantage they need or, at least, decrease their cost disadvantage. Nevertheless, endogenous learning decreases investment costs which may create technology lock-in, if massive investments occur in the technology with the larger learning. To prevent this situation, some authors apply additional constraints such as upper expansion bounds for certain technologies (Loulou *et al.*, 2004). Models which include higher *lr* for new technologies, or even no LBD for the mature technologies include Mattsson and Wene (1997), Seebregts *et al.* (1998), Sano *et al.* (2006), Manne and Richels (2004), Van Vuuren *et al.* (2004) (which considered time dependent *pr*. The *lr* for RES assume several values in the literature, but are usually around 20%. Another possibility is the inclusion of time dependent *lr* (e.g., van Vuuren *et al.*, 2004; van Der Zwaan *et al.,* 2002). Other authors, as Messner (1997), include advantageous *lr* for advanced non-RES technologies. Given the importance of the *lr*, some authors perform a sensitivity analysis to it. For example, Sano *et al.* (2006) concluded that for wind power the effects were negligible. For PV, the timing of initial introduction depended mainly on the *lr*. In general it is possible to conclude that the cost reduction provided by LBD is fundamental for the growth of new technologies (especially wind) as fossil ones became relatively more expensive. The RES shares became higher the higher the learning possibilities.

It is also possible to find authors which consider mixed approaches. For instance, some models include ETC (for instance LBD) and the AEEI (e.g., de Vries *et al.,* 2001; van Vuuren *et al.*, 2004;

[1] The learning rate is the rate at which the cost declines for each doubling of cumulative production or installed capacity.

Manne and Richels, 2004; van Der Zwaan *et al.*, 2002). Other models included LBD and R&D efforts (e.g., Bosetti *et al.,* 2006, 2007; Köhler *et al.*, 2006; Edenhofer *et al.*, 2005).

On the other hand, few models conclude that the treatment of TC ws not that relevant. For example, Barker *et al.* (2006), showed that the treatment of TC did not significantly change the results (even thought with ETC the RES penetration was faster and earlier), since the effects of TC in improving energy efficiency were offset by the increased rates of growth in exports, in income and in energy demand.

2.7. Upper expansion bounds

Another aspect that is often considered in the literature is the upper bounds for RES expansion. Expansion bounds may be imposed mainly for two reasons: physical limits and technical constraints. When these restrictions are imposed, once a technology has achieved the upper level, the model cannot invest further in that technology even if it was cost effective to do that. This has strong implications on the RES expansion possibilities which when restrictions are imposed generally imposes a maximum RES growth below 30%. As referred, this limits are sometimes imposed to prevent tecknology "lock-in" for the technologies with higher learning. Usually, under environmental requirements, these sources always grow at the limit which shows the importance of the limit imposed. Another example of their importance is provided by Seebregts *et al.* (1998) where solar PV grew more than other sources because no maximum expansion bounds were imposed for this technology.

The first reason, physical limits, may occur due to the lack of new sites to place dams, wind turbines or solar panels. Once achieved these potentials, the sources could no longer grow or less favorable places need to be used which imposes additional cost to the energy system (van Vuuren *et al.* 2004). This limitation is very common for large hydropower, which explains the relatively small growth for this sources in most models. Examples of the inclusion of upper expansion bounds for at least one of the RES are Sano *et al.* (2006), Böhringer and Löschel (2006), Capros and Mantzos (2000), Capros *et al*. (2001). This limitation plays a very important role even when there are environmental goals to achieve. Using a different approach, de Vries *et al.* (2001), and van Vuuren *et al.* (2004) supposed a relative (i.e., in terms of costs) and not absolute limitation. In concrete, there was a depletion effect of the most favorable sites and at higher production levels less attractive sites or technologies needed to be used which increased the energy system costs. As a consequence, only a limited RES share (set at 20%) could be adopted with no additional costs. After that level, further investments (e.g., in storage or grid extensions) needed to be done to guarantee the system reliability.

The second reason, technical constrains, may emerge, for instance, from the consideration of intermittency for RES like wind and solar power. As their share increases there is the need to build additional back-up capacity and storage (to satisfy the demand peak) creating an extra cost to the energy system. This extra cost emerges from different reasons than in de Vries *et al.* (2001), and van Vuuren *et al.* (2004). To minimize this problem, authors often imposed limits on RES shares and growth rates (Mattsson and Wene, 1997; Seebregts *et al.* 1998).

Other authors refer the existence of upper bound contributions for at least some technologies, but do not specify those limits (e.g., Manne *et al.*, 1995; Kurosawa, 2004; Paltsev *et al.*, 2005; Köhler *et al.*, 2006; Bosetti *et al.*, 2006, 2007). Some technical nuances may also be included, for instance, Paltsev *et al.* (2005) specified a minimum or entry-level cost since generation from high quality sites could be easily integrated into the grid.

2.8. Cost reduction limits

Another important aspect when studying RES evolution is the consideration of cost reduction limits for these technologies. This aspect is regularly taken into account since even when there is LBD and costs decrease with cumulative capacity, they cannot decrease indefinitely. The models consider a floor cost/price, which is the minimum cost/price a technology can have. Commonly cost limits are associated with capacity expansion restrictions, especially, when there is LBD. If costs decrease with cumulative installed capacity, but if this capacity cannot increase more than a certain value, then costs will not decrease below a specific threshold (e.g., Sano *et al.*, 2006). The convergence of costs to a floor price may also imply that the *lr* decreases for a mature technology (van der Zwaan *et al.*, 2002). This sets a crucial distinction between relatively new RES and mature fossil sources.

Among the models with cost reduction limits, it is possible to refer Seebregts *et al.* (1998) (related to expansion limits), Chakravorty *et al.* (1997), Manne and Richels (2004), Van Der Zwaan *et al.* (2002), and Edenhofer *et al.* (2005).

Some authors refer the existence of these limits but do not specify them (e.g. Messner, 1997; Sano *et al.*, 2006; Bossetti *et al.*, 2006, 2007). It is also possible to limit cost reductions from LBD with upper expansion bounds (e.g., Capros and Mantzos, 2000; De Vries *et al.*, 2001; Van Vuuren *et al.*, 2004). Finally, some authors assume that cost reductions can continue infinitely as a function of experience as, for example, Mattsson and Wene (1997) where cost stabilization occurred due to market saturation.

2.9. Scenario bases (Environmental policy)

Most E3 models simulate and compare several scenarios. The aspects considered in each scenario are decisive to the RES penetration. One of the most effective mechanism to promote RES penetration is the definition of scenarios which limit GHG atmospheric concentration. Without them generally, RES penetration is very modest. Models which included these scenarios generally present higher RES shares, and the more restrictive the concentration targets, the higher the shares (e.g. Akimoto *et al.*, 2004; Capros and Mantzos, 2000; Capros *et al.*, 2001). With tight environmental constraints RES (mainly wind and also solar power which have higher TC) grow as much as they can (given the expansion limits often set). Notwithstanding, some RES may remain nearly unchanged due to limited expansion possibilities (e.g., Capros *et al.*, 2001). As RES grow, fossil fuels use decreases.

It is common to find authors who limit emissions to the 1995 levels (e.g., Mattsson and Wene, 1997), or the CO_2 stabilization concentration targets to 550 ppm (e.g., Paltsev *et al.*, 2005; Kurosawa, 2004; Kurosawa *et al.*, 1999; Bosetti *et al.*, 2006, 2007; Sano *et al*., 2006). Nevertheless, often other targets are tested, for example, Manne and Richels (2004) tested three GHG concentration targets, 450ppm, 550ppm and 650 ppm. Without carbon constrains fossil fuels remain dominant until they become scarce (Manne and Richels, 2004).

Another very common approach is the consideration of emission taxes (e.g., Manne *et al.*, 1995). The consideration of these taxes decreases the RES cost disadvantage by increasing the cost of carbon sources. Therefore, with carbon taxes investment in REs increases.

It is also common to find authors who base their scenarios in the inclusion or not of TC and in different TC rates. For example, the presence or not of LBD was used in Manne and Richels (2004) and the authors found that changes in the energy generation mix were more determined by CO_2 constraints than LBD. TC effects have already been analyzed, but we may refer that the higher the learning possibilities, the more RES grow.

The most common approach, however, is to include a mix of several scenarios or policy actions. Some authors consider both GHG concentration targets and taxes on emissions (e.g., van Vuuren *et al.*, 2004; Manne *et al.*, 1995;). Others combine at least one of the previous policies (targets or emissions) with the presence or lack of TC and with different TC growth rates or *lr* (e.g., Seebregts *et al.*, 1998; Sano *et al.*, 2006; Köhler *et al.*, 2006; Chakravorty *et al.*, 1997; Edenhofer *et al.*, 2005).

Other scenario specifications are also possible including different perspective of the economic evolution (e.g., Messner, 1997), different targets for the RES share (e.g., Böhringer and Löschel, 2006), different atmosferic temperature constraints where the lower the temperature target the more RES grow since the temperature corresponds to an emissions constraint (e.g., van der Zwaan *et al.*, 2002), the presence or lack of CCS which delayed and smoothed RES use (e.g., Bauer, 2005), the presence or lack of a BT technology, its R&D and different levels for the initial price of the BT (e.g., Popp, 2006). Popp (2006) showed that ETC was important, but the strongest impacts on welfare and environmental cost reductions resulted from the inclusion of a BT.

2.10. Other aspects

Other aspects may be also important when assessing RES. For example, some authors show that to reduce emissions, energy efficiency improvements were more important in the short-run and transition from fossil fuels to RES was crucial in the long-run (e.g., De Vries *et al.*, 2001; Van Vuuren *et al.*, 2004; Capros, 1995; Capros and Mantzos, 2000; and Capros *et al.*, 2001). Others suggested that the transition to a BT may be the only viable solution to the threat of global warming (Chakravorty *et al.*, 1997). Bosetti *et al.* (2006, 2007) showed the role of international learning spillovers which reduced the incentives of early investments in RES since countries had an incentive to wait until others had already invested and benefited from sufficient LBD in those technologies (free-rider incentive).

3. Conclusions

In this article we tried to capture the main characteristics of renewable energy sources and their consequences, reviewing important economic, environmental and technical aspects of these sources. There is a diversity of factors influencing the importance of these sources in the literature.

Several aspects emerged from our analysis. First, the level of disaggregation for energy sources (both renewable and non-renewable) is important to increase the realism and the technical details of the models. The inclusion of advanced non-renewable technologies is also a critical aspect. For example, the presence of carbon capture and sequestration technologies was shown to delay and smooth the renewable resources increase.

Additionally, it was evident that most models already include endogenous technical change (through learning-by-doing or other sources). The endogeneity of technical change is crucial and learning possibilities are the most commonly used. The introduction of experience curves for new technologies allows early investments to reduce costs through experience accumulation and provides the rational for public intervention to support renewable sources. Without that support, these technologies will not have lower costs and may be permanently "locked-out" (Manne and Barreto, 2004) or investments in them would be postponed until they became competitive. Therefore, early investments are essential to gain experience and reduce costs (Mattsson and Wene, 1997). According to Bauer (2005) to minimize economic costs and production losses of achieving climate goals, investment in renewable energy sources need to start earlier and faster than when society is compeled to it.

Related to the previous aspect we find the consideration of niche markets. Without these markets more expensive technologies will not be able to benefit from learning and cost reductions. Despite the vital role of niche markets for the initial deployment of new technologies some models neglect their existence. However, a large number of models already considers them.

The consideration of renewable sources (especially wind and solar) as intermittent sources is also very frequent. Intermittency requires additional back-up capacity and storage needs when generation from renewable sources grow. As a result energy system costs increase. Thus, frequently authors impose upper expansion limits to these technologies. Additionally, as renewables gain a considerable market share, the best production/generation sites start being occupied which is another reason to impose expansion limits. When there is learning-by-doing for renewable sources but upper expansion limits are established, usually the technologies grow as much as they can, i.e., until the upper bound. This shows how important these maximum limits are and highlights the relationship between learning possibilities and other aspects such as expansion limits or intermittency.

The results further indicate the importance of the learning rates and the discount rates assumed. Higher learning rates and lower discount rates favor renewable sources.

Even though assumptions about learning and endogenous technical change are central, most models indicate that fossil fuels will still dominate the energy system until they become scarce. As scarcity increases their costs renewable sources became competitive.

Most models show the importance of emission taxes and emission stabilization scenarios to the competitiveness of renewable energy sources. In fact, many scenario bases can be considered, but it is evident that the CO_2 stabilization targets and the environmental policy levels (in particular emission taxes) are the most used ones. Tighter emission targets and higher emission taxes induce early investments in renewable technologies.

To sum up, given the upper expansion limits for renewable energy sources and the fact that they only become considerably used as fossil fuels get exhausted, most models predicted that the energy system remained dominated by fossil fuels for many years. Nevertheless, technical change in the renewable sector appears to be fundamental and environmental policies such as taxes on emissions and stabilizations targets play a crucial role in promoting the renewables share increase. Consequently, these sources are pointed as fundamental mitigation option in the long run (Bauer, 2005; Edenhofer *et al*., 2005).

This review of the most important economic, environmental and technical aspects concerning renewable energy sources is necessarily incomplete and many other aspects could be consider. Nevertheless, it provides interesting highlights on the characterization of these energy sources and the consequences for its deployment.

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CO_2 reduction potentials and costs of biomass-based alternative energy carriers in Austria

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Abstract

A forced use of renewable energy sources (RES) is necessary to reduce GHG emissions significantly. Among RES biomass-based resources play a specific role regarding their CO_2-reduction potentials, their energetic potentials and their overall costs for different derived energy carriers. From various categories of biomass resources – forestry, agricultural crops, short rotation coppices or waste products – different alternative energy carriers (AEC) like biofuels 1st or 2nd generation, biogas, electricity or hydrogen can be produced. In this paper we analyse possible chains to use several biomass resources with different AEC for Austria. We investigate their specific life-cycle-based CO_2 emissions, their overall CO_2 reduction potentials and the CO_2-saving costs. The core result of this analysis: The overall potential by 2050 is approximately 130 PJ compared to 30 PJ in 2010. The corresponding CO_2-reduction potential is about 7 Mill. tons CO_{2equ}. This is roughly two third reduction compared to the use of conventional fuels. The major conclusion is that only if a tuned portfolio of actions – CO_2 tax, ecological monitoring system, a focussed R&D programme for BF-2 and fuel cells – is implemented the potential of new biomass-based AEC can be exploited up to 2050 in an optimal way for society.

JEL classification codes: Q42, Q48

Keywords: alternative energy carriers, biomass, Austria, ecological assessment, costs

1. Introduction

The current energy supply is mainly relying on fossil fuels. Alternative energy carriers (AEC) – based on renewables, CO_2-poor or CO_2-free sources of energy - are of central importance for the transition towards a sustainable energy system and economy. One of the major reasons for a forced introduction of AEC is that they are expected to reduce greenhouse gas (GHG) emissions significantly.

Among renewable energy sources (RES), biomass-based resources play a specific role regarding their CO_2-reduction potentials, their energetic potentials and their overall costs for different derived energy carriers, see e.g. Faaij, 2006. From various categories of biomass resources – forestry, agricultural crops, short rotation coppices or waste products – different alternative energy carriers (AEC) like biofuels 1st or 2nd generation, biogas, electricity or hydrogen can be produced.

The core objective of this paper is to analyse possible CO_2 saving potential in Austria due to the increasing use of AEC in a policy forced scenario (Policy Lead Scenario) as well as to estimate CO_2 saving costs. This is one of the various scenarios derived in Ajanovic et al (2011).

The most important AEC considered in this study are: (i) AEC from 1st generation biofuels (bio-ethanol and biodiesel) and biogas; (ii) 2nd generation biofuels; (iii) hydrogen from renewable energy sources; (iv) electricity from renewable energy sources; (v) other biomass-based energy carriers. In this context it is important to note that 2nd generation biofuels currently are expected to offer the largest biofuel quantity potential since the range of raw materials includes all plant components and waste products.

We investigate in detail what are the quantities of AEC that can be possibly produced in Austria till 2050 in a Policy Lead Scenario (current and planed policy measures are considered in a dynamic context as well as technological learning effects).

The paper continues with a description of our research methodology in Section 2. In Section 3 we present future long-term prospects of AEC in Austria. Resulting CO_2 emission savings and costs of emission reductions are discussed in Sections 4 and 5, respectively. Conclusions complete the analysis, Section 6.

2. Method of approach

The method of approach applied in this paper consists of the following major steps (see also Bird et al., 2011 and CONCAWE, 2008):

- Firstly, based on literature we have done a survey on AEC and then based on availability of feedstocks and resources in Austria we have extracted the most promising energy chains and AEC for a further detailed analysis;

- Next we have considered different technologies regarding technological learning which is expected to be of high relevance for future cost decreases of the analysed AEC;
- For all considered AEC dynamic ecological and energetic assessment is conducted based on Life Cycle Assessment (LCA) up to 2050
- For all considered AEC dynamic economic assessment is conducted based on technological learning up to 2050;
- In order to be able to evaluate the long-term perspectives of AEC the following major influence parameters are considered in scenarios:
    - possible developments of the energy price level and the energy demand;
    - global developments (particularly regarding learning effects);
    - environment and energy policy in Austria and at EU level.

2.1. Ecological assessment

The calculation of GHG emissions and primary energy demand is based on the method of Life Cycle Assessment. According to EN ISO 14040:2006 “Environmental management - life cycle assessment - principles and framework” the environmental impacts are calculated along the supply chain of a product or service: from extraction of raw materials for its production through its use to its disposal (Well-to-Wheel). In LCA are included all relevant materials, energy inputs and emissions related to the environment and to the extraction of the primary resource, transportation of the resource to a conversion facility, conversion of the resource into a final energy carrier (AEC) that can be used, distribution of the final energy carrier and use of the energy carrier to provide an energy or transport service.

In addition to a Well-to-Wheel (WTW) analysis including the entire supply chain from primary energy to energy or transport service, the systems were also analysed Well-to-Tank (WTT) part, which includes the supply chain from primary energy to final energy (AEC), see Figure 1.

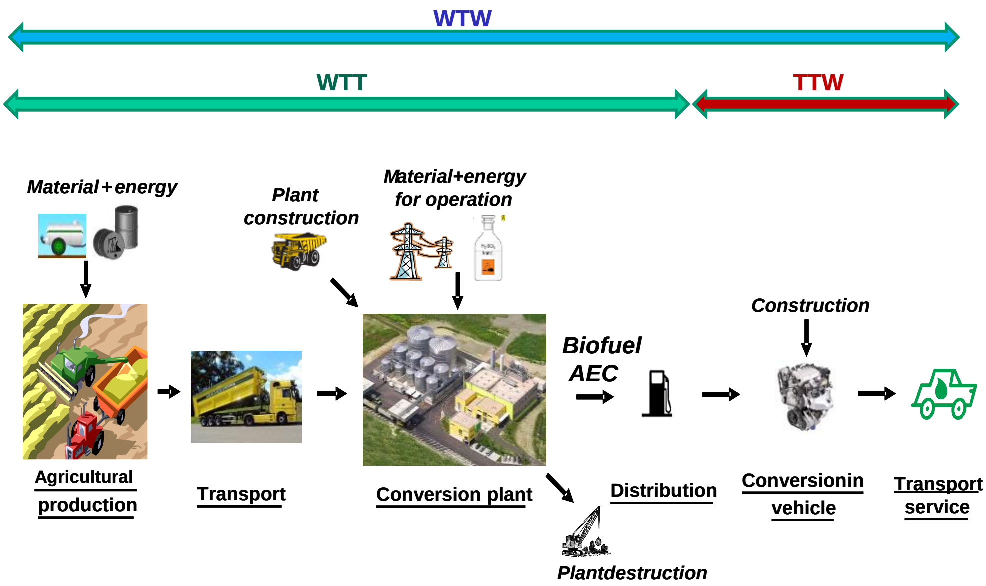

Figure 1: Example of the biofuel supply chain (adapted from Ajanovic et al., 2012)

2.2. Greenhouse gas emissions

In the LCA carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are considered. All gasses are converted into the equivalent amounts of CO_2 (CO_2-eq.) using conversion factors from Table 1.

Table 1: CO2-equivalent conversion factors

Gas	CO_2-equivalent
CO_2	1
CH_4	25
N_2O	298

CO_2-emissions from biomass used for energy service are balanced zero, according to IPCC (IPCC, 2006) guidelines. This is based on the assumption that the balance of net CO_2-fixation of biomass by photosynthesis and the CO_2-emissions during production and conversion of the fuel is zero. In LCA CO_2-fixation is considered as negative CO_2-emission during agricultural production. Carbon losses in fuel production processes (e.g. carbon in press cake from rapeseed pressing) are accounted as biogenic CO_2-emissions (Figure 2).

The calculation of WTT-net CO_2 emission balances described in detail in Figure 2 is based on the following equation:

$$WTT_{net} = WTT_{\mathrm{minus}} + WTT_{plus} \tag{1}$$

WTT_{plus} .....CO_2 fixation due to biomass planting

WTT_{minus}... CO_2 emissions during fuel production

$$WTW = WTT_{net} + TTW \tag{2}$$

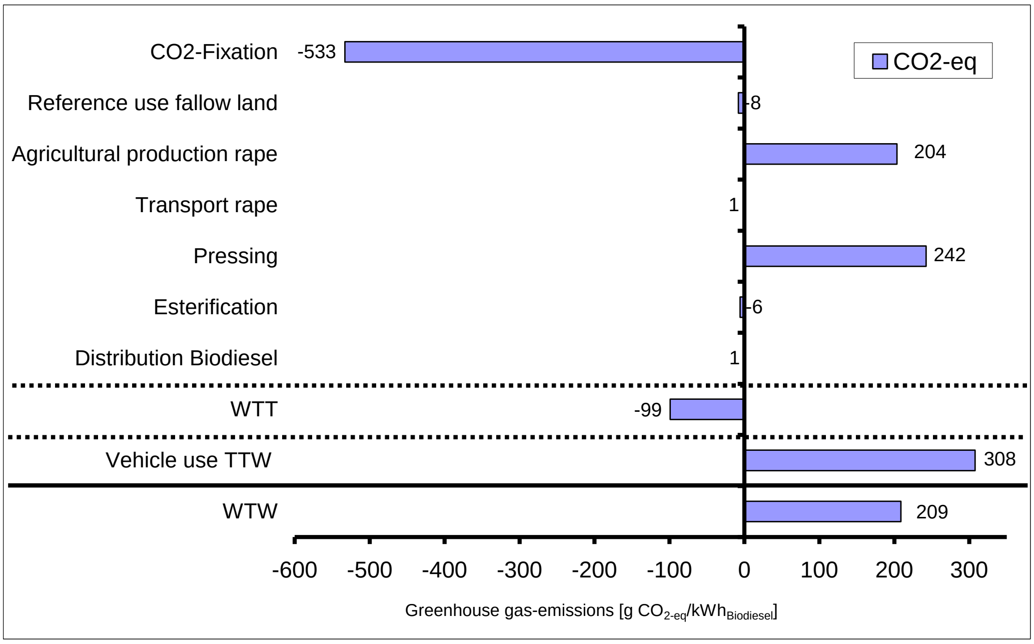

Figure 2: Balance of biogenic CO_2-emissions for biofuels (example biodiesel from rapeseed)

2.3. Calculation of CO_2 savings

CO_2 savings (ΔCO_2) of a specific AEC are calculated as:

$$\Delta CO_2 = CO_{2\_fossil} - CO_{2\_AEC} \tag{3}$$

where CO_{2_fossil} are the corresponding CO_2 emissions of the corresponding reference fossil energy carrier.

Costs of CO_2 savings ($C_{\Delta CO2}$) are calculated as:

$$C_{\Delta CO2} = \frac{\Delta C}{\Delta CO_2} \tag{4}$$

ΔC………Difference in costs between a specific AEC and corresponding reference fossil fuels (e.g. between bioethanol and gasoline)

ΔCO_2…. Difference in specific CO_2 emissions between AEC and corresponding fossil fuels (e.g. between bioethanol and gasoline)

3. Future prospects of AEC from “new” biomass in Austria up to

In order to provide a sound assessment of the future prospects of alternative energy carriers in Austria up to 2050 the following major influence parameters are considered:

- possible developments of fossil energy prices;
- global developments (particularly regarding technological learning effects);
- environmental and energy policies in Austria and at the EU level, mainly CO_2 taxes.

The results in this paper are based on a “Policy Lead Scenario” (PLS) which corresponds to the assumptions of international deployments of biofuels and hydrogen according to IEA (IEA, 2006; IEA, 2008). In this scenario priority is given to the production of liquid biofuels over electricity. A major focus is put on alternative energy carriers based on “new” biomass resources. An increasing use of biomass in the future in Austria could raise two issues: (i) the use of biomass requires large amounts of land which otherwise could be used for other purposes (e.g. food production); (ii) increasing biomass production might be in contradiction with sustainability issues.

In this section we conduct a comparison of AEC from “new” biomass (excl. pellets, wood chips, fuel wood) in the Policy Lead Scenario with additional use of arable land, with introduction of CO_2 based tax and with priority for biofuels.

Figure 3 depicts the energy production in this scenario. As can be seen in this scenario by 2050 finally more than 130 PJ of AEC will be produced. This is about four times more than in 2010. After about 2023, due to technology maturity, a significant and continuously increasing share of the 2nd generation bioethanol can be noticed. The share of 2nd generation biodiesel is increasing starting from 2032. Finally, most BD-2 are produced from corn stover (whole plant used) from arable land. In this scenario with biofuels priority SNG provide significant contribution to energy production starting from 2017. Yet, this takes place only if it can be managed that these technologies – BTL, FT-Diesel, SNG – become mature and if significant learning effects are achieved. Due to the finally better energetic and economic performance of BD-2 it also substitutes BE-2 production after 2040. However, it must be noticed that energetic as well as economic developments of the different categories of BF-2 are of course not known in detail today. Due to these uncertainties other fractions of BF-2 could also “win”. What can be stated today is that – given that the economic performance of any BF-2 leads to cost-effectiveness under the suggested CO_2-tax policy – there is a significant potential for BF-2 after 2030 regardless which one will succeed.

A note on biogas: There is a temporarily slight decrease of biogas, because its production from maize silage will phase out. But on the other hand gradually more biogas will be produced from grass and cover crops.

Electricity will due to the priority for biofuels in PLS be produced only from those feedstocks which are not usable for biofuels production such as waste wood.

The major reasons why in Figure 3 BD-2 and SNG reach so high amounts are:

- they have highest energy efficiency and hence lowest feedstock costs;
- they have lowest CO_2-emissions and hence lowest CO_2-taxes.

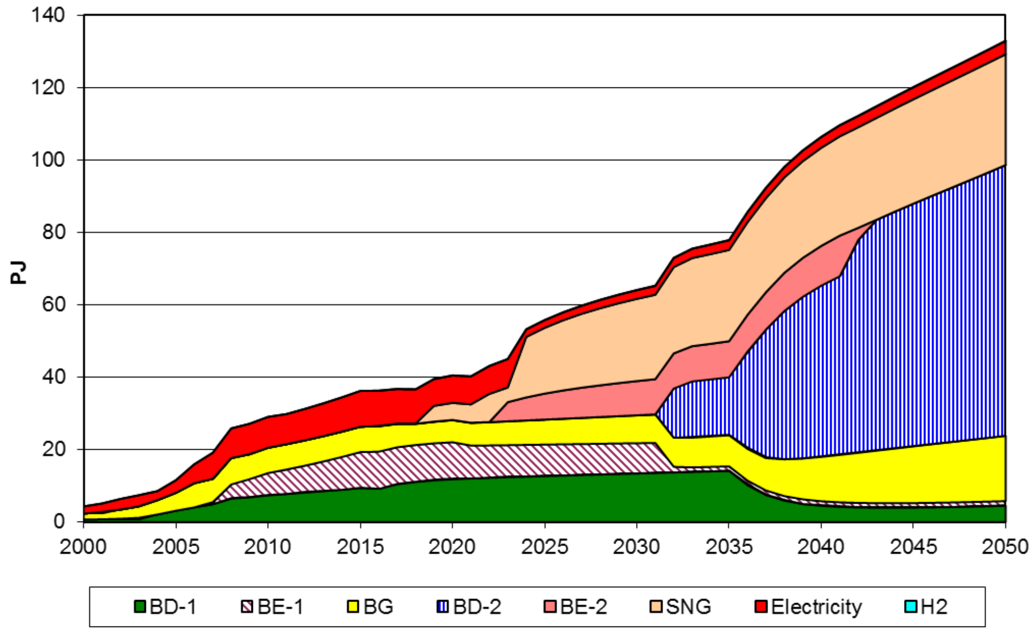

Figure 3: Energy production (final energy) in the Policy Lead Scenario (With max. 30% arable land in 2010, with CO_2 tax, and with priority for biofuels)

4. Potentials of CO_2 emission savings

One of the major reasons for a forced introduction of AEC is that they are expected to reduce GHG emissions significantly. The following figures depict for the Policy Lead Scenario, the effects on CO_2 emissions in Austria.

In Figure 4 the CO_{2eq} savings per GJ output of AEC in 2010 vs. 2050 in Austria are shown. Hydrogen, electricity and BD-2 as well as SNG are from this point the most favourable AEC.

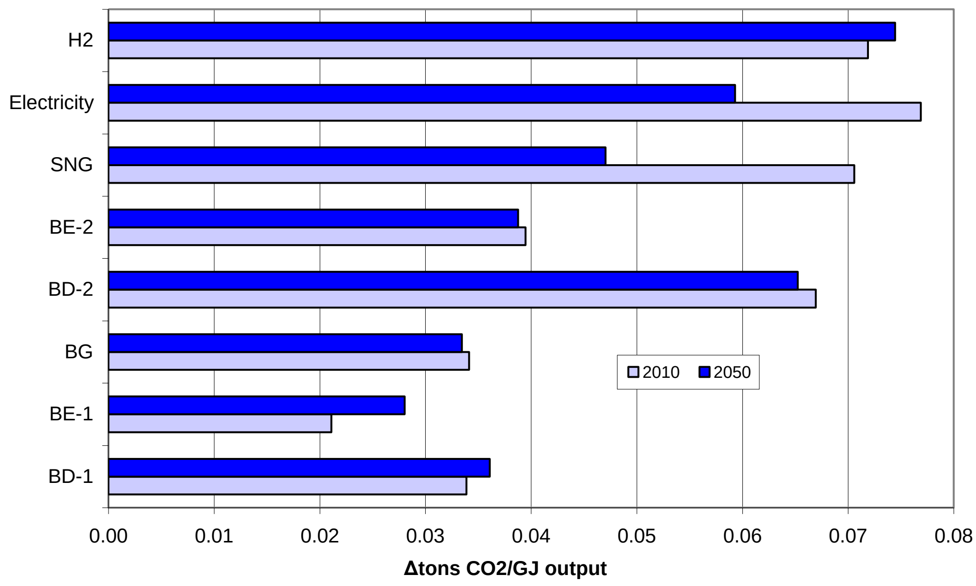

Figure 4: CO_{2eq} savings per GJ output of AEC, 2010 – 2050 in Austria

The total CO_2 emission savings compared to fossil fuels are shown in Figure 5 (bioethanol compared to gasoline, biodiesel compared to diesel, biogas compared to gasoline and electricity and hydrogen compared to conventional production). It can be seen that with increasing shares of BF-2 the CO_2 savings increase. Finally, the largest shares of savings are achieved by the use of BD-2 and SNG. The remaining CO_2 emissions from AEC are depicted in Figure 6. Yet, most interesting is how the difference of savings vs. remaining emissions evolves. This effect is shown in Figure 7.

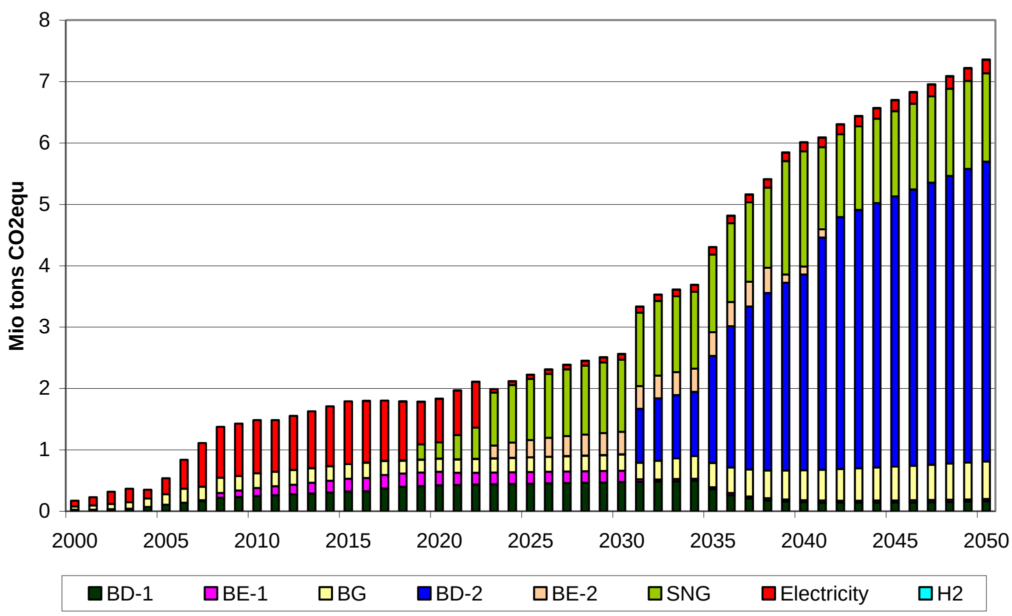

Figure 5: CO_2 emissions savings due to biomass-based AEC in Austria from 2000 to 2050 in the Policy Lead Scenario

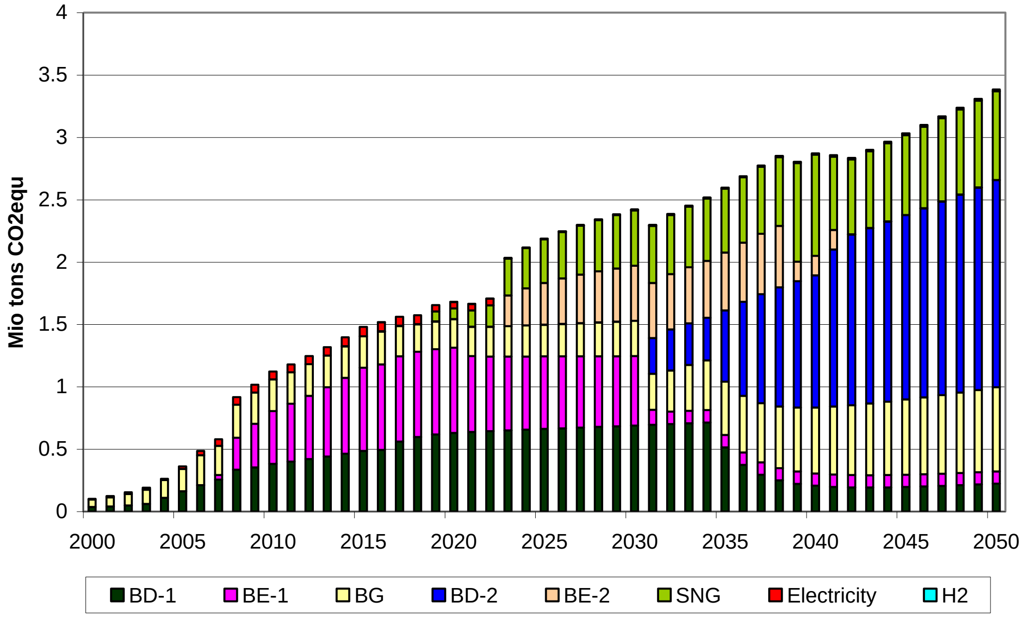

Figure 6: Remaining CO_2 emissions from biomass-based AEC in Austria from 2000 to 2050 in the Policy Lead Scenario

Figure 7 depicts the total CO_2 emissions from biomass-based AEC in Austria from 2000 to 2050 in the Policy Lead Scenario in comparison to total CO_2 emissions without the use of AEC. We can see that by 2050 the CO_2 emissions will be reduced finally by about 7 Mill. tons CO_{2equ}. This is about two third reduction compared to the use of conventional fuels.

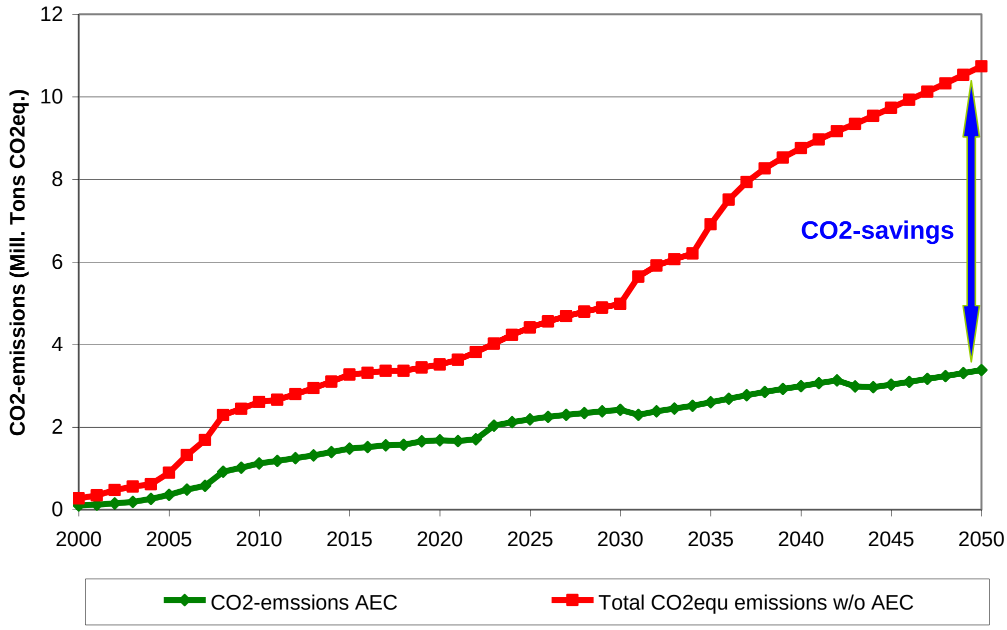

Figure 7: Total CO_2 emissions from biomass-based AEC in Austria from 2000 to 2050 in the Policy Lead Scenario in comparison to total CO_2 emissions without the use of AEC

5. Costs of CO_2 emission reduction

In addition to the savings in CO_2 emissions also the costs of biomass-based AEC are relevant. In this analysis we consider the introduction of a CO_2-based tax for all energy carriers. The design of this tax is as follows: The highest excise tax in 2010 – which was on gasoline – is converted in a CO_2 tax of the same magnitude. For all other fuels including diesel and CNG this tax is set relative to their WTW - CO_2 emissions compared to gasoline. This tax starts in 2013 and is increased by 0.015 EUR/kg CO_2/yr up to 2050. Of course AEC with lowest CO_2 balances have lowest tax levels (Ajanovic et al., 2011).

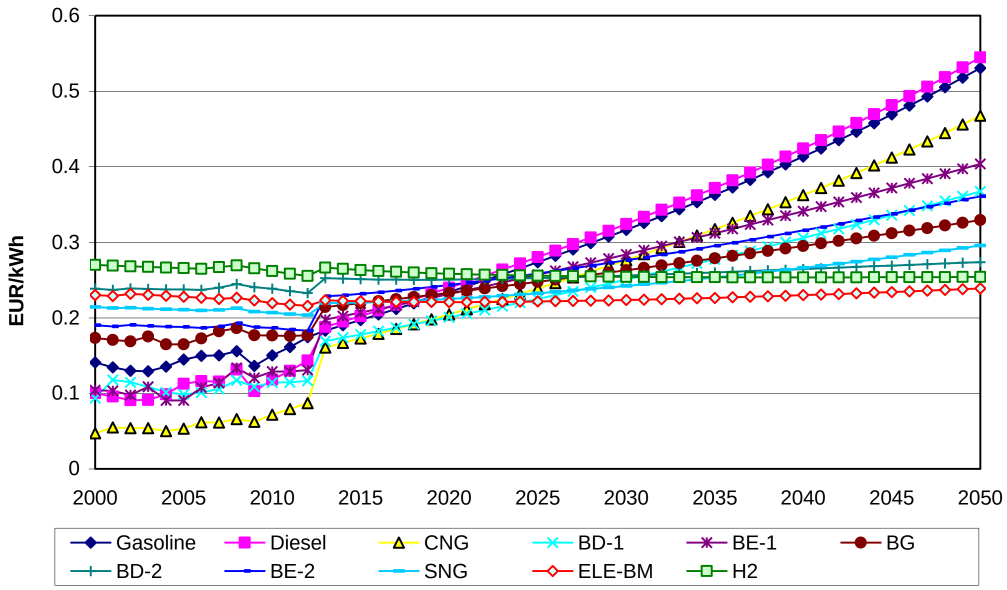

Figure 8: *Development of costs of various AEC in comparison to conventional fuels including taxes up to 2050*

Figure 8 depicts the development of costs of various AEC in comparison to conventional fuels including all taxes up to 2050 and fossil fuel price forecast from IEA (2009). The fuels with the lowest CO_2 taxes – electricity and hydrogen from biomass, biodiesel (BD-2) and SNG – are the cheapest ones by 2050. In the presence of this CO_2 tax AEC could become competitive with fossil fuels starting from 2020.

The costs of CO_{2eq} savings by type of AEC are depicted in Figure 9 over the period 2010 – 2050 in Austria in the Policy Lead Scenario. This figure shows very impressive that due to the increases in the prices of fossil energy carriers up from about 2020 the CO_{2eq} savings show negative costs. That is to say that after this period of time it is even profitable to use these AEC.

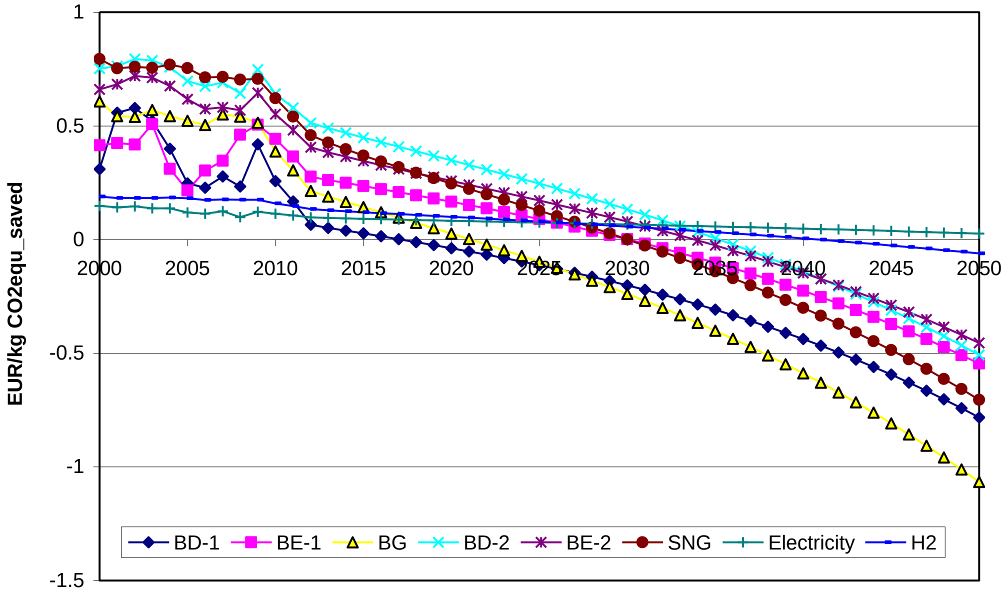

Figure 9: Costs of CO_{2eq} savings by type of AEC, 2010 – 2050 in Austria in the Policy Lead Scenario

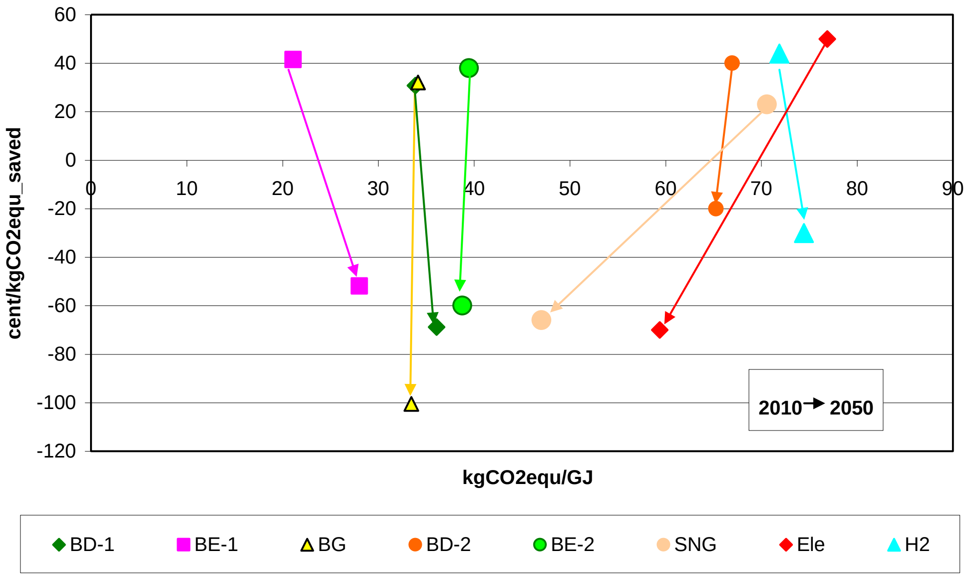

Figure 10: A comparison of the costs per kgCO2equ saved and the overall savings of CO2equ per GJ in 2050 in comparison to 2010

A comparison of the costs saved per $kgCO_{2eq}$ and the overall savings of CO_{2eq} per GJ in 2010 and 2050 are shown in Figure 10. The major perception is that up to 2050 costs of all investigated AEC will turn into profits. With CO_2 tax these AEC will earlier become profitable.

6. Conclusions

The major steps towards harvesting an optimal portfolio of AEC in Austria up to 2050 are:

1. Introduction of a CO_2 based tax: This tax ensures that different AEC will enter the market depending on their dynamic ecological performance;

2. A rigorous tightening of the standards regarding CO_2 emissions of these AEC: It should be made sure that , e.g. by means of a strict and continuous certification and monitoring programme, the ecological balance mainly of BF-1 but also of the emerging new BF-2 is improved gradually.

3. A focussed R&D programme for 2nd generation biomass and for fuel cell with an accompanied performance evaluation from energetic and environmental point of view.

The final major conclusion is that only if the portfolio of actions described above – CO_2 tax, ecological monitoring system, and a focussed R&D programme for BF-2 and fuel cells – is implemented in a tuned mix it will be possible to exploit the potential of AEC up to 2050 in Austria in an optimal way for society.

Acknowledgement

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Entry strategies in the face of incumbents dominant position: the case of advanced renewable energy technologies

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Abstract

The paper discusses the entry strategies adopted by research-firms introducing advanced renewable energy technologies in the electricity production sector, which combines strong incumbent power with fast technological change. Drawing on contributions from the literatures on sustainability transitions and on strategic management of technology we build an analytical framework to address the conditions faced by the new entrants and the attitude of established incumbents towards their technologies. This framework is applied through in-depth case studies of new firms in two energy fields that display different levels of technological maturity: wind and wave energy. The paper presents preliminary results from a first set of case studies, which provide some insights into the "commercialisation environment" prevailing in those fields. They suggest that research-based firms tend to depend on the complementary assets possessed by incumbents, but have conditions to protect their technologies; and that the technology is relevant for (at least some) incumbents, which show interest on them, or are directly involved in their development/use. This is, in most cases, conducive to "cooperation" strategies, which assume different forms according to the stage of development of the technology and its proximity to incumbent competences and business models.

Keywords: renewable energy technologies; technology commercialisation; research-based firms; entry strategies; incumbents attitude

JEL: L21, L22, O32, Q42

1. Introduction

The paper investigates the entry strategies adopted by new firms exploiting advanced renewable energy technologies (RET). Firms that introduce new technologies targeting the energy/electricity production are confronted with a very particular environment. They are entering a sector where, despite the profound transformations occurred in the last decade, powerful incumbents still occupy dominant positions. But where the acceleration of the pace of technological change creates opportunities for technology-intensive new entrants (Brown et al, 2007) and influences the incumbents' attitude towards those entrants and their technologies (Hockerts and Wustenhagen, 2010). Since research-based start-ups are typically small firms with strong knowledge competences but limited financial and market-related resources and competences (Mustar et al, 2006), they inevitably need to establish relationships to transform their technologies in marketable products/services and sell them (Colombo et al, 2006). In sectors dominated by large established firms at least some of those "complementary assets" may be possessed by them (Rothaermel, 2001), and therefore firms' commercialisation strategies need to take into account the incumbents' behaviour.

Thus, the capacity of new energy firms to exploit their technologies depends on their ability to devise the appropriate strategies to deal with this particular commercialisation environment (Gans and Stern, 2003). However, research on the strategic behaviour of entrepreneurial energy firms is still scarce (Wustenhagen and Wuebker, 2011; Krishna et al, 2011). This paper contributes to fill this gap, by investigating the commercialisation of RET in different stages of development, in order to uncover the strategies adopted by the new firms and their positioning relatively to large incumbents. For this purpose the research combines contributions from the sustainability transitions literature on the dynamics of the energy sector (Verbong and Geels, 2010; Hekkert and Negro, 2009; Sine and David, 2003) and from the strategic management of technology on the exploitation of advanced technologies by new entrants, in industries dominated by powerful incumbents (Teece, 1986; Rothaermel, 2001; Gans and Stern, 2003).

Drawing on this framework, empirical research is conducted on the creation and early development of Portuguese research-based energy firms, investigating the process of commercialisation of their technologies and the nature of the relationships established for this purpose. This paper presents the results of an exploratory analysis, based on case studies in two renewable energy fields in different stages of development - wind and wave energy. The analysis provides a first approach to the entry strategies open to the new firms and to the impact of differences between energy technologies on the conduction of these processes.

2. The technological and business environment in the energy sector(s)

New firms developing RET that have an application in the process of electricity generation and/or distribution are entering a large and highly complex sector that is undergoing a profound transformation (Jacobsson and Bergek, 2004; Jager-Waldau et al, 2011). The structural processes taking place in the sector and their impacts on the prevailing sectoral regime have been addressed by the various streams of the "sustainability transitions" literature (Markard and Truffer, 2008). According to this literature, these processes introduced some destabilisation in the prevailing regime (Geels, 2002), leading to changes in the industrial structure and knowledge base.

The liberalisation of the energy sector brought about the extinction of public monopolies and forced the separation between energy production, transmission, distribution and commercialisation, making market entry comparatively easier, at least in some segments (Verbong and Geels, 2010). In parallel, the creation of a growing space for renewable energies, drove a renewal of the industry knowledge base, creating opportunities for firms that develop and/or exploit new technologies targeting the energy production, or system-level problems associated with the introduction of renewable sources (Brown et al, 2007). A fast increase in the level of R&D and innovative activity in RET was observed (Ayari, 2012). The new technologies often started being developed in niches, given the high technological and market uncertainty associated with their exploitation (Raven, 2007). But some of them have reached a stage where wider commercial exploitation became viable (if not fully competitive with conventional sources). The distributed nature of some of the new sources also favoured new entry (Schoettl and Lehmann-Ortega, 2010), which was further encouraged by a variety of policy incentives for renewables. This challenged the dominant position of the old utilities (Duncan, 2010) and led to some readjustments in the actor composition and balance of power (Verbong and Geels, 2010). However, despite these changes, the sector still retains its infrastructural and centralised nature and is still largely dominated by large companies (Hockerts and Wüstenhagen, 2010).

3. The position of incumbents and conditions for new entry

3.1. Incumbents behaviour in the electricity production sector

As a result of the processes described above, the renewable electricity production and distribution sub-sector is currently characterised by fast technological change and, simultaneously, by an industrial structure where large established firms occupy dominant positions, at least in the renewable segments that are closer to maturity. However, there are great differences between RETs in terms of stage of development and level of market diffusion and therefore in terms of the actual structure of the respective "industrial segments" (Jäger-Waldau et al, 2011; IPCC, 2011). This have implications for research-based firms entering the energy business, since it influences the opportunities that are created and the conditions in which these can be exploited.

Established companies are often reluctant to get involved in the early exploitation of more immature technologies, given the high uncertainty and their lack of competences (Levinthal, 1997). Thus, ex-utility operators repositioning themselves in the renewable field, or companies diversifying from other sectors are more likely to invest in mature technologies, preferably those that enable large scale projects and are closer to their competences and competitive advantages (Hockerts and Wustenhagen, 2010; Duncan, 2010). But even in these fields there remains a variety of complex problems, both at technology and at system level, that require extensive technological developments, creating opportunities for technology-intensive specialised suppliers.

The still unsatisfactory performance of several RET already in the market (in terms of energy yield, costs and security of supply) also opens some space for the emergence of alternative designs, often in an experimental stage, that are explored in niches. The same happens in the case of emerging RET that have not yet reached a commercial stage, such as those related with ocean energy conversion. These emerging fields offer good opportunities for new firms originating from academic research that base their competitiveness on the production and exploitation of advanced knowledge (Conceição et al, 2012).

Incumbents attitude to emerging technologies vary (Hockerts and Wustenhagen, 2010; Ansari and Krop, 2012). But the growing international competition has quickened the technological pace and increased the pressure to invest in innovation, and thus the need to look for new technologies, or get involved in alternative technological paths (Hekkert and Negro, 2009). Thus incumbents may wish to keep an eye on the new developments, in order to follow-up (or even influence) their evolution and/or to guarantee an early position, once a dominant design emerges (Sine and David, 2003). But they usually prefer to achieve this through collaborations that reduce the risks and costs involved.

3.2. Start-up strategies in conditions of incumbent dominant position

The combination of strong incumbent power and fast technological change creates a particular environment for new firms introducing new technologies. The conditions faced by entrants in this type of environment and the strategic opportunities open to them have been addressed by the literature on the strategic management of technology (Teece, 1986; Arora et al, 2001). According to this literature, the capacity to protect the technology and the conditions of access to a number of downstream resources or competences that are necessary to sell a complete product/service – the "complementary assets" - are basic elements in the start-up strategic decisions. In particular, it has been shown that when large incumbents control a number of key complementary assets, small technology-intensive start-ups may benefit from adopting "cooperation strategies" (Gans and Stern, 2003), entering in relationships with them (Colombo et al, 2006). These alliances can be mutually favourable, even if often characterised by power asymmetry (Rothaermel, 2001). Since this asymmetry increases the appropriability hazards, making firms vulnerable to the expropriation of their main (or even unique) asset (Teece, 1986), the capacity to protect the technology is critical. Formal appropriation mechanisms like patents are often the only effective means of protection for small technology-intensive firms (Arora and Merges, 2004).

The strategies open to new technology-based entrants were addressed in detail by Gans and Stern (2003), who argue that the characteristics of the commercialisation environment constrain the choices to be made by the entrepreneurs. They define "commercialisation environment” along two dimensions - the extent to which innovation by the start-up precludes the incumbent’s development and the relevance of incumbent complementary assets to the start-up – and devise a typology of environments and associated strategies. This framework is relevant for our analysis, since it addresses the type of conditions that may influence the attitude of incumbents towards the advanced technologies being developed by the new energy firms and the nature of the relationships that are likely to be established between both.

The environment labelled by the authors as “ideas factories” configures a set of conditions that is likely to emerge in the renewable energy sector. In this case, invention by the start-up precludes effective development by established firms, because the start-up ability to protect the technology makes its appropriation difficult; but established firms control the complementary assets required for its commercialisation. This environment is conducive to a “cooperation strategy”, which may range from the licensing of the intellectual property, to the establishment of a variety of strategic alliances to, in the limit, the acquisition of the start-up. For incumbents the relationship with several innovative start-ups offers a fertile source of new ideas in fields where they have limited competences and/or where uncertainty is still too high and thus experimentation with a variety of competitive paths is still required (Raven, 2007).

Alliances with incumbents have benefits for the start-up, enabling it to access markets and supply chains; and providing capital for technology development and sometimes conditions for the testing or demonstration of its technologies/products. Thus, they reduce the start-up investment on downstream assets (Arora et al, 2001) and offer advantages in terms of legitimacy building. However, very often they strengthen the basis for incumbents’ advantage and thus their market power (Gans and Stern, 2003).

Gans and Stern (2003) also argue that when incumbent complementary assets are less important and the technology can be protected from appropriation - the “greenfield competition” environment - the start-up may consider the choice between collaborating and competing. The ability to control the development of platforms and standards is critical if the start-up decides to engage in product market competition. Cooperation is equally an alternative and in this case the start-up has stronger bargaining power and can define where and which conditions to cooperate.

3.3. Research-based firms and the process of commercialisation of the new RET

Although there is a body of empirical research on the conditions faced by technology-intensive start-ups that are entering industries dominated by large incumbents and on the relationships they establish, there is still limited knowledge about the behaviour of start-up firms that are willing to introduce new technologies in the energy sector.

This gap reflects a more general problem in the research on the transformation of the energy sector: a focus on the processes occurring at the system level and a still limited understanding of micro-level aspects, such as the strategies of individual firms and their relationship with the system (Markard and Truffer, 2008; Wustenhagen and Wuebker, 2010). The sustainable transitions literature presents entrepreneurs as playing an important role in the transition process, bringing in new technologies and attitudes and contributing to set-off change (Hekkert et al, 2007); and as interacting with other actors to build support to the development and diffusion of new ideas/technologies (Raven, 2007). However, there is limited knowledge on how firms effectively act/interact to introduce these technologies (Kishna et al, 2011; Hockerts and Wustenhagen, 2010).

To address this gap, this paper proposes an exploratory research at the micro-level, based on an in-depth analysis of the relational behaviour of research-based firms, in the process of development and early commercialisation of their technologies. Building on Gans and Stern (2003) concept of commercialisation environment we define an analytical framework to address the firms' positioning, that draws on and extends its two main dimensions:

1) The relevance of incumbents' complementary assets, for the new firm to capture the value of its technology, i.e. the start-up need for and mode of access to those assets. At this level we distinguish, first of all, between firms that decide to avoid engaging in the development of products/services based on the technology and thus *skip the need for those assets*; and the companies that at least partly engage in the activities necessary for such development and thus *require downstream assets* (Arora et al, 2001). Regarding the latter, we consider the established distinction between assets mostly *supplied competitively in the market* and assets co-specialised to the innovation and mostly *controlled by incumbents* (Teece, 1986).

2) The positioning of incumbents relatively to the technology exploited by the new firm, i.e. whether the technology is relevant for them and whether the new firm can preclude appropriation. Three generic levels of incumbent involvement are considered: keep a *watch* on the activities conducted by the developers of the technology; show *interest in their development*, expressed through direct participation (investment), or through the use of the resulting IP, products or services; be involved in the development and/or commercialisation of *competitor* technologies. The two first levels are conducive to cooperation between incumbents and new entrants, while in the third one there is competition. As pointed out above, whether "interest" induces cooperation or brings the threat of appropriation depends on the firms' capacity to protect the technology, which will also be considered.

The precise characterisation of the environment(s) prevailing in the energy sector – which supports our assessment of incumbents' behaviour – will be based on the analyses conducted by the transitions literature on the nature and dynamics of the energy regime and the implications of the changes underway. It will be complemented by the empirical literature addressing the emergence and development of the renewable energy sector, which points to substantial differences between RET in terms of maturity and market penetration. This supports the notion that different energy fields - and within them different energy segments – may generate variation in the competitive environments and thus dissimilar conditions for new entrants. The strategic implications of this variety will be investigated in the empirical analysis.

4. Empirical analysis

4.1 Methodology and sample

The empirical analysis uses a case study approach to gain an in-depth understanding of the technology commercialisation process, addressing firm creation and early development and focusing on the role played by relationships with different types of actors in that process.

The paper is focused on Portuguese research-based firms operating in two energy fields in different stages of technology development and market penetration: i) wind energy, already in full commercial exploitation and deploying the most stabilised technologies, despite some less developed segments, which are also considered; ii) wave energy, that only recently started to move from R&D to the early stages of industrial development, but where a dominant design has not yet emerged. This choice was based on our expectation that such differences lead to variation in the behaviour of the new firms, as well as on the attitude of established companies relatively to the technologies.

Portugal was regarded as providing a good empirical setting for this research. In the last decade the country invested strongly in the development of RET, both at the research and at the industrial level. It also introduced a very favourable incentive regime for the production and use of energy from renewable sources. As a result Portugal is currently positioned among the European countries with a greater penetration of renewable energy in electricity production and also with more ambitious targets regarding for its future development (MEID, 2010).

The favourable environment thus generated led to a recent upsurge in the creation of research-based firms exploiting advanced technologies targeting the renewable electricity production sector, which are the object of this empirical research. An extensive search conducted by the authors identified around 35 firms active in 2012, with particular focus on the bioenergy, wind and solar fields (Fontes et al, 2012). From this group, we selected, in a first stage, four firms for detailed case studies. In this selection there was an attempt to include some variety of situations in terms of maturity of the technology, firm age and also type of business (which is expected to influence the resources needed and thus produce variation in the nature of relationships established). The firms operate in the following areas:

- Wind: Plant optimisation; High-altitude wind; Off-shore engineering services
- Wave: Engineering solutions (services and products); Conversion systems

Data were collected through detailed interviews with the founders, supported by a semi-structured questionnaire, complemented with an extensive search for documentary information on the firms. The interviewees were asked to provide a brief history of the firm creation and then to give detailed information on the relationships established along the process of development and market introduction of the technologies being exploited. The main characteristics of the firms studied are presented in Table 1. Their individual case stories can be found in Fontes et al (2012).

Table 1 – Firms in case studies*

	WAVE-TECH	**OCEAN**	**WIND-TECH**	**WIND-SERV**
Year creation	2009	2005	2003	2004
Field	Wave energy conversion	Solutions in wave energy conversion; Engineering services to off-shore wind	High altitude Wind Energy Conversion (& energy storage)	Wind resource assessment (on-shore)
Business	Product development	Customised development (products); R&D and engineering services	IP development and licensing	Plant optimization services based on own methods
Stage of development	Prototype	In market with products & services	R&D	In market with services
Patents	Y	Y	Y	N
Market *(expected)*	*(Energy producers & distributors)*	Wave energy companies; Off-shore wind companies	Research organizations *(Energy producers & distributors)*	Wind companies

** Firms' names are fictitious to guarantee confidentiality*

4.2. Commercialising strategies

Drawing on the analytical framework presented in section 3.3 we started by assessing the nature of the technology being introduced and the industrial structure of the segment where the firm operates. We subsequently draw on the information obtained from the case studies to understand the firms' positioning concerning the framework dimensions: whether some of the key complementary assets are possessed by incumbents and in which conditions the new firm can gain access to them; whether the technology being introduced by the new firm is relevant for the incumbents and thus which is their attitude towards the technology and its supplier(s); whether the new entrants have the capacity to protect their technology from expropriation.

Regarding the capacity to protect the technology, all firms studied are, at least in principle, in a similar position. In fact, all but one have the core technology protected by patents. The one that did not patent the technology benefits from the protection afforded by the tacit and experiential nature of the knowledge base. It is therefore possible to assume that these firms had conditions to exclude others from imitating their technology, thus retaining the capacity to establish market relationships with incumbents or even to compete with them. We will now discuss the various firms' situations regarding of the remaining dimensions.

OCEAN and WAVE-TECH, that operate in the wave field, are introducing technologies still in a very immature stage, which require extensive testing, first at prototype and later at pilot stage in real life conditions. These experiments involve complex infrastructures and extensive financial resources that are beyond the reach of a small firm, being often possessed by large firms or consortia that lead large scale demonstration projects. For OCEAN, access to these settings is critical, since it provides a market for its products and services and simultaneously a test bed to improve its technologies. The incumbents show interest in its technologies and are prepared to get involved in its testing and validation. Thus OCEAN has to establish alliances with the owners of the co-specialised assets. However, because no dominant design has emerged, there are several experimental projects underway. This provides OCEAN with opportunities for establishing relationships with different partners, the main challenge being to capture their interest in a context where there are several small suppliers with competing technologies. The fact that OCEAN emerged within the Portuguese "wave energy community" and that its entrepreneurs were actively involved in the early development of the sector was instrumental in this process. In fact, the firm benefited from their scientific reputation, industry visibility and extensive contacts to gain access to experimental settings at national and international level. It was thus able to establish a close relationship with local energy incumbents (both the ex-utility and an equipment manufacturer) that have a strategic interest in ocean technologies and thus provide it with a market for technologies and skills that can be applied both to wave energy and offshore wind. But OCEAN was equally able to establish relationships with foreign companies that lead the wave sector and to participate in consortia involving several public and private actors conducting experimental projects in Portugal and abroad. Thus OCEAN capitalized on the still turbulent nature of the sector to propose its technology and extensive skills to different partners, deflecting the risks of exclusive relations.

A similar reasoning may apply to WAVE-TECH, which is still developing a prototype, in its future efforts to introduce its innovative wave technology. The main issue in this case concerns the extent to which the new technology being introduce will require the same degree of integration with incumbent assets to obtain a final product, since its system is presented as having a greater autonomy. In any case, the incumbents' attitude relatively to the technology is likely to be different. Contrary to OCEAN, this firm emerged outside the "wave energy community" with a technology design that departs from the one in which the local incumbents are involved. Nevertheless, we observe an interest of the ex-utility in watching the development of a technology that deviates from its core competence, but appears to have some potential. This is materialised in some contribution to its development (seed capital, access to facilities and human resources), as well as advice and credibilisation. That is, the incumbent is offering access to some key assets that will enable the new company to complete the development of the technology. We observe a strong reliance of the new firm on the "benevolent" interest of the influential company, but its strategy is not confined to the local market. In fact, it profited from the visibility afforded by winning a series of entrepreneurship contests to gain access to an international incubator that can provide it with a wider range of connections. The firm plans to manufacture its core product and eventually license the technology for other applications. Once it engages in these activities it will have to make some new decisions regarding the type of relationships to establish.

The case of WIND-TECH that is also introducing an emerging technology, presents an interesting contrast. First of all, because WIND-TECH opted for focusing on the development of the technology and licensing the intellectual property, thus avoiding the need to build production and commercialisation assets altogether. Second, because high-altitude wind is at an even earlier stage than wave conversion, and thus the essential of the relationships WIND-TECH established so far concern R&D activities and are taking place in the context of European RTD consortia (involving public and private organisations). However, subsequent developments may require other types of alliances and, in the limit, licensing contracts. Finally, the technology that is being developed is much outside the competences of local incumbents. Indeed, the genesis of the company was an international organization in a different field (space) that remains a key partner, being a source of knowledge and contacts. However, the ex-utility integrates the European RTD consortium, denoting some interest in keeping a watch on a technology that is a potential extension - or even a competitor – to its core wind area.

Finally, the structure of relationships is clearly different in the case of WIND-SERV that operates in the onshore wind segment, dominated by large incumbents. In this case the new firm is a typical small specialised supplier of services that improve the performance of the incumbents' core business. Thus, its activities provide value to the incumbents, but competition with them is unlikely given the different set of competences involved, and the risk of expropriation is low because imitation is difficult. Although the firm business depends on the incumbents' activity, it sells its competences in a market populated by a variety of potential clients and thus arms' length commercial relationships prevail. But long standing relationships exist with important clients, some of whom had a lead-user role at early stages and have consistently included the firm in their wind plant installation projects. WIND-SERV early expansion to foreign markets also benefitted from the interest of the incumbents in the technology, since it often took place in the context of their international projects. This was instrumental for the firms' penetration in some markets. WIND-SERV also draws some visibility from the participation of its entrepreneurs in activities for the promotion of the industry.

The above analysis enables us to uncover some sources of variation in the conditions experienced by firms, that can at least partly explain their positioning relatively to incumbents and thus the nature of the relationships established with them in the commercialisation process. Drawing on it, we can position the firms along the main dimensions of the "competitive environment", as defined by our framework (Table 2).

Table 2 – Positioning of case study firms and types of relationships established

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Relevance of complementary assets possessed by incumbents:
Firm access to complementary assets</td></tr>
<tr><td>Access in market</td><td>Controlled by incumbents</td><td>Skip (sell technology)</td></tr>
<tr><td rowspan="4">Relevance of technology for incumbents:
Incumbent attitude</td><td>Watcher</td><td></td><td>WAVE-TECH
(Wave conversion)
Alternative technology design developed outside “wave community”.
Support to new firm as monitoring device</td><td>WIND-TECH
(High altitude wind)
Alternative conversion technology that deviates from incumbents core competence & operational control. R&D alliances as sources of potential clients for technology</td></tr>
<tr><td rowspan="2">Interested in development</td><td rowspan="2"></td><td>OCEAN
(Wave conversion; Offshore wind engineering)
Wave technology design developed jointly in local “wave community”
Offshore: technology adds value to incumbents assets and is used by them
Alliances combining technology and market elements</td><td rowspan="2"></td></tr>
<tr><td>WIND-SERV
(Wind plant optimization)
Technology that adds value to incumbents assets and is used by them
Market relations, but some longstanding alliances with lead-users</td></tr>
<tr><td>Competitor</td><td></td><td></td><td></td></tr>
</table>

Considering the generic commercialisation environments proposed by Gans and Stern (2003), it is possible to conclude that the “ideas factory” environment appear to prevail in the energy fields analysed, although we observe at least one emerging technology that has potential to operate outside the centralised regime favoured by incumbents (high-altitude wind) and thus offer different conditions. But the case studies permitted to go in greater depth into the nature of the relationships that are associated with different positioning of the new firms relative to incumbents and different attitudes of the later.

In both fields, most new firms depend more or less clearly on the complementary assets possessed by large energy incumbents, although the analysis enable us to understand that this happens for different reasons and assumes different forms, depending on the energy field and also the on technology. In wind, this results from a combination of incumbents' dominant position in the industry and interest in the complementary technologies that add value to their assets. This is valid for both onshore and offshore, because despite the less mature stage of the technology in the latter, the relative position and function of the two actors is similar. Thus, new firms act as specialised technology suppliers to incumbents, establishing market relationships with them, which are more arms-length in onshore given the maturity of the technology and the wider number of customers. But we observe, in both cases, the presence of closer, longstanding relations with an important role in the early market introduction of the technology (in onshore) or in the access to service opportunities (in offshore).

In wave, where technology still has a "niche" nature, it results from the strong interest and resulting positioning of a number of incumbents (national and foreign) in the emerging field. Thus, the new firms develop the conversion technologies, but incumbents have a dominant position in what concerns the resources and infrastructures required for test and demonstration. They are also well positioned to come to control the final installations, which are likely to match their operational competences and knowledge base and to require important investments. The nature of relationships established depends on the degree of incumbents' familiarity with the technology: close, longstanding relationships when they were involved in the development of a given design vs. monitoring of alternative designs, through the identification and early support of new companies introducing them.

Despite the small number of cases, it is possible conclude that in the energy fields being analysed there appears to be some incumbents' interest in the new technologies - and even some involvement in their development and use. On the other hand, the incumbents' attitude appears to be beneficial for the early activity of the new firms, providing resources, markets and legitimacy. However, it also implies a great dependency on powerful companies, which is stronger when the number of incumbents involved in the field or interested in the technology is smaller, as becomes particularly evident in the case of wave energy. Indeed, new firms operating in this field search for partnerships with foreign companies, which can offer greater scope for exploitation and limit the threat of excessive dependence on one large partner.

5. Conclusions

This paper investigated the strategies open to new firms introducing advanced RET in the particular context of the electricity production sector. Given the nature of the sector – that combines a strong incumbent power with fast technological development - particular attention was put on the new firms' position relative to the large established companies and on the attitudes of the latter towards the new technology.

An analytical framework was developed and tested on the basis of case studies in two fields with different levels of technology maturity: wind and wave energy. The research presented in this paper, although still preliminary, permitted an in-depth analysis of the strategies adopted by the new firms and provided some insights into the behaviour of incumbents in these fields. These first results suggest that both fields are characterised by a competitive environment where: new research-based firms tend to depend, to a greater or lesser extent, on the downstream complementary assets possessed by large energy incumbents (unless they opt for selling the technology), but have the conditions to protect their technology from appropriation (mostly with patents); and where the technology is relevant for (at least some of) the incumbents, which show interest in their development, although with different levels of involvement. This is conducive to "cooperation strategies", which can assume diverse forms, depending on the stage of development of the field, the maturity of the technology and its proximity to the incumbents' knowledge base and operational competences.

Subsequent research will expand these results by applying the framework to a larger number of cases along the different categories considered, in order to verify whether these preliminary results are confirmed and to achieve a more precise understanding of the modes of interaction between the different actors. It will also be relevant to extend the analysis to energy fields with a less centralised regime (such as solar energy), where the competitive environment may differ, leading to potentially different strategies.

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DAY 10 - 11:30		
Room 642 - Economic Growth and Sustainability 2		
Economic Growth and Useful Work	João Santos[1]; Rui Mota[1]; Tânia Sousa[1]; Tiago Domingos[1]	[1]IN+, Center for Innovation, Technology and Policy Research, Environment and Energy Scientific Area, Department of Mechanical Engineering, Instituto Superior Técnico, UTL
Fossil&Renewable Energy Consumption, GHGs and Economic Growth: Evidence from a Panel of European Union (EU) Countries	Gulden Boluk[1]; Mehmet Mert[1]	[1]Akdeniz University
Towards sustainable product development: an environmental and economic study	Carla L. Simões[1]; Lígia M. Costa Pinto[2]; C. A. Bernardo[1]	[1]Institute for Polymers and Composites – IPC/I3N, University of Minho; [2]Department of Economics/NIMA, University of Minho
A Macroeconomic Model For An Oil Scarcity Scenario	O. Carvalho, J. Magalhães, T. Sousa	Instituto Superior Técnico Department of Mechanical Engineering

Economic growth and useful

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Abstract

This paper contributes to the on-going debate on energy variables as drivers of economic growth by constructing a two-sector model with a separation between the energy and non-energy sectors. An innovative definition of the energy sector is introduced, which includes all processes and devices that convert primary exergy into useful work. The non-energy sector includes useful work as the appropriate variable for the production function, besides capital and labor. Uzawa's Theorem is extended to a broader concept of regular growth in the context of our model. It is shown that technological progress can be reduced to a purely labor-augmenting form, as a consequence of assuming a regular growth path for the economic variables in the model. This allows the equation system for the model to be written in terms of effective-labor variables, permitting the study of its steady state and comparative statics. Future research will apply this framework to the assessment of several stylized facts of economic growth and characteristic phenomenons related to the energy consumption and economic growth causality relationship.

Keywords: Economic Growth, Useful Work, Exergy

JEL Classification: O4, Q43, O13

1. Introduction

The idea of a causality relationship between energy consumption and economic growth has important policy implications. Several studies have focused on different countries, time periods, proxy variables and methodologies, with varied and sometimes conflicting results (Ozturk 2010). So far no consensus has been reached on whether energy use is responsible for economic growth or the other way around. Meanwhile, conventional economic theory attributes only a marginal importance to energy as a factor of production by following the argument that energy's share in total factor cost is small when compared to the cost shares of capital and labor.

In order to resolve the apparent inconsistency between small factor shares for physical resources/energy proxies and their explanatory power in the production function, we introduce an additional sector (energy sector) and establish a parallel with standard models in order to simulate the availability dynamics of energy as a factor of production and understand its importance for growth. This meets the criticisms of several economists on the absence of energy and material resources from standard theory. Energy use is expected to be as much a driver of growth as a limiting factor, since other factors of production such as labor or capital cannot do without energy (Arbex & Perobelli 2010).

Meanwhile, recent empirical and theoretical work suggests that the driver of growth is not energy (exergy) consumption as such, but exergy converted to *useful work* in the economy (Ayres 2001; Ayres & Warr 2002, 2003, 2005). The term energy consumption, as used in most economic literature, is technically incorrect since energy is conserved in every activity in accordance to the laws of thermodynamics. *Exergy* is the correct term for energy capable of performing mechanical, thermal or chemical work. Unlike energy, exergy is used and dissipated in all transformation processes. Exergy consumption and useful work are also measures that can be estimated with acceptable accuracy, not only for traditional fuels, but also for all agricultural products and industrial materials. This enables the construction of an aggregate measure of all resource flows into the economic system, as well as of all processed intermediate flows.

Basing our work on the ideas stated above, we construct a two-sector model with a separation between an innovative energy sector and the non-energy sector. Useful work is considered the appropriate variable in the production function for the non-energy sector. However, since useful work is not considered a primary input, it is introduced as a product of the energy sector.

Section 2 describes the economic model in some detail, while determining the effects of several parameters on capital formation and output through comparative statics. We show that technological progress can be represented as purely labor-augmenting in the context of our model, by extending Uzawa's steady state growth theorem to a more general concept of regular growth. From this result, the model can be reformulated in terms of effective labor variables, which allows for its steady-state and comparative statics to be studied. Section 3 states some conclusions and discusses possible applications of the model.

2. The model

K: Total capital; K^E: Energy capital; K^{NE}: Non-energy capital;

Y: Total output; Y^E: Output E-Sector; Y^{NE}: Output NE-Sector;

C: Total consumption; C^E: E-Sector consumption; C^{NE}: NE-Sector consumption;

A^L: Total Tech. Progress A^E: Energy efficiency A^{NE}: NE-Sector Tech. Progress;

L: Labor;

The economy we wish to study can be described by a two-sector model with a separation between the energy and the non-energy sectors (Figure 1). This model is inspired by former literature on the inclusion of an energy variable as a factor of production (Ayres 2001). We assume the existence of a *primary* sector (E-Sector), responsible for producing useful work, B^U, of which a constant fraction is consumed by households as *energy consumer goods,* C^E and the remainder is an intermediate good. This sector requires *primary exergy inputs*, B^P and capital inputs K^E, while labor inputs are considered negligible. The *secondary* sector (NE-Sector) produces all final investment goods, $I = I^E + I^{NE}$, and non-energy consumer goods and services, C^{NE}. This sector uses the outputs of the E-Sector not attributed to household consumption, γB^U, as well as inputs of capital K^{NE} and labor L.

For the rest of this paper we will assume that we are dealing with a closed economy in continuous time, without government. We are therefore ignoring such factors as imports/exports, taxes and subsidies, as well as net capital transfers and net lending/borrowing. The total GDP of the economy is simply the sum of the output of the NE-Sector and the value of final energy consumption.

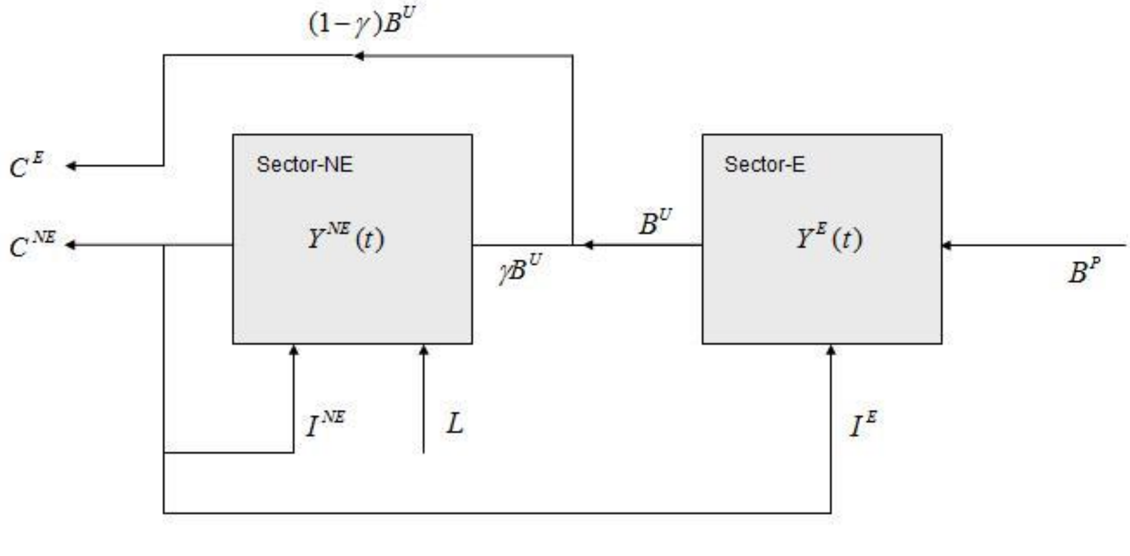

Figura 1 – Diagram for the two-sector model of the economy.

2.1. The E-Sector

In general economic models and accounts, the energy sector corresponds mostly to the energy industries, including those involved in fuel extraction, manufacturing, refining and distribution. The energy sector in this model aggregates all processes that convert primary exergy into actual useful work performed, and therefore includes not only the usual energy industries but also any apparatus, machine or process that performs this conversion (final-use devices). This means that such goods as appliances (refrigerators, toasters, etc) or vehicles, whether used by firms of households, also belong in the E-Sector, and their production should be considered as investment in the form of energy capital, K^E.

Useful work, B^U, is the minimum amount of energy needed to produce the energy consumed by households and the energy used by the NE-Sector. It is related to primary exergy inputs by a thermodynamic efficiency, ε. This conversion takes place within the E-Sector, and the thermodynamic efficiency is related to the technological capacity, A^E. It is assumed that A^E is given exogenously. Useful work is then produced as a function of the capital invested in the energy sector, K^E, and the primary exergy input, B^P:

$$(1) \qquad \boldsymbol{B^U} = \boldsymbol{F^E}[\boldsymbol{K^E}, \boldsymbol{A^E B^P}]$$

Primary exergy and useful work are measured in gigajoules (GJ), to which a positively time-varying price p_{B^U} is associated. For simplicity this price is initially assumed to be normalized to unity. Technological capacity appears as a multiplicative factor of primary exergy because an upgrade in conversion efficiency is equivalent to an increase in primary exergy used to perform useful work. In value terms, the output for the E-Sector will be divided into useful work consumption by households and input to the NE-Sector. The resource constraint for the E-Sector is:

$$(2) \qquad \begin{aligned} Y^E &= p_{B^U} B^U \\ Y^E &= C^E + \gamma p_{B^U} B^U \\ C^E &= (1-\gamma) p_{B^U} B^U \end{aligned}$$

Primary exergy and energy capital are considered to be perfect complements. However, while K^E is a scarce good, primary exergy is not considered as limited at this stage of the analysis. This means that it suffices to increase energy capital in order to increase the input of B^P, although an increase in A^E allows for a higher B^P with the same value of K^E. Assuming that the production function for this sector takes a Leontief form, and choosing K^E to be well defined at a given moment, production can be maximized by putting:

$$(3) \qquad \max F^E(K^E, A^E B^P) = \max\left(\min\left(\mathrm{aK^E}, \mathrm{bA^E B^P}\right)\right), \text{ with constant } a, b > 0$$

This, in turn, means that the primary exergy use will be proportional to the energy capital. Therefore, the total primary exergy used in production is only calculated after the total output for the economy is known. For simplicity, Y^E is written as:

$$(4) \qquad Y^E = F^E(A^E K^E) = A^E K^E$$

2.2. The NE-Sector

The non-energy sector uses a three factor production function to generate non-energy consumption goods and services, and investment goods for both sectors. Technological progess in the NE-Sector, A^{NE}, is assumed to be labor-augmenting in order for a steady state to exist for this model.

$$(5) \qquad Y^{NE} = F^{NE}(K^{NE}, \gamma A^E K^E, A^{NE} L)$$

This is a neoclassical production function, and follows the same properties, including constant returns to scale (Euler's Theorem), and positive and decreasing marginal products and essentiality in all three factors of production. The Inada conditions for non-energy capital and labor also apply. However, by considering useful work as a factor of production we must attend to the Inada conditions for this factor such as not to contradict the principles of thermodynamics, namely the law of mass/energy conservation (Baumgärtner 2004). Denoting $\rho(t)$ as the intensity of useful work in output Y^{NE}, the marginal product of useful work will be bounded by above by:

$$(6) \qquad \lim_{B^U \to 0} \left(\frac{\partial F^{NE}}{\partial \gamma B^U}\right) = \frac{1}{\rho(t)}$$

Since the economy is assumed to be closed, the resource constraint for the NE-Sector is:

$$(7) \qquad Y^{NE} = C^{NE} + I^E + I^{NE}$$

All capital invested in the economy is produced by the NE-Sector, and corresponds to a constant fraction of output, given by an exogenous saving rate s. Investment is then allocated between the energy and non-energy sectors according to a variable σ.

(8) $$I = I^{NE} + I^{E} = sY^{NE} = \sigma sY^{NE} + (1-\sigma)sY^{NE}$$

This concludes the description of the two-sector model for the economy. The next step is to analyze the existence and conditions for a steady state according to the assumptions of this framework.

2.3. Steady-State and Comparative Statics

The laws of motion for energy and non-energy capital depend on the amount of investment allocated to each sector and on specific depreciation rates. Labor and technological progress in the NE-Sector grow at constant exogenous rates, while the form by which energy efficiency evolves is unknown. However, it can be admitted that its variation in time is a function of A^{E}. The economic model presented before can be summarized by the system of equations:

(9) $$\begin{cases} \dot{K}^{NE} = \sigma sF^{NE}[K^{NE}, \gamma F^{E}(A^{E}K^{E}), A^{NE}L] - \delta_{NE}K^{NE} \\ \dot{K}^{E} = (1-\sigma)sF^{NE}[K^{NE}, \gamma F^{E}(A^{E}K^{E}), A^{NE}L] - \delta_{E}K^{E} \\ \dot{A}^{NE} = gA^{NE} \\ \dot{L} = nL \\ \dot{A}^{E} = E(A^{E}) \end{cases}$$

Given the initial endowments for all factors of production, the exogenous growth rates g and n, and the investment in each sector as well as respective depreciation, the level of consumption for both sectors, C^{NE} and C^{E} can be obtained, from equations (2) and (7). Technological progress, in this model, is present in two forms: as energy capital augmenting progress and as labor augmenting progress. The vector valued index of technology can be written as:

(10) $$\boldsymbol{A}(t) = \left(A^{E}(t), A^{NE}(t)\right)$$

The steady state growth theorem stated by Uzawa in 1961 shows that if a neoclassical growth model exhibits steady-state growth, then technical change must be labor augmenting asymptotically, i.e., along the balanced growth path (Jones & Scrimgeour 2004). The production function must then have a representation with purely labor-augmenting technical change in the steady state. This theorem has been previously proved for exponential growth without assumptions about savings behavior or factor pricing (Schlicht 2006). In the present paper, a similar proof is proposed for a more general regularity concept than that of exponential growth. This general concept is labelled *regular growth* and subsumes exponential growth, arithmetic growth, and the range between these two (Groth et al 2006). This broader concept of regularity relates to the way growth rates change over time. Let the variable $x(t)$ be a positively-valued differentiable function of time t. The criterion for defining regular growth is given by:

(11) $$\begin{cases} \frac{\dot{x}}{x} = g \\ \frac{\dot{g}}{g} = -\beta g \end{cases}, \ \beta \geq 0, \ \forall t \geq 0$$

The growth rate of $x(t)$ is assumed to be strictly positive within the time range considered, with initial value $g(0) = \alpha$. The constant coefficient β indicates the rate of damping in the growth process. The unique solution to this second-order differential equation describes a family of growth paths:

(12) $$x = x_0(1 + \alpha\beta t)^{\frac{1}{\beta}}$$

The special case of expoential growth occurs when $\beta = 0 \to x(t) = x_0 e^{\alpha t}$, with $x_0 = x(0)$ constant. This is the basic characterization of regular growth.

In the context of our model, we assume an asymptotic path in which output from the NE-Sector, consumption from both sectors, as well as labor and energy/non-energy capital, follow a behavior similar to (12). We will have:

(13) $$\begin{cases} i = i_0(1 + \alpha_i\beta_i t)^{\frac{1}{\beta_i}} \\ g_i(0) = \alpha_i \\ \frac{\dot{g}_i}{g_i} = -\beta_i g_i \end{cases}, \text{ with } i = Y^{NE}, C^E, \ C^{NE}, K^{NE}, K^E, L$$

Like before, i_0, α_i and β_i are constant positive values, different for each variable in the model. The time-varying growth rate g_i is positively defined for all variables as in (11), e.g. $g_L = \dot{L}/L$.

It can be shown that, if the sector-specific variables exhibit this kind of regular growth, then the aggregate variables of total capital, $K = K^{E} + K^{NE}$, total consumption, $C = C^{E} + C^{NE}$, and total output, $Y = Y^{NE} + C^{E}$, will also behave in this form. Moreover, we will have that $g_{K^{E}} = g_{K} = g_{K^{NE}}$ and $g_{Y} = g_{Y^{NE}} = g_{C^{E}} = g_{C} = g_{C^{NE}}$.

From the resource constraints in (9), we will have that the growth rates for total capital and total output are identical. For initial time $t = 0$, we obtain:

(14) $$\begin{cases} \sigma[Y_0 - C_0] = (\alpha_K + \delta_{NE})K_0^{NE} \\ (1-\sigma)[Y_0 - C_0] = (\alpha_K + \delta_E)K_0^{E} \end{cases}$$

Differentiating the aggregate resource constraints with respect to time, substituting from (14) and noting that $g_Y = g_C \rightarrow \alpha_Y = \alpha_C$, it results that, for initial time:

(15) $$\begin{cases} (1-\beta_K)\alpha_K^2 = \alpha_Y(\alpha_K + \delta_{NE}) - \alpha_K\delta_{NE} \\ (1-\beta_K)\alpha_K^2 = \alpha_Y(\alpha_K + \delta_E) - \alpha_K\delta_E \end{cases}$$

Where some relations derived directly from the definition of regular growth were applied. Namely:

(16) $$\begin{cases} \dot{x} = gx \\ \ddot{x} = (1-\beta)gx \\ \dot{g} = -\beta(g)^2 \end{cases}$$

The left-hand side in (15) is the same for both equations, so adding the r.h.s. gives the equality:

(17) $$(\delta_{NE} - \delta_E)\alpha_Y = (\delta_{NE} - \delta_E)\alpha_K$$

From (17) is results that $\alpha_K = \alpha_Y$, if $\delta_E \neq \delta_{NE}$. Differentiating the aggregate constraints again with respect to time, and performing similar simplifications and substitutions, we obtain that $\beta_K = \beta_Y$. We have, therefore, that $g_K = g_Y$ and, since $g_Y = g_{Y^{NE}} = g_{C^{NE}}$, we get:

(18) $g_K = g_{Y^{NE}} = g_{C^{NE}}$

Now, writing the production function for initial time $t = 0$ and multiplying by $\left(1 + \alpha_{Y^{NE}}\beta_{Y^{NE}}\, t\right)^{1/\beta_{Y^{NE}}}$ results in:

(19) $$Y^{NE} = F^{NE}\left[\frac{\left(1+\alpha_{Y^{NE}}\beta_{Y^{NE}}\, t\right)^{1/\beta_{Y^{NE}}}}{(1+\alpha_K\beta_K t)^{1/\beta_K}}K^{NE}, \frac{\left(1+\alpha_{Y^{NE}}\beta_{Y^{NE}}\, t\right)^{1/\beta_{Y^{NE}}}}{(1+\alpha_K\beta_K t)^{1/\beta_K}}K^{E}, \frac{\left(1+\alpha_{Y^{NE}}\beta_{Y^{NE}}\, t\right)^{1/\beta_{Y^{NE}}}}{(1+\alpha_L\beta_L t)^{1/\beta_L}}L\right]$$

Since both $\left(1 + \alpha_{Y^{NE}}\beta_{Y^{NE}}\, t\right)^{1/\beta_{Y^{NE}}}$ and $(1 + \alpha_K\beta_K t)^{\frac{1}{\beta_K}}$ grow at the same constant rate $g_K = g_{Y^{NE}} = g_{C^{NE}}$, their ratio is constant, and time-varying technological progress assumes the purely labor-augmenting form:

(20) $$A^L(t) = \frac{\left(1+\alpha_{Y^{NE}}\beta_{Y^{NE}}\, t\right)^{1/\beta_{Y^{NE}}}}{(1+\alpha_L\beta_L t)^{1/\beta_L}} \to \frac{\dot{A}^L(t)}{A^L(t)} = g_{Y^{NE}}(t) - g_L(t) = \lambda(t)$$

This result is a very powerful one, as its demonstration only exploits the definitions of asymptotic paths and regular growth, the constant returns to scale nature of the production function and the resource constraint. This concludes the proof.

In light of this result the system of equations (9) can be rewritten as:

(21) $$\begin{cases} \dot{K}^{NE} = \sigma s F^{NE}(K^{NE}, \gamma K^E, A^L L) - \delta_{NE} K^{NE} \\ \dot{K}^E = (1-\sigma) s F^{NE}(K^{NE}, \gamma K^E, A^L L) - \delta_E K^E \\ \dot{L} = nL \\ \dot{A}^L = \lambda A^L \end{cases}$$

The model can be simplified by writing the variables in terms of effective labor units, $A^L L$. The laws of motion for both kinds of capital in this new variable system are:

(22) $$\begin{cases} \dot{k}^{NE} = \sigma s f^{NE}(k^{NE}, \gamma k^E) - (\delta_{NE} + n + \lambda) k^{NE} \\ \dot{k}^E = (1-\sigma) s f^{NE}(k^{NE}, \gamma k^E) - (\delta_E + n + \lambda) k^E \end{cases}$$

New energy (non-energy) capital formation depends on the difference between investment in the E-Sector (NE-Sector) and the effects of depreciation, population growth and labor augmenting technological progress. The steady state equilibrium will be given by$\left(\dot{k}^{NE} = 0, \dot{k}^{E} = 0\right)$. Moreover, from (6), an additional condition for steady state growth will be:

$$\lim_{k^E \to 0}\left[\frac{f^{NE}}{k^E}\right] = \frac{\gamma}{\rho} > \frac{(\delta_E + n + \lambda)}{(1-\sigma)s} \tag{23}$$

In this steady state, total savings allocated to investment in the E-Sector (NE-Sector) are used for replenishing the energy (non-energy) capital stock for three different reasons: the depreciation of energy (non-energy) capital at rate δ_E (δ_{NE}), the growth of population at rate n which reduces the amount of capital per worker, and the evolution of technical change at rate λ. A trivial steady state exists for $f^{NE}(0,0)$, but the existence and uniqueness of equilibria with $k^{NE^*} > 0$ and $k^{E^*} > 0$ can be easily proven (Acemoglu 2008). Comparative statics for this model can be obtained by usual methods:

$$\begin{array}{lll}
\frac{\partial k^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial s} > 0; & \frac{\partial k^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \sigma} > 0; & \frac{\partial k^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \gamma} > 0; \\
\frac{\partial k^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \delta_{E,NE}} < 0; & \frac{\partial k^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \lambda} < 0; & \frac{\partial k^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial n} < 0; \\
\frac{\partial k^{E^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial s} > 0; & \frac{\partial k^{E^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \sigma} < 0; & \frac{\partial k^{E^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \gamma} > 0; \\
\frac{\partial k^{E^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \delta_{E,NE}} < 0; & \frac{\partial k^{E^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \lambda} < 0; & \frac{\partial k^{E^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial n} < 0;
\end{array} \tag{24}$$

.

$$\begin{array}{lll}
\frac{\partial f^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial s} > 0; & \frac{\partial f^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \delta_{NE}} > 0; & \frac{\partial f^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \delta_E} < 0; \\
\frac{\partial f^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \gamma} > 0; & \frac{\partial f^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial \lambda} > 0; & \frac{\partial f^{NE^*}(s,\sigma,\delta_E,\delta_{NE},\lambda,n,\gamma)}{\partial n} > 0;
\end{array} \tag{25}$$

Higher saving rates and an increase in the amount of useful work used in production by the NE-Sector will lead to higher capital-effective labor ratios and therefore higher non-energy output. Likewise, higher depreciation and population growth results in lower capital-effective labor ratio and lower non-energy output.

3. Conclusions

A general observation from the literature on the energy-growth nexus is that these studies have failed to produce a consensus on the existence and direction of causality between energy consumption and economic growth. Instead of employing the usual methods for different countries and intervals of time, authors should focus on new approaches and perspectives of growth theory.

The model presented in this paper is constructed with the intention of providing such a new perspective, by dividing the economy in two distinct sectors, energy and non-energy, and introducing *useful work* as a factor of production. Under the assumptions of regular growth adopted for the model constructed in this paper, it was shown that technological progress must be purely labor-augmenting along the growth path. In other words, the production function must have a representation with strictly Harrod-neutral technological progress, asymptotically. This means that the equation system developed in this paper can be rewritten in terms of effective labor variables. The model verifies steady-state equilibrium under certain conditions and the set of comparative statics obtained can be used to extrapolate economic behaviours relating to the effect of energy consumption on growth.

Extensions of our study include the use of the framework developed in this paper to attempt an explanation on several phenomenons of the energy-growth causality relationship, such as: the rebound effect, the constraints on growth caused by a limited exergy-to-useful-work efficiency and the future effects of scarcer and more expensive resources on the economy. It is also the aim of the researchers involved that the model can address the validity of some recent stylized facts of economic growth that have appeared in the global literature (Li & Ayres 2008, Jones & Romer 2009) and specifically for Portugal (Serrenho et al 2012), as well as the familiar Kaldor facts for long term economic growth. This will be the next step.

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Fossil&Renewable Energy Consumption, GHGs and Economic Growth: Evidence from a Panel of European Union (EU) Countries

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Abstract

Recently many empirical research has examined the certain indicators of environmental degradation and income. The Environmental Kuznets Curve (EKC) hypothesis has been tested for various types of environmental degradation. The EKC states that the relationship between environment degradation and income per capita takes the form of an inverted U shape. In this paper we investigate the relationship between carbon emissions, income and energy in 16 European Union (EU) countries. We conducted a panel data analysis for the data set of 1990-2008 period. This paper’s main contribution is EKC hypothesis has been investigated by separating final energy consumption into renewable and fossil fuel energy consumption. Unfortunately, inverted U-shape relationship (EKC) does not hold for carbon emissions in 16 EU countries. Second important finding is renewable energy consumption contributes less around 1/2 than fossil energy consumption to GHG emissions in EU counties. This implies that much more renewable energy consumption may improve the GHGs emissions.

Keywords: Environmental Kuznets Curve, Carbon Dioxide emissions, economic growth, renewable energy.

1. Introduction

The increasing threat of global warming and climate change has been a major ongoing concern in the world since 1990s. Because greenhouse gas (GHG) emissions results primarily from the combustion of fossil fuels, energy consumption and production is at the center of the climate change debates. According to the latest report of Joint Research Center (JRS), (see Oliver et al, 2012), fossil fuel combustion accounts for about 90% of total global CO2 emissions. The relationship between energy consumption and economic development, as well as economic development and environmental pollution has been studied intensively in last three decades.

There are basically three main research bunches in the literature on economic growth, energy consumption and environment pollution (Zhang and Cheng, 2009). The first bunch focuses on environmental pollution and economic growth relationship testing the validity of the so-called environmental Kuznets Curve (EKC) hypothesis. Economic growth has both harmful effects (via the scale of industry and changing structure of economic activity) and beneficial effects (via shift toward cleaner production techniques) on environmental quality. In many empirical studies, a U-shaped relationship appears: a relatively low levels of income per capita, growth leads to greater environmental damage, until it levels of at an intermediate level of income after which further growth leads to improvements in the environment (Frankel, 2008).

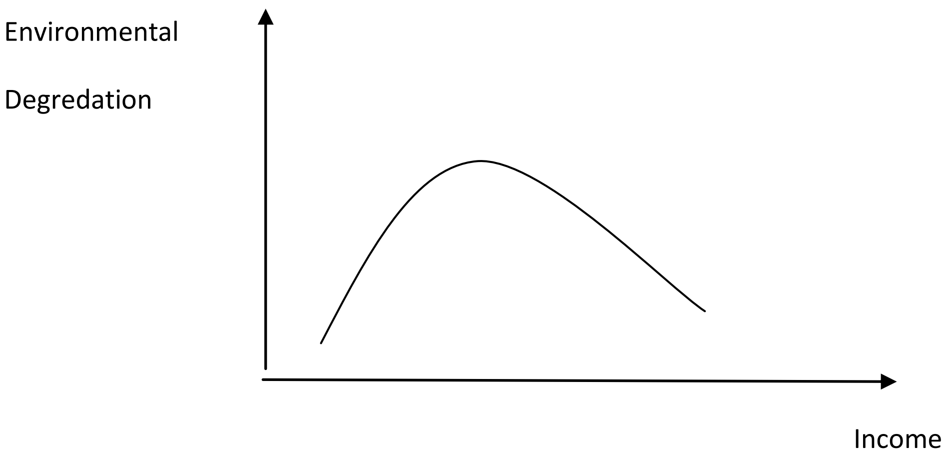

Figure 1: Environmental Kuznets Curve

Source: Panayotou, 1993.

The EKC hypothesis assumes emissions as a function of income which indicates unidirectional causility running from income to GHG emissions (Acaravci and Ozturk, 2010). The EKC states that pollution level increases as a country develops, but begin to decrease as rising income pass beyond a turning point. In other words, environmetal quality will get worse first and than improve with the economic growth (Bo, 2011).

The EKC concept first emerged in 1991 with the Grossman and Krueger’s pioneer study of potential impacts of North American Free Trade Agreement (NAFTA). First bunch of EKC studies use basic EKC models relating environmental impacts to income without explanatory variables have been estimated. Grossman and Krueger (1991), Grossman and Krueger (1995), Shafik and Bandyopadhyay (1992), Beckerman (1992), Panayotou (1993), Holtz-Eakin and Selden (1995), Shafik (1994), Selden and Song (1994), Moomoaw and Unruh (1997), Schmalensee et al (1998), Heil and Selden (2001) test the economic growth and environmental pollution relationship and EKC hypothesis. Stern (2004), Dinda (2004), Lieb (2003), Bo (2011), provide review survey of emprical EKC studies.

The second bunch of the EKC studies concentrates on energy consumption and economic growth relationship. The main argument of these studies is that economic growth and output is closely related to growth in energy consumption becasue the more enegy is used, the higher the economic development. These studies test the causal relationship between output and energy consumption and intensively uses time series models such as causality (Granger, Toda Yomomota, Dolado-lutkepol), Vector Error Correction Model (VECM), Vector Autoregresive Model (VAR), ARDL bound test etc. Paper by Kraft and Kraft (1978) found the unidirectional causality from GNP growth to energy consumption in USA for 1947-1974 period. A number of emprical works tested the relationship between energy and economic development (See Akarca and Long(1980), Yu and Choi (1985), Erol and Yu (1987), Yu and Jin (1982), Masih and Masih(1996), Hondroyiannis et al.(2002), Soytas and Sari(2003), Lee and Lee (2010) etc .Payne(2010), provides an extensive review of the studies on the emprical results of energy consumption and economic growth relationship.

The third bunch of the EKC studies combines the time series and panel data analysis (Granger causality and cointegration model which are widely used for energy consumption and economic growth studies) to investigate the dynamic relationship between economic growth, environment, pollution and energy consumption. The studies of Richmond and Kaufman (2007), Ang (2007), Zhang and Cheng (2009), Halıcıoğlu (2009), Apergis and Payne (2009), Soytas and Sari (2007), Akbostancı et al. (2009), Acaravci and Ozturk (2010), Pa and Tsai (2011) focus on economic growth, energy consumption and pollution relationship.

According to the International Energy Outlook (2011), renewables are the fastest growing source of world energy and the share of the renewables in total energy use increases from 10 % in 2008 to 14 % in 2035 (EIA, 2011). In many countries, considerable attention has been focused on renewable energy because of the concerns over the volatility of oil prices, the dependency on foreign energy sources (energy security problem) and environmental consequences of GHGs. To develop the renewable energy market based and non-market based promotion mechanism for renewables all over the world are ensrured such as feed-in tarif, premium, quota based green certificate, bidding incentives, incentives for investment, tax exemptions and discounts (Deloitte, 2011). Recently, number of energy consumption-economic growth studies focuses on renewable energy consumption. Chien and Hu (2007), Chien and Hu (2008), Sadorsky (2009a), Sadorsky (2009b), Apergis and Payne (2010a), Apergis and Payne (2010b), Apergis and Payne (2011), Mahmodi and Mahmodi (2011) examined the relationship between renewable energy consumption and economic growth.

To our best knowledge, there is no study testing EKC hypothesis that includes the renewable energy consumption as a variable effecting the environment. In research paper of Marrero (2010), however, panel data analysis was conducted for 24 EU countries and it was assumed that impacts of energy consumption on emissions had been dependent on the primary energy mix. But we directly use the renewable energy consumption as an important variable on GHGs. Because it is expected that greater use of renewables in final energy consumption will lower the GHG emissions in the world. In this study, we examine the relationship issue between economic growth, GHG emissions and energy consumption taking into account the renewable energy for EU countries by using panel data analysis. The rest of the paper is organized as follows. In the second section, methodology and data are presented. The third section discusses the empirical results. Final section concludes important results.

2. Methodology and data

Annual time series data for EU countries were taken from the World Development Indicators (WDI) online database for 16 European countries. The date period have not varied for 16 EU countries but some countries (Bulgaria, Czech Republic, Estonia, Ireland, Latvia, Lithuania, Romania, Slovakia, Slovenia) were excluded from data set because their greenhouse emissions data had not been available since 1990. The countries we have taken into analysis and some descriptive statistics of the variables for them can be seen in Table-1.

[Table-1 about here]

To test the EKC hypothesis we investigate the relationship between GHG emissions per capita, energy consumption per capita, renewable energy consumption per capita, and reel Gross Domestic Product (GDP) per capita.

We employed the following equation:

$$CO2_{it} = \alpha + \beta_1 \, GDPPC_{it} + \beta_1 \, GDPPC2_{it} + \beta_3 \, REN_{it} + \beta_4 \, FOSS_{it} + \varepsilon_{it} \qquad \text{(Eq.1).}$$

t= 1990,1992,…,2008, i=1,2,…,16.

Where CO2 is CO_2 gases emissions per capita (measured in metric tons per capita), GDPPC is per capita Gross Domestic Product (at constant 2000 USD Dollar), GDPPC2 is square of per capita real GDP, REN is the energy consumption quantity (measured in kt of oil equivalent) per capita, FOSS is fossil fuel energy consumption per capita (measured in kt of oil equivalent) and ε is the error term. Moreover, i is the subscript of countries and t is the subscript of time dimension.

Since economic development is closely related to energy utilization we expect the multicollinearity among independent variables. To solve this problem, we used centered values of the independent variables. That is, we got the independent variables GDPPC-mean (GDPPC), REN-mean (REN) and FOSS-mean (FOSS) for each country. After centering, we took the variable GDPPC2 as the square of the centered GDPPC in the model. To check the multicollinearity, we got correlations for the variables, variance inflation factors (VIF) and coefficients of determinations after running fixed effect regression for centered and original values of the independent variables. In Table-2, R^2 is the coefficient of determination for the general regression, that is, when the dependent variable CO2 is regressed on all the variables GDPPC, GDPPC2, REN and FOSS. When the dependent variable GDPPC is regressed on GDPPC2, REN and FOSS, we obtained R_1^2; when the dependent variable GDPPC2 is regressed on GDPPC, REN and FOSS, we obtained R_2^2 ; when the dependent variable REN is regressed on GDPPC, GDPPC2 and FOSS, we obtained R_3^2 and finally when the dependent variable FOSS is regressed on GDPPC, GDPPC2 and REN, we obtained R_4^2 . We got the coefficients of determination for centered and original values. As seen in Table-2, without centering, we had seriously multicollinearity problem. Correlation matrix had high correlations, VIF were very high and $R_1^2 > R^2$. But, after centering, correlations and VIF values became smaller as acceptable and R^2 was higher than the other coefficients of determination R_1^2 , R_2^2 , R_3^2 and R_4^2 As a result of this diagnostics, we used centered values of the independent variables in the model.

[Table-2 about here]

The expected sign of the fossil energy consumption is positive because a higher level of energy consumption should result in greater economic activity and stimulate CO_2 emissions. The expected sign of the renewable energy consumption is also positive because a higher level of greater economic activity and stimulate CO_2 emissions. But consumption of renewable energy should stimulate emissions at lower level than fossil fuels. Under the EKC hypothesis the sign of GDP per capita and GDP per capita square are expected to positive and negative, respectively to reflect the inverted U-shape pattern.

3. Empirical Findings

The annual data of the period between 1990-2008 for 16 EU countries was used to estimate Equation 1. This study utilizes panel fixed effect analysis to examine the relationship between greenhouse gases, energy consumption and GDP. Panel data methods increase the power of empirical analysis since it combines information from both the time and cross-section dimension and allow the researcher great flexibility in modeling differences in behavior across individuals (Greene, 2010, p.345).

There are three models that are used for analysis of panel data. The first model is to simply combine or pool all the time series and cross section data an estimates the model using OLS (pooled least squares). The intercept term is assumed to be common (Paul, 2011).

$$\alpha_{it=}\alpha \qquad \text{(Eq.2).}$$

The difficulty of pooled least square is it's assumption of constant intercept and slope is unreasonable. The fixed effects model is estimated to allow for different intercepts for different cross section units, hence:

$$\alpha_{it=}\alpha_i \quad \text{where } E(\alpha_i\varepsilon_{it}) \neq 0 \qquad \text{(Eq.3)}$$

But the random effect model treats intercept as random variable across pooled member countries so that:

$$\alpha_{it=}\alpha+u_i \quad \text{where } E(u_i\varepsilon_{it}) = 0 \qquad \text{(Eq.4)}$$

Our problem is that we could not estimate random effect model as it requires the number of cross-sections to be greater than the number of repressors. In order to test which model is better between pooled and fixed effect model, we conduct the following F-test, where the null and alternative hypothesis are:

$$H_0 = \alpha_{it=}\alpha$$

$$H_A = \alpha_{it=}\alpha_i .$$

According to F test, we got test statistic $F_{15, 284}$=950.51 and Prob>F=0.000. As a result of this test, we concluded that the fixed effects model is better than the pooled model for our data set. After F test, we performed Hausman test to decide to which fixed or random effects we should use for the data set. As a result of Hausman test, we concluded that the fixed effects (FE) estimation is necessary for the data. Hausman test results can be seen in Table-3.

[Table-3 about here]

We run FE panel estimation and then checked out the presence of cross-sectional dependency, heteroskedasticity and autocorrelation problems. Testing for cross-sectional dependency, we performed Pesaran's test of cross-sectional independence and got test statistic 3.488 and P-value=0.000 so, our data set is cross-sectional dependent. And also, we performed modified Wald test for groupwise heteroskedasticity in fixed effects regression models and got Chi2(16)=4763.83 and Prob>Chi2=0.000 and rejected the null of constant variance. Lastly, we performed Wooldridge test for autocorrelation in panel data and got $F_{1, 15}$=21.267 and Prob>F=0.000 and rejected the null of no first-order autocorrelation. As a result of this diagnostics, our fixed effect model is cross-sectional dependent, heteroskedastic and first-order autocorrelated. Because of this results, we used fixed effects estimator with Driscoll and Kraay standard errors to estimate Eq.1(Hoechle, 2007). The panel results are given in Table-4.

[Table-4 about here]

The estimated regressions of the CO2s functions appear to fit the data well with more than 85 of the variation in CO2s explained by the model. All the coefficients are statistically significant at 5% level of significance, except for constant term. All country constants (intercepts) have positive values and they are significant. The statistical significance of the square of per capita real income rules out the suggestion in which output raises monotonically with the level of CO_2 emissions. But the results do not seem to provide support for the EKC hypothesis that the level of environmental pollution initially increases with the income until it reaches its stabilization point than decreases. However our results show that inverted-U shape is not available for EU countries. In other words, first environment pollution decreases with the income than increases.

The coefficients of fossil energy and renewable energy consumption are also statistically significant at 5% significance level and they have the expected signs. Estimated coefficients states that pollution increases with the both fossil and renewable energy consumption. As expected, fossil fuel consumption leads more increase in pollution level than the renewable energy consumption. Renewable energy consumption contributes less around 1/2 than fossil energy consumption to CO_2 emissions in EU counties.

EKC hypothesis has been studied empirically in many studies. Most of these studies have used the cross-sectional data. The empirical evidence for the existence of an EKC can be found in various papers: de Bruyn et al (1998), Holtz-eakin and Seldan (1995), Moomaw and Unruh (1997), Pao and Tsai (2011), Markandya et al (2006), Auci and Travato (2011), Saatci and Dumrul (2012), Lee at al.(2009), Hammit-Haggar(2012). Results of many research, however, concluded that there is no EKC relationship: Grossman and Kruger (1991), Grossman and Kruger (1995), Bengochea-Morancho et al (2001), Huang et al, (2008), Marrero (2010), Poudal et al.(2009), Friedl and Getzner (2002), Mazzanti and Zoboli (2009), Akbostancı et al.(2009), Roca et al (2001). Our results in the line with the second group findigs. Therefore, empirical evidence for the existence of EKC is not conclusive.

4. Conclusion

This paper has proposed and estimated a panel model for EU-16 for 1990-2008 period, which relates greenhouse emissions (CO_2) per capita with real GDP per capita and aggregate energy consumption. The availability of emissions data for 1990-2008 period is a limitation of this paper. However, in spite of limited data, we can still provide an initial inference on the validity of EKC hypothesis. This paper's main contribution is, EKC hypothesis has been investigated by separating the renewable and fossil fuel energy consumption.

The main findings of this paper are summarized as follows. Our results indicate that between 1990-2008, there is no evidence in favor of existence of EKC (inverted-U) among the EU countries. It is surprising to see that EU countries, having ambitious renewable energy targets (Kyoto commitment and EU 20/20/20 targets) do not have EKC hypothesis. On the contrary we found the existence of a U shaped relationship in Europe between emissions and real GDP. And, the actual emissions reduction efforts were not improved by the regulations in EU countries.

Second important finding is renewable energy consumption contributes less around 1/2 than fossil energy consumption to GHG emissions in EU counties. This implies that a much more improvements in efficiency and/or a shift in the energy mix towards less polluting energies (renewable energy technologies) are very important to achieve the environmental targets. Our findings also highlight that regulations to support renewable sources would yield significant reductions in per capita emissions. This result of our research ensures important information for policy makers in both EU and world.

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Apendix

Results of Analysisis

Table-1: Descriptive statistics of the variables for Countries

		Mean	Median	St. Deviation	Min.	Max.
	CO2	10.94	11.15	0.64	9.65	11.78
BELGIUM	GDPPC	21,775.06	21,946.73	2,197.69	18,738.03	25,100.47
	REN	115.54	99.15	43.95	74.67	221.06
	FOSS	5,312.56	5,342.52	261.20	4,768.49	5,606.41
	CO2	10.17	10.01	1.21	8.38	13.05
DENMARK	GDPPC	28,576.35	29,055.27	2,888.69	24,097.91	32,767.40
	REN	354.33	313.48	107.30	221.68	547.03
	FOSS	3,300.08	3,289.22	222.69	2,950.95	3,879.93
	CO2	10.58	10.39	0.73	9.57	12.01
GERMANY	GDPPC	22,350.24	22,295.10	1,721.39	19,600.84	25,620.08
	REN	116.57	93.23	68.03	59.83	278.15
	FOSS	4,047.13	4,030.66	139.92	3,757.54	4,363.52
	CO2	8.03	8.10	0.70	6.59	8.89
GREECE	GDPPC	11,570.97	10,942.83	1,844.94	9,635.29	14,728.86
	REN	90.79	89.61	4.08	87.45	105.53
	FOSS	2,312.63	2,276.42	249.25	2,000.92	2,632.66
	CO2	7.00	7.07	0.77	5.79	8.14
SPAIN	GDPPC	13,746.97	13,836.70	1,824.47	11,335.55	16,351.11
	REN	103.95	102.04	10.91	89.86	126.19
	FOSS	2,725.31	2,809.57	341.50	2,214.15	3,149.95
	CO2	6.38	6.23	0.39	5.85	7.30
FRANCE	GDPPC	20,973.73	21,146.40	1,717.02	18,731.66	23,516.22
	REN	192.49	188.51	14.00	173.29	226.99
	FOSS	3,916.38	3,939.51	143.33	3,652.17	4,116.01
	CO2	5.77	5.74	0.20	5.44	6.12
HUNGARY	GDPPC	4,627.83	4,358.70	803.16	3,707.13	5,947.16
	REN	86.15	75.89	24.23	63.27	151.79
	FOSS	2,476.74	2,451.81	93.79	2,338.31	2,699.15
	CO2	7.72	7.70	0.24	7.25	8.13
ITALY	GDPPC	18,612.43	18,713.35	1,296.47	16,610.79	20,291.23
	REN	43.32	38.20	23.64	16.59	89.30
	FOSS	2,842.26	2,880.02	178.86	2,554.48	3,066.16
	CO2	22.57	21.96	3.57	17.32	30.10
LUXEMBOURG	GDPPC	43,684.26	43,420.31	7,817.49	32,476.86	56,388.99
	REN	115.93	101.53	50.74	59.66	246.06
	FOSS	8,318.01	8,356.11	803.50	6,968.41	9,351.93
	CO2	10.91	10.87	0.48	10.21	12.00

NETHERLANDS	GDPPC	22,814.90	23,429.80	2,763.88	18,858.00	27,348.47
	REN	109.83	104.67	40.15	63.77	191.53
	FOSS	4,542.39	4,534.48	108.87	4,329.44	4,720.49
	CO2	8.06	7.94	0.52	7.26	9.04
AUSTRIA	GDPPC	22,921.55	23,181.69	2,635.17	19,192.07	27,295.13
	REN	423.19	391.12	96.35	322.72	663.20
	FOSS	3,221.72	3,174.92	242.48	2,880.72	3,606.99
	CO2	8.56	8.37	0.61	7.77	9.62
POLAND	GDPPC	4,247.74	4,249.28	1,037.52	2,872.97	6,235.76
	REN	109.21	116.16	26.30	54.17	153.58
	FOSS	2,398.31	2,402.80	134.46	2,208.04	2,646.90
	CO2	5.53	5.58	0.60	4.38	6.44
PORTUGAL	GDPPC	10,614.95	11,097.16	1,160.40	8,771.93	11,966.00
	REN	264.36	260.00	18.30	244.15	300.38
	FOSS	1,907.19	2,004.03	281.04	1,428.69	2,227.68
	CO2	11.21	10.95	1.00	9.74	13.21
FINLAND	GDPPC	22,594.13	22,386.63	3,763.67	17,643.55	28,839.22
	REN	1,177.17	1,217.23	227.43	810.68	1,475.93
	FOSS	5,120.51	5,103.58	326.27	4,570.32	5,671.95
	CO2	6.02	6.07	0.43	5.25	6.85
SWEDEN	GDPPC	26,980.61	26,724.35	3,808.87	22,065.24	33,259.26
	REN	865.81	866.70	129.83	643.34	1,079.09
	FOSS	4,744.30	4,813.58	208.54	4,302.70	4,982.08
	CO2	9.41	9.31	0.51	8.52	10.34
UK	GDPPC	24,051.33	24,098.55	3,814.82	19,008.94	29,627.91
	REN	38.17	30.42	20.19	10.96	77.14
	FOSS	3,656.75	3,694.07	129.25	3,313.17	3,850.64
	CO2	9.30	8.51	4.06	4.38	30.10
TOTAL	GDPPC	20,008.94	20,317.72	9,886.25	2,872.97	56,388.99
	REN	262.93	117.66	319.96	10.96	1,475.93
	FOSS	3,802.64	3,548.13	1,572.52	1,428.69	9,351.93

Table 2: Multicolinearity analysis of the independent variables

Without centering

Correlation matrix					VIF	Coefficients of determination
	GDPPC	GDPPC2	REN	FOSS		R^2=0.98
GDPPC	1				148.17	R_1^2=0.99
GDPPC2	0.9376	1			62.23	R_2^2=0.98
REN	0.2508	0.1609	1		34.07	R_3^2=0.97
FOSS	0.8030	0.7988	0.2198	1	32.98	R_4^2=0.97

With centering

Correlation matrix					VIF	Coefficients of determination
	GDPPC	GDPPC2	REN	FOSS		R^2=0.99
GDPPC	1				1.79	R_1^2=0.44
GDPPC2	0.1296	1			2.31	R_2^2=0.57
REN	0.6568	0.1136	1		1.77	R_3^2=0.43
FOSS	0.1758	0.1881	0.1530	1	1.10	R_4^2=0.09

Table-3: Hausman Test

```
---- Coefficients ----
|     (b)        (B)            (b-B)       sqrt(diag(V_b-V_B))
|    fixed      random      Difference          S.E.
-------------+----------------------------------------------------------------
GDPPC  |   -.0001698    -.0001701       2.69e-07        4.69e-08
GDPPC2        |   1.53e-08    1.59e-08       -5.80e-10       1.01e-10
REN      |   .0014468     .0014415        5.36e-06        9.33e-07
FOSS     |   .0031594     .0031529        6.42e-06        1.12e-06
------------------------------------------------------------------------------
b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test:  Ho:  difference in coefficients not systematic

chi2(1) = (b-B)'[(V_b-V_B)^(-1)](b-B)
=  32.96
Prob>chi2 = 0.0000
```

Table-4: Panel results for CO2

	Coef.	Drisc/Kraay Std. Err.	P-value
Cons.	9.166838 **	0.0402996	0.000
GDPPC	-0.0001698 **	0.0000243	0.000
GDPPC2	1.53e-08 **	2.49E-09	0.000
REN	0.0014468 *	0.0005974	0.026
FOSS	0.0031594 **	0.0001514	0.000
N	304		
F(4, 18)	141.62		
Prob>F	0.000		
Within R-squared	0.8569		

**: significant at the .01 level, *: significant at the .05 level.

Towards sustainable product development: An environmental and economic study

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Abstract

The LCA/LCC integrated methodology was applied in a "cradle-to-grave" assessment of a specific engineering product. This product is a lighting column for roadway illumination made in three alternative materials: a glass fibre reinforced polymer matrix composite, a natural fibre reinforced polymer matrix composite and steel. The life cycle total costs and environmental performance results make clear the win-win situations and trade-offs involved in these systems. The *Fossil fuels* and *Respiratory inorganics* impact categories, as well as the total economic impacts of both composite lighting columns represent a win-win situation relatively to the steel system. However, with *Land use* and *Climate change* categories and the economic impacts there is a trade-off situation. Although the three systems present very similar internal costs, the steel column has higher external costs in the use phase that contribute for its higher total cost. The analysis of the dependence of the LCC results on the fluctuations of crude oil price show that the conclusions do not change with the latter. The present work constitutes a contribution to demonstrate that LCA/LCC integrated studies can help develop more sustainable products from an environmental and societal perspective.

Keywords: Life Cycle Thinking; Life Cycle Assessment; Life Cycle Costing; Product development; Crude oil price; Composite material price; Metal price

JEL classification codes: L74 – Construction; Q01 - Sustainable Development; Q55 - Technological Innovation; Q56 - Environment and Development; Environment and Trade; Sustainability

1. Introduction

The consideration of a sustainable product involves the analysis of inherent environmental, economic and social aspects: This approach is known as the three pillar model (Klöpffer 2008). These three pillars have to be properly assessed and balanced if a new product is to be developed or an existing one is to be improved, in order to achieve sustainability (Klöpffer 2003; Klöpffer 2008). Lately, several methodologies have been proposed in various studies (Bovea and Vidal 2004; Rebitzer et al. 2003; Rüdenauer et al. 2005; Simões et al. 2012a), showing that only a systemic approach allows addressing the conflicting trade-offs that emerge in these assessments (Klöpffer 2003; Klöpffer 2008; Norris 2001; Zamagni 2012).

Life Cycle Assessment (LCA) (ISO 2006a; ISO 2006b) and Life Cycle Costing (LCC) (Ciroth et al. 2008; Swarr et al. 2011) belong to the group of sustainability tools that take into account the full life cycle (LC) from raw material extraction, production to use and final disposal. The LCA methodology allows understanding all relevant processes and environmental impacts involved in the LC of products (Bauman and Tillman 2004). The LCC methodology is the equivalent of LCA for economic assessment (Hunkeler and Rebitzer 2003). The LCC methodology accounts for all costs associated to a product that are directly covered by one, or more, of the players involved in its LC (supplier, producer, user or costumer, and/or final disposer) and includes the externalities that are anticipated to be internalized in the decision-relevant future.

On the other hand, crude oil is a major economic and environmental risk factor in production cost control, due to high price volatility. In fact, crude oil strongly affects the raw materials price (Asche et al. 2003; Gjolberg and Johnsen 1999; Masih et al. 2010; Weinhagen 2006). Also, raw material production cost is the main contributor to the LC total cost, followed by the product manufacturing cost (Castella et al. 2009; Simões et al. 2012a; Simões et al. 2013). This is largely related to the internal costs of raw materials production. It is, therefore, important to relate crude oil price with raw materials price, in order to analyse the sensitivity of the choice of materials to fluctuations in crude oil price. Further, it is also important to be able to predict future crude oil prices, to have an idea, albeit of a probabilistic nature, how the conclusions obtained will propagate into the future.

In this context, the present work aims at assessing the environmental performance and all costs involved in the full LC of a specific engineering product. This product is a lighting column for roadway illumination, which can be made in two different materials: a glass fibre reinforced polymer matrix composite (CLC) and steel (SLC). An alternative composite lighting column with the same matrix, but reinforced with natural jute fibres (NCLC) was also analysed for comparison. The alternative NCLC was designed to achieve a technical performance similar to that of the CLC, assuming equivalent fibre volume fraction and bending stiffness (Simões et al. 2012b). The relationship between crude oil and raw materials prices, and the dependence of the LCC results obtained on crude oil price fluctuations was also investigated.

2. Methodology

The LCA/LCC integrated framework adopted, which includes all stages of a product's life (Simões et al. 2012a), consists in a parallel assessment, using the LCA methodology according to the ISO 14040 series (ISO 2006a; ISO 2006b), and the LCC methodology based on the SETAC guidelines (Ciroth et al. 2008; Swarr et al. 2011). The LCA/LCC model consists in implementing the LCA methodology to the product system and, in parallel, incorporating its results into the LCC study, namely the Life cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) results. Globally, the LCA/LCC integrated results are "portfolio presentations" of the LC cost, combined with the key environmental LC impacts. The long-term relationship between crude oil and raw materials prices was studied using econometric models that allow understanding the dependence of LCC results on future fluctuations of crude oil price.

3. Results

3.1. Life Cycle Assessment

The study considered as functional unit a lighting column for roadway illumination that meets the requirements of EN 40 series (EN 2004), 8 meters height and with a lifespan of 30 years. The system boundary encompasses the following LC stages: raw materials production, column production, on-site installation, use and maintenance, dismantlement and End-of-life (EoL).

The CLC, made of unsaturated polyester and E-glass fibres, is produced by vacuum infusion and weights 60 kg. The NCLC, made of unsaturated polyester and natural jute fibres, was assumed to be also produced by vacuum infusion, to weight 84 kg. It is assumed that at their EoL, both types of CLC are sent to incineration with energy recovery facilities. The SLC, made of galvanized steel, is produced by cold rolling and hot-dip galvanization, and weights 109 kg. At EoL, SLC are sent to recycling facilities. One important difference between these systems is that the SLC needs maintenance after 20 years of use due to metal corrosion (to be recoated with paint), attaining a 30 years lifespan. On the other hand, the CLC and NCLC have no maintenance during the use phase. In order to compare the lighting columns, the CLC and NCLC lifespans were defined as equal to that of the steel column.

The Eco-Indicator 99 (EI99) (Goedkoop and Spriensma 2001) was selected as LCIA method, due to the impact categories that it considers, namely *Fossil fuels*. The *Fossil fuels* environmental impact category is considered by the authors as being of great relevance for the plastic industry, as oil is the main raw material used in that industry (Simões et al. 2011). Figure 1 presents the LCIA characterization results of the full LC of the three lighting column systems, on a functional unit basis. The SLC system depicts the worst environmental profile, with a higher impact in all categories, except *Carcinogens*, *Climate change*, *Land use* and *Minerals*. The CLC system only has the worst environmental performance regarding *Carcinogens* and *Minerals*, while in the NCLC system this corresponds to *Climate change* and *Land use* categories.

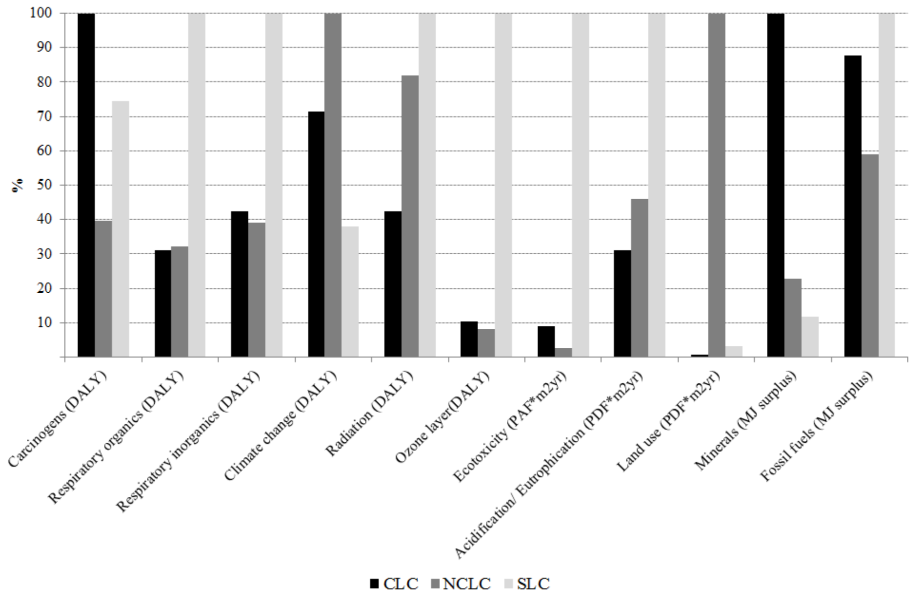

Figure 1 – LCIA characterization results of the lighting column systems. DALY: Disability Adjusted Life Years (years of disabled living or years of life lost due to the impacts); PAF: Potentially Affected Fraction (animals affected by the impacts); PDF: Potentially Disappeared Fraction (plant species that disappear as result of the impacts); MJ surplus: Surplus Energy (MJ) (extra energy that future generations must use to extract scarce resources)

Figure 2 presents the LCIA normalization results of the full LC of the three lighting column systems, on a functional unit basis. The *Respiratory inorganics* and *Fossil fuels* categories are the most significant environmental burdens of all systems. The SLC is the worst performer in these categories. The NCLC also shows a significant environmental impact in the *Land use* category, since natural fibres use land extensively for crop cultivation that stays temporary unavailable for other purposes. The lighting column manufacture phase was found to be responsible for most of the impacts in all systems, with the production of the raw material being the largest contributor for that phase.

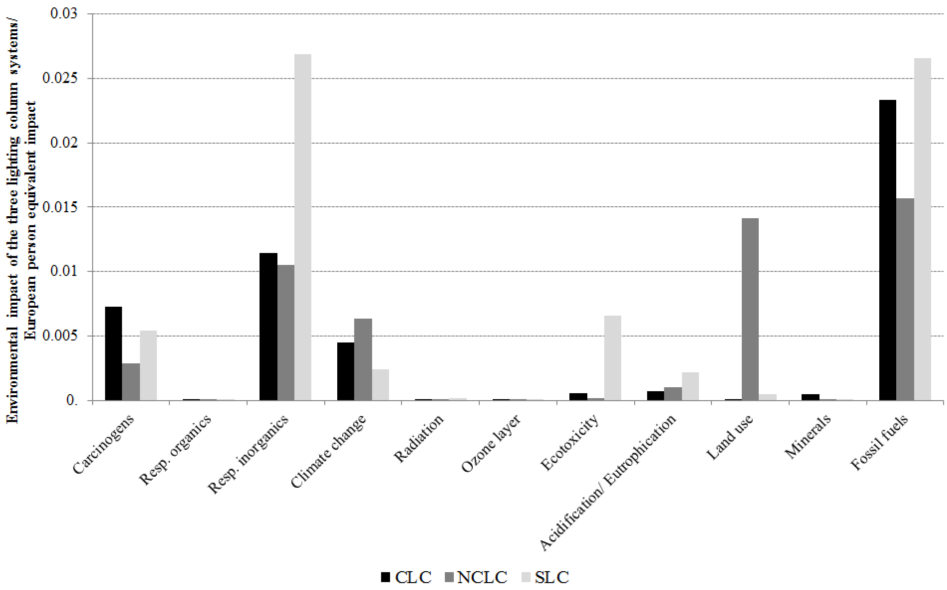

Figure 2 – LCIA normalization results of the lighting column systems

Although glass fibre polymer composites are produced through a more energy intensive process than steel, the SLC has a worst performance regarding *Fossil fuels* consumption. This is due to the higher amount of steel needed to fabricate the column and corresponding higher transport load, and also due to the need of maintenance in the use and maintenance stage. Even though the NCLC is heavier than the CLC, due to a higher thickness necessary to achieve an identical bending stiffness, the jute fibre composite still uses less 32% *Fossil fuels* than the glass fibre one, contributing to its good performance. It is also interesting to note that the *Climate change* category is higher in the case of the NCLC than in the CLC, even though the natural fibres are carbon neutral. As the NCLC is thicker and uses more polyester resin, its EoL contributes 68% to this category while that of the CLC contributes only 51%.

3.2. Life Cycle Costing

All economic aspects considered in this study were identified and quantified, taking in consideration that a LCC accounts for all conventional costs plus the environmental and societal costs (Ciroth et al. 2008). The LCC reference year chosen was 2010 and the discount rate used 3.5%. The jute fibre cost was assumed to be 7.5 times less than that of the E-glass fibre (Alves 2010). Costs of CO_2 eq. emissions were accounted for, based on the carbon tax established by the EU ETS (Point Carbon 2011). The damage costs corresponding to the emissions of SO_2, NOx and fine particles were accounted for, based on the ExternE project as adapted by NETCEN (Watkiss and Holland 2000). The damage costs of a reduced mortality risk were also accounted in this study. The value of statistical life (VSL) monetizes the benefits of that risk, capturing the value that persons bearing the risk assign to an enhanced safety. The CLC usually score well in passive safety tests (Lightweight Structures B.V. 2010). Many impact tests have shown that these resilient and tough columns increase traffic safety. In the present case, the risk to life brought in by the features inherent to the SLC was monetised using the VSL for traffic accidents of Carlsson et al. (2010).

Figure 3 presents the potential total costs of the three column systems, on a functional unit basis. Due to confidentiality issues, the results are reported as “monetary units”. The systems present very similar internal costs, although the SLC potential internal LC cost is 3% and 11% above those of the CLC and NCLC, respectively. This is due, in part, to the SLC internal costs during the use and maintenance stages, which represent about 8% of the total internal costs. The higher internal costs of the CLC in the production phase are compensated by the absence of maintenance in the use and maintenance phase. The SLC has higher potential external costs, 97% above those of the CLC and NCLC. The use and maintenance phase of the steel column is the main contributor for these costs. All lighting columns present small external costs related to emissions damage (CO_2 eq., SO_2, NOx and particles). Notwithstanding, the SLC has a very high cost associated to the safety features, since it presents a higher risk to the life of individuals. The potential total costs of the SLC are the highest, almost 40% and 45% above those of the CLC and NCLC, respectively. Although the glass fibres are 7.5 times more expensive than natural fibres, the potential total cost of the NCLC is only 9% lower than that of the CLC, due to the higher amount of polyester resin it uses.

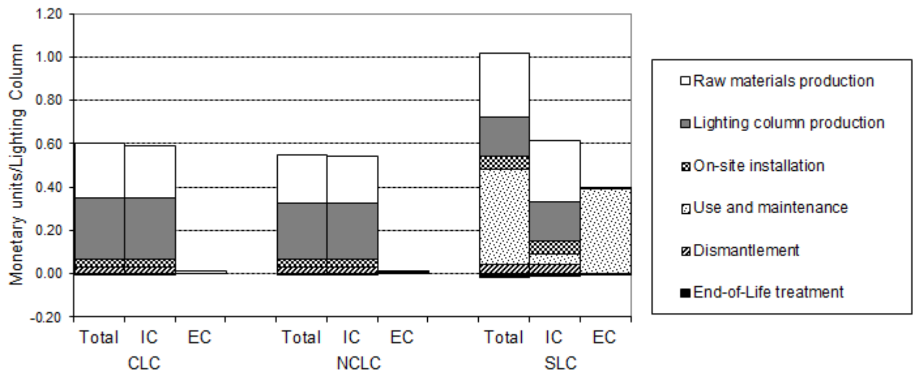

Figure 3 – Internal (IC), external (EC) and total costs of the three lighting column systems

3.3. LCA/LCC

In order to perform an integrated LCA/LCC study, the *Fossil fuels*, *Respiratory inorganics*, *Land use* and *Climate change* environmental impact categories were selected as the key environmental impact indicators. This was done on the basis of the LCIA normalization results that show the significance of each environmental impact in terms of scale of contribution. The LC cumulative total costs (internal plus external costs) are analysed in combination with the characterization results of *Fossil fuels*, *Respiratory inorganics*, *Land use* and *Climate change* environmental impact categories in Figure 4, on a functional unit basis.

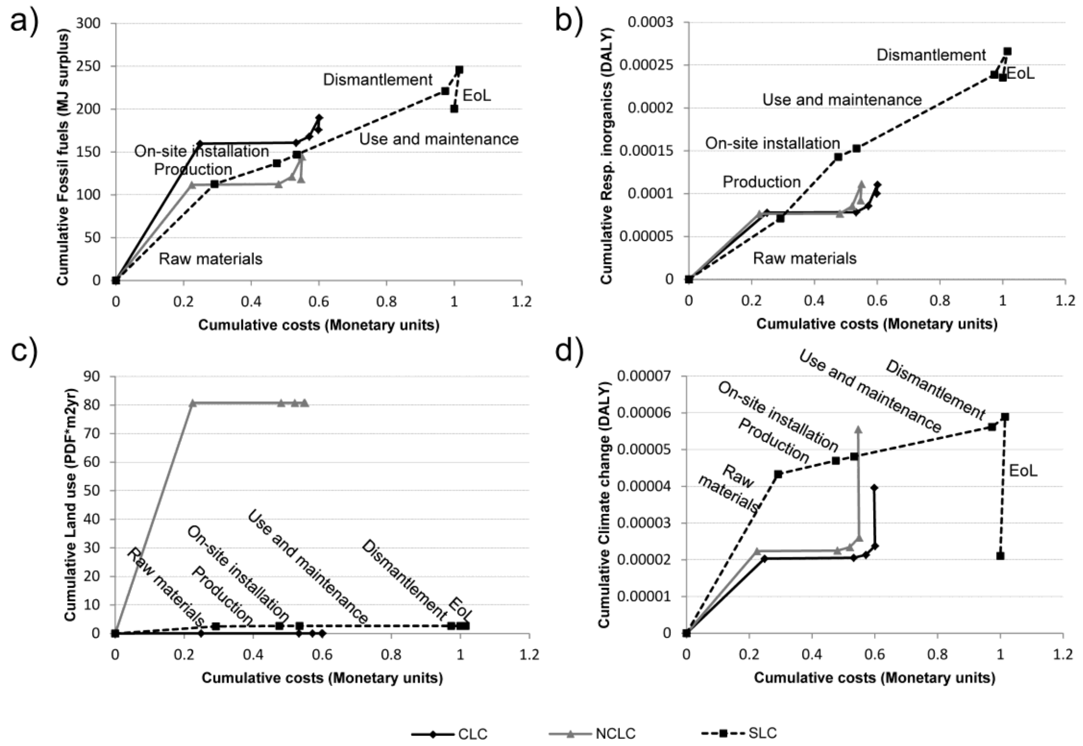

Figure 4 – Cumulative total costs versus Fossil fuels (a), Respiratory inorganics (b), Land use (c) and Climate change (d) environmental impact categories for all lighting column systems

In Figure 4 each line is constituted by segments that correspond to the sequential lighting columns LC stages. It can be concluded that the raw material production costs are very similar for all column systems, while the *Fossil fuels*, *Land use* and *Climate change* environmental impact of this phase is quite higher for the CLC, NCLC and SLC, respectively. On the other hand, the *Respiratory inorganics* environmental impact of this phase is very similar for all column systems. The CLC and NCLC present similar LC total costs. The potential total cost and *Fossil fuels* and *Respiratory inorganics* environmental impacts of the SLC are higher than those of the other columns, the use and maintenance phase being significant contributors for this result. The situation persists, even including the revenues and avoided emissions in the EoL phase (metal recycling). This results show that regarding *Fossil fuels* and *Respiratory inorganics* and the economic impacts, both composite lighting columns correspond to a win-win situation (Figure 4a and Figure 4b). However, with *Land use* and *Climate change* and the economic impacts, a trade-off situation occurs (Figure 4c and Figure 4d). In fact the NCLC presents a higher impact in these environmental categories but the potential total cost is lower. The main contributor for the *Land use* environmental impact results is the raw material production of the natural fibres. For both composite columns, the emissions in the EoL phase (incineration with energy recovery) are a significant contributor for the results regarding the *Climate change* environmental impact.

4. Effects of crude oil price in the LCC results

The LCC results show that the raw material production internal cost is the main contributor to the LC total cost, followed by the product manufacturing internal cost. As mentioned before, crude oil is a major economic and environmental risk factor in production cost control, due to high price volatility. It is, therefore, important to analyse the sensitivity of the choice of materials to fluctuations in crude oil price. The long-term relationship between crude oil and raw materials price was studied using econometric models. Only the prices of the more important raw materials were studied, namely UP resin, glass fibre and steel. The analysis was based on monthly price series of Brent and West Texas Intermediate (WTI) crude oil in the period October 1998 to April 2012 (World Bank 2012). The raw materials monthly price series used were: UP resin, in the period of January 2003 to December 2011[1], glass fibre rovings in the period January 2010 to June 2011 (Plastics Information Europe 2011), and steel in the period October 1998 to April 2012 (London Metal Exchange 2011). Crude oil price prediction data is used to obtain a raw materials price prediction. The future WTI crude oil annual price series used was published by the US Energy Information Administration for the period 2012 to 2035 (US Energy Information Administration 2012). To study the relationship between crude oil and raw materials prices, the collected data was, when necessary, adjusted by price level to express all values in Euros 2010. The long-term relationship between crude oil and raw materials prices was based on the Brent blend, since it is generally accepted as the reference price for crude oil trade throughout Northern Europe.

The stationarity of the series was analysed in linear and natural logarithmic (ln) form, using the Augmented Dickey-Fuller test (Dickey and. Fuller 1979), the optimal number of lags being determined through the Akaike Information Criteria (AIC) (Akaike 1981). After determining the autoregressive pattern, the Autoregressive Integrated Moving Average (ARIMA) model was used to predict the future evolution of each raw material price as a function of the Brent future price. These relationships were used to investigate how the fluctuations in crude oil prices influenced the LCC results of the present study. Since there is no information on the influence of crude oil prices on production costs (energy, labour, etc.), the estimation assumes that they vary proportionally to the price of the relevant raw material.

Figure 5 shows the future (up to 2035) total LC costs of the three systems. These results do not contradict the previous conclusions, as the SLC still presents in the long-run a higher total cost than those of its composite counterparts. Indeed, the SLC LC cost increases more rapidly than those of the other systems. In the next 10 years, these results predict around 29%, and 1% LC cost increases for the steel and both composite lighting columns, respectively. In the long-run, both composite lighting columns will be around 70% less expensive than the steel one. Therefore, regarding the economic aspect, the composite material (glass or natural fibre composite) will be the best choice for this application.

[1]Information kindly provided by Dr. Pedro Nunes of the Institute for Polymers and Composites (IPC).

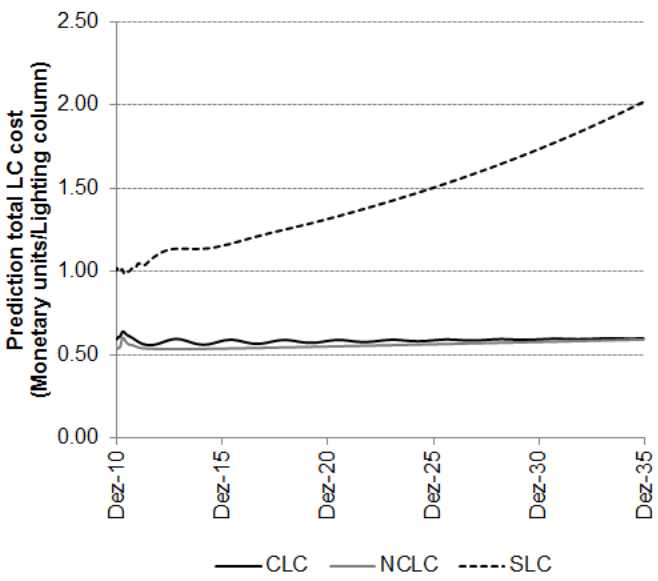

Figure 5 – Prediction of the total LC costs of all lighting column systems

5. Conclusions

The present work allowed a further insight into the environmental performance and full LC costs (internal and external) of lighting columns made with three different materials. The LC total costs and environmental performance (*Fossil fuels*, *Respiratory inorganics*, *Land use* and *Climate change*) results evidence the win-win situations and trade-offs are involved in these systems. Even though the three systems present very similar internal costs, the SLC has higher external costs in the use phase that contribute for its higher total cost. Since the SLC presents a higher risk to life to individuals, it has a very high cost related to safety features. The raw material production phase was found to be responsible for most of the environmental impacts in all systems. The composite lighting columns present zero environmental impacts in the use and maintenance phase, because they do not need maintenance, contrarily to their metal counterpart.

The LCC results showed that raw material production internal cost is the main contributor to the LC total cost of all systems, followed by the product manufacturing internal cost. As the former is highly dependent on the price of crude oil, an analysis of the sensitivity of the choice of materials to its fluctuations was performed. The results show that the conclusions do not change with the predicted future new material prices, as the SLC still presents in the long-run a higher total cost than those made in composite. Therefore, regarding the economic aspect, the composite material (glass or natural fibre composite) will be the best choice for this application.

The present work was able to demonstrate that LCA/LCC studies increases the probability of developing more sustainable products from a societal perspective. Furthermore, the incorporation of external costs in LCA/LCC studies can help to successfully achieve that objective.

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A Macroeconomic Model For An Oil Scarcity Scenario

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1 Abstract

The persistent increases in oil prices over the past decade point to a break with the earliest experiences of the oil price boom of the 1970s, 1980s and 1990s, and suggest that global markets have entered a period of increased scarcity. However, considerable uncertainty exists about the future growth rate in oil demand in emerging markets, as well as in the oil supply downshift trends. In fact, new technology for heavy oil exploitation or shale oil extraction could have a considerable impact on oil supply. In order to study the effects of oil scarcity on the future global economy we have developed and implemented in C++ a non-equilibrium macroeconomic sectorial model, where the energy sector produces (and sells) final energy, and the remaining sectors consume (useful) energy. Each sector is characterised by a CES production function or a CES utility function. It also incorporates specific dynamics dynamics, such as reserve depletion, time-dependent energy efficiencies (which obey thermodynamic limits) in the conversion of final energy to useful energy, investment in extraction technologies on oil, or accumulation of stocks. From the interaction of these sectors we have four markets where energy and goods price as interest rates and wages are calculated. The goal of this paper is to described the model and present some results already got.

Keywords: Growth Theory, Energy, Labour, Capital, CES Production Function
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2 Introduction

In its first version the Solow model - traditionally used to study economic growth - completely ignored natural resources as a factor of production. Only in 1973, in Solow [7] finally recognizes the environmental effects on long-run growth. No wonder that the unexplained "Solow residual" accounted for over more than 85% of the per capita growth in output [10]. But of course, naming a disease is not the same as explaining it [6]. The mechanism of the Solow model - the capital' s diminishing marginal returns - also emphasizes the convergence amongst economic nations. However according to econometric evidence, convergence clubs apparently only exist at both ends of the economic spectrum, but rich and poor clubs are polarized diverging from each other [6]. Indeed, today physical capital has been pushed to periphery [2]. Catch-up growth is now associated with the dynamics of non-rivalry ideas [2]. However, while neighborhood effects may have a positive influence on growth, poor education endowment [1] and the hardness of tacit knowledge transfer are according to other authors [4] the causes of divergence amongst nations. Still, for [4] the economic complexity - which reflects the connectivity structure of human networks characterized by the clustering coefficient and characteristic path lenght parameters [8]- is the driver of economic growth as it reflects the structure that holds and combines knowledge.
On the other hand at the time scale of centuries, the link between economic growth and the transitions that occur in energy systems, triggered by technology, is obvious [9]. Technological change, particularly at the end use, [12] drove the emergence of the steam power relying on coal and the displacement of the dominating coal-based steam technology cluster by the electricity and petroleum -based technology, shaping the structure of the global energy system. For [9] the most important transition in global energy systems is that of increasing energy quality and energy productivity - i.e the energy return on investments (EROI) - correlated with energy efficiency. However, according to [5] nowadays EROI's declining is threatening not just growth but also the level of global GDP and sustainability. Indeed, last century, energy intensity declined by 0.68% per year, while global energy use has grown by a factor of more than 20 over the past 200 years. As a result, the global size of social metabolism - i.e. wastes and emissions - increased several times [3]. Accurately for [10], the driver of growth is not energy (exergy) consumption as such, but exergy converted to "useful work" in economy . In order to overpass the limitations of the economic growth theory mentioned above, i.e the omission of the essential role of energy in the economy, we developped a macroeconomic model of where energy is modelled as a production factor. In section 3 we shall describe the main components of this model and the goals

we intend to reach with it. In 3.1, 3.2, 3.3 subsections the three sectors of the model are described and in subsections 3.4, 3.5, 3.6, 3.7 the four markets. The main results are in section 4, and some conclusions in section 5.

3 The Macroeconomic Model

This macroeconomic model intends to coordinate three economic sectors (i.e non-energy, households, energy) in order to solve four markets (i.e labor, money, goods and energy). All these markets are the result of the interaction of at least two of the three previous sectors (see Figure. 1).

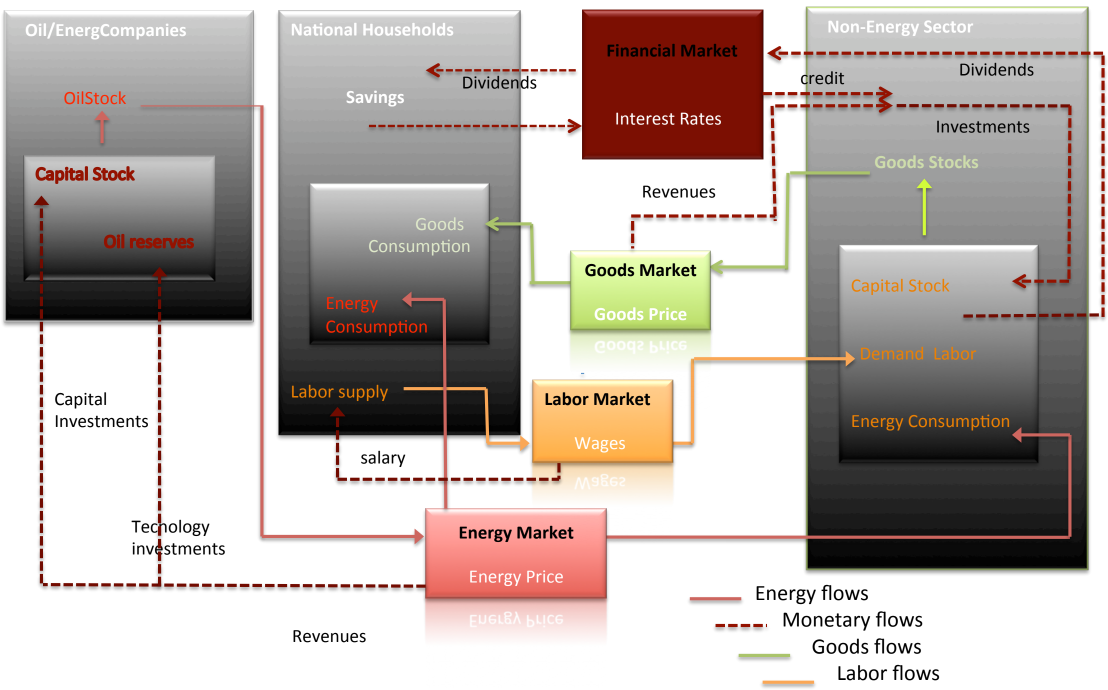

Figure 1: The Macroeconomic Scheme

As illustrated in the figure above we can observe that modelling all these sectors and markets is a complex task due to the number of endogenous variables, feedbacks and precedences and interconnections between this variables . The non-energy sector, which produces an aggregated good, excluding

energy goods, is essentially characterized by the maximization of its profits (objective function) constrained to a CES production function [11] with three factors of production, labour, capital and energy (see equation 2). In this sector we determine goods produced, and labour, capital and energy production needs, as well as the profits and investments of the sector.
The households sector is characterized by a CES utility function that depends on aggregate consumption (energy plus goods) and leisure (see equation 9). Households decide the amount of their savings and their goods and energy consumption in order to maximize their utility. They also determine their labour offer and desirable wages for the future. However, households are constrained by their income and past savings. Their income is the result of payments for the labour used by the non-energy sector (wages) and for their savings invested in the same sector (dividends).
Goods and Labour Markets are the result of the interaction of the two previous sectors, the non energy-sector provides labour's demand and the supply of goods while the households provide demand of goods and labour's supply. The match between demand and supply of goods is accommodated with the stock of goods, and the future price of goods depends on it.
The energy sector determines the supply of energy. The energy production is constrained by the oil reserves, partially controled by the level of technology the level of capital. Oil stocks accommodate the mismatch between energy supply, of the energy sector, and demand, from households and non-energy sector. Oil stocks also are one of most important feedbacks that the oil futures market takes into account in order to calculate oil price.
Finally, the financial sector only receives from the households and from the non-energy sector their respective desired interest rates and calculates the future interest rate.
In sort, this model is a dynamic model, implemented in C++, and characterized by a periodic output, of several endogenous variables. Each variable is allocated to one of the three sectors and has several other parameters (see table 6, table 7,table 8, table 9) as initial conditions (see table 1, table 2, table 3 , table 4, table 5). In order to better understand its goals, explain its dynamic forces and expose its mechanisms we shall better characterized each one of its sectors, markets, and the respective endogenous variables.

3.1 The Non-Energy sector

The Non-Energy sector tries to reproduce the aggregate economic behaviour of a non-energy industry that produces an aggregate good. The sector is characterized by a CES production function [11] that depends on the following production factors: labor, energy and capital (see equation 2). Furthermore the price of goods is endogenous, depends on the stocks of goods, and cannot be below the value of the marginal costs of production. The new desired quantity of the goods supply is the optimal quantity that would have maximized the profits in the previous state and is calculated by comparing the marginal benefits of this sector with its marginal costs of production. Each state is charaterized by a certain amount of labor, capital and energy. The amount of goods produced is the desired supply of goods minus the stock. The production dictates the useful energy consumption which given the energy efficiency (which is time dependent and obeys thermodynamic limits) controls the final energy consumption. Profits are obtained after knowing the consumption from households and are equal to revenues (goods consumption times price) minus production costs (capital, labor and energy costs). The variation of goods stocks, that corresponds to the difference between goods production and consumption, establishes a new endogenous price . A lower limit to goods price is established by the marginal costs. New investments are equal to profits plus savings from the households. The capital increases due to investments and is divided between equity and debt capital. The present equity corresponds to the sum of all previous profits and the debt capital corresponds to the sum of all households' savings. Amongst several endogenous variables of this sector, we get as output, for each interaction, the quantity of produced goods, the mean and marginal costs of the respective production function, the profits, investments, the stocks of goods, the labor, the energy consumption and the capital.

3.2 The Households sector

The main purpose of the households sector is consumption. The sector is characterized by a CES utility function that depends on leisure and consumption (see equation 9). On the other side consumers offer their labour in change of some income (i.e wages) in order to be able to consume. Consumption is implemented as a CES function that depends on energy and aggregate goods (see equation 10). Households energy consumption and goods consumption is calculated by comparing the ratio of their marginal utility with the ratio of their respective prices (see equations 15 and 16). The energy price is known from the oil futures market, and we first calculate the energy that households desire to consume at this price. With the energy consumption, the price of energy and the good's price (from the previous state) we calculate the consumption of goods. The households desired aggregate consumption (energy plus goods) is restricted to their income (i.e wages and capital rents) plus past savings and by the supply of goods and energy. The households present savings corresponds to the difference between income (i.e wages plus capital rents) and the price paid for the present aggregate consumption. Savings are invested on non-energy sector. From this investment households receive some rents (i.e capital' s interest rate). Households also decided their optimal wages, i.e the minimum salary at which they would sell their work, and their optimal interest rates, i.e the minimum interest rates they want to receive for their savings.

3.3 The Energy Sector

The energy sector is modelled as a kind of agent-based-model platform where firms (i.e economic agents) operate on an oligopolistic market structure and behind an oil reserves scarcity scenario. These companies can invest on new technology, reserves substitution (i.e exploration), production capacity (i.e capital) and on the financial market (i.e the futures oil market). Each company has asymmetric information, different profiles (e.g. more green or risk adverse) and are able to use multi-objective optimization, portfolio and game theory. They also based their strategies and their energy supply decisions on the trends of the economy (i.e GDP growth, energy demand and interest rates) and on the energy price.

3.4 The Financial Market

The matching between savings from the households and investments from the non-energy sector (i.e the matching between the optimal, and desired, interest rate of both sectors) occur through an endogenous interested rates mechanism. This mechanism charaterizes the financial sector. On one side the households optimal interest rate corresponds to the ratio of households' marginal utility from the last two states. On the other side the non-energy sector optimal interest rate is marginal productivity of the sector. The new interest rate is equal to the interest rate from last state plus a difference between the previous interest rate and the optimal interest rate of households and the optimal interest rate of the non-energy sector (see equation 41).

3.5 The Labor Market

The labour market results from the negotiation between the households and the non-energy sector, namely, from their desired wages. On one hand by comparing the marginal rate of substitution between the leisure and the consumption with the ratio between their respective prices households optimal salary is found (see equation 22). On the other hand by comparing the marginal cost of labour with the marginal benefit that it brings to non-energy sector we found the optimal salary of this sector (see equation 24). Salary is adjusted by these two optimal values and so labour will be. If the salary is above house- holds optimal salary and increases supply labour also increases. On the opposite side demand labour increases if the salary is below non-energy sector s optimal salary and decreases even more.

3.6 The Energy Market

On one side the energy market is the result from the interaction between the energy demand (i.e energy consumption from the households and the non-energy sector) and the energy supply (i.e energy production from the energy sector). Demand and supply differences are accommodate by oil stocks. On the other side establishes the oil price.
The oil price accommodates various possible implementations: constant returns, random walks or an agent-based simulation (i.e futures oil market), where the agents use available information in the macro and micro spheres to trade in a global oil futures market exchange, and where the price is determined such as to adjust long to short positions.
Futures oil market has, essentially, two feedbacks from the economy. The first is related with the variation of oil stocks, mentioned before. The second are interest rates, from the financial sector.

3.7 The Goods Market

The goods market results from the interaction between goods demand, from the households sector, and the goods supply, from the non-energy sector. The goods price is the economic value that characterizes this relationship based on the variation of goods stocks. On one side if stocks of goods increase price tends to decrease. On the other side if stocks of goods decrease price increases. This adjustment between price and stocks of goods is made by a price versus stocks of goods elasticity parameter.
A goods market only exists if the goods price is above the marginal production costs of the non-energy sector. The same is to say that the marginal utility that households obtain with the consumption of one additional good should be higher than the marginal cost of the additional good, otherwise production does not take place.

4 Results

Before results we may inform that this model is not yet finalised and the results that we already had are on the assumption of constant oil prices. Additionally, the energy sector and market will be replaced by a more sophisticated code in agreement with the full description of the energy sector and market made before. In the present energy sector is just a simplified code that calculates the sector energy production based on oil stocks, capital and technological investments and oil reserves.

Some other improvements are also needed and thought for the labour and the financial market. The labour market as it is, is in equilibrium. This means that we don't have unemployment. It will be modified in order to give us this feedback. On the other hand interest rates are not directly depend on the savings of households i.e money supply. This may be the answer why the modelled economy breaks down after several iterations.

Despite that we already got, from the current model, some interesting feedback. The model runs quite well for the first six iterations. Indeed, the non-energy sector departs from negative profits but has positive profits in the fifth and sixth iterations. The sector, however, ends with low production capacity and very high negative profits. Capital stills positive due debt (households' savings), but goods price is very high, almost infinite. Goods price is so high because the marginal price (i.e the marginal production cost) also is. This is almost due to capital investments and the quantity of labour. On one side capital investments are almost the same as in the beginning, however, equity has been always negative and in the last iteration has an extremely low negative value. The explanation of it is the presence of negative profits for almost all iterations, with the exception of two, as equity corresponds to the some of past profits. On the other side labour stills almost the same as in the beginning, however, production of goods decreased significantly. We may conclude that the sector is bankrupt.

Households have very high savings, high salaries, low utility, high consumption of energy and almost zero consumption of goods. The almost zero goods consumption is explained by very high prices of non-energy goods. Nevertheless the elasticity of substitution between goods and energy is very low, i.e 0.1.

Energy produced has been always increasing, and investments on capital and technology of energy sector, consequently its oil reserves. In the last iteration we have negative oil stocks.

In sort, as it was explained at the beginning of this section and emphasized by results the link between demand and labour supply is not yet well defined. As leisure is dependent on labour it also be affect. On its turn the utility function as depends on leisure. On the other side, the non-energy sector labour' s marginal costs also increased due the fact that production of goods has significantly decreased but labour has not. The same reasoning is applied to capital marginal cost due debt that was been always increasing. Another observation is related with Interest rate that at the end is infinite. This was also rather expected as agrees with our previous perception that financial sector must be improved in other to catch the right feedback from households savings and non-energy sector capital investments. We may impose a restriction that does not allow equity to be negative. Finally, on the CES production function, of the non-energy sector, elasticities of substitution between energy and capital had to be inferior to one and near zero on the CES production function. This suggests that there is a very low level of substitutability between both factors.

5 Conclusions

The goal of this paper was to describe a macroeconomic model, implemented in C++, with three sectors, energy, non-energy, households, and four markets, financial, goods, labour, energy market, also to present some results. The non-energy sector is characterized by a production function with three factors of production, labour, capital and energy. Households are characterized by a CES utility function dependent on consumption and leisure. Consumption is composed by a non-energy good and energy. Energy sector according to its oil reserves, dependent on technological and capital investments, calculates the energy production. From the interaction between households and non-energy sector we get the labour and goods markets. The labour market corresponds to the matching between demand labour, from non-energy sector, and labour supply, from households. From that market we get the wages. The goods market corresponds to the matching between goods demand, from households, and goods supply, from non-energy sector. From this market we get good stocks and the goods price. The energy market is established between the energy supply, from the energy sector, and the energy demand, from the households and the non-energy sector. This later market gives us oil stocks and the energy price. Finally the financial market establishes the matching between the optimal interest rates of the households and non-energy sector in order to calculate the interest rate. Savings from households are invested in non-energy sector. Energy sector capital and technological investments are financed by the sector' s own oil revenues.
We may emphasise, however, that this model is not yet finished. We have currently working with constant energy prices and the energy sector and

market will be replaced, in the future, by two more sophisticated platforms. Indeed, is not surprising that, currently, the model stops running after several iterations. Despite that we already got some interesting results that have been helpful to improved it, namely, in what it concern to labour market and the financial market. In the future we also intend to enlarge this model to several regions. Energy production and consumption shall be also divided between oil and electricity. Such a model may be useful to help us to better visualize key factors and explain current country debts imbalances between oil exporters and non-oil exporters nations, developed and developing economies.

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6 annexes

6.1 Equations

The model is strutured by the following equations.

Non energy-sector objective function

$$\Pi_t^{ex-ante} = P_{t-1}^{NE} Q_{t-1}^{NE} - P_t^E E_t^{NE} - w_{t-1} L_{t-1} - r_{t-1} KNE_{t-1} - \mu Stocks_{t-1}^{NE} \tag{1}$$

CES Production function

$$Q_t^{NE} = A_{NE} Q_0^{NE} \left[A_L (\frac{L_t}{L_0})^{\frac{\phi-1}{\phi}} + (1-A_L) \left(A_k (\frac{K_t^{NE}}{K_0^{NE}})^{\frac{\phi_2-1}{\phi_2}} + (1-A_k)(\frac{\varepsilon_t}{\varepsilon_0} \frac{E_t^{NE}}{E_0^{NE}})^{\frac{\phi_2-1}{\phi_2}} \right)^{\frac{\phi_2}{\phi_2-1} \frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} \tag{2}$$

The non-energy sector calculates its optimal production Q_{t+1}^{NE*} by comparing its maginal benefit with its marginal cost of goods for t-1

$$\frac{\partial \Pi}{\partial Q*_{t-1}^{NE}} = 0$$

$$\Rightarrow \frac{P_{t-1}^E}{\partial Q^{NE} \partial E_{t-1}^{NE}} + \frac{w_{t-1}}{\partial Q^{NE*} \partial L_{t-1}} + \frac{r_{t-1}}{\partial Q^{NE*} \partial K^{NE}{}_{t-1}} \equiv Q_{t-1}^{NE*} \tag{3}$$

where:

$$\left(\frac{\partial Q^{NE*}}{\partial E^{NE}} \right)_{t-1} =$$

is

$$(A_{NE} Q_0^{NE})^{\frac{\phi-1}{\phi}} (1-A_k)(1-A_L) \left(\frac{\varepsilon_t E_t^{NE}}{\varepsilon_t E_0^{NE}} \right)^{-\frac{1}{\phi_2}} \left(\frac{\varepsilon_t}{\varepsilon_0 E_0^{NE}} \right) \left[(1-A_k) \left(\frac{\varepsilon_t E_{t-1}^{NE}}{\varepsilon_0 E_0^{NE}} \right)^{\frac{\phi_2-1}{\phi_2}} + A_k \left(\frac{K_{t-1}^{NE}}{K_0^{NE}} \right)^{\frac{\phi_2-1}{\phi_2}} \right]^{-\frac{1}{\phi} \frac{\phi-\phi_2}{\phi_2-1}} \tag{4}$$

and,

$$\left(\frac{\partial Q^{NE}}{\partial L} \right)_{t-1} =$$

$$(A_{NE} Q_0^{NE})^{\frac{\phi-1}{\phi}} \left(\frac{L_{t-1}}{L_0} \right)^{-\frac{1}{\phi}} \frac{A_L}{L_0} \tag{5}$$

and,

$$\left(\frac{\partial Q^{NE}}{\partial K^{NE}} \right)_{t-1} =$$

$$(A_{NE} Q_0^{NE})^{\frac{\phi-1}{\phi}} \left(\frac{A_k}{k_{t-1}^{NE}} \right) (1-A_L) \left[(1-A_k) \left(\frac{\varepsilon_t}{\varepsilon_0} \frac{E_{t-1}^{NE}}{E_0^{NE}} \right)^{\frac{\phi_2-1}{\phi_2}} + A_k \left(\frac{K_{t-1}^{NE}}{K_0^{NE}} \right)^{\frac{\phi_2-1}{\phi_2}} \right]^{-\frac{1}{\phi} \frac{\phi_2}{\phi_2-1}} \tag{6}$$

After discovering its Q_{t-1}^{NE*} the non-energy sector finds how much should be produced for the moment t

$$Q_t^{NE} = Q_{t-1}^{NE*} - Stocks_{t-1} \tag{7}$$

Knowing how much Q_t^{NE}will be produced for moment t, as Capital and Labor are fixed in the short time, the non-energy sector can calculate how much energy E_t^{NE} will be consumed at moment t (energy is a variable cost)

$$Q_t^{NE} = A_{NE}Q_0^{NE}\left[A_L\left(\frac{L_{t-1}}{L_0}\right)^{\frac{\phi-1}{\phi}} +(1-A_L)\left(A_k\left(\frac{K_{t-1}^{NE}}{K_0^{NE}} + (1-A_k)\left(\frac{\varepsilon_t}{\varepsilon_0}\frac{E_t^{NE*}}{E_0^{NE}}\right)^{\frac{\phi_2-1}{\phi_2}}\right)^{\frac{\phi_2}{\phi_2-1}}\right]^{\frac{\phi}{\phi-1}} \tag{8}$$

Households have a CES utilitity function that depends on aggregate consumption (energy+goods) and leisure

$$U_t = \left(A_1\left(\frac{C_t}{C_0}\right)^{\frac{\rho_1-1}{\rho_1}} +(1-A_1)\left(\frac{Leisure_t}{Leisure_0}\right)^{\frac{\rho_1-1}{\rho_1}}\right)^{\frac{\rho_1}{\rho_1-1}} \tag{9}$$

$$C_t = \left(A_2\left(\frac{C_t^{NE}}{C_0^{NE}}\right)^{\frac{\rho_2-1}{\rho_2}} +(1-A_2)\left(\frac{\varepsilon_t}{\varepsilon_0}\frac{C_t^E}{C_0^E}\right)^{\frac{\rho_2-1}{\rho_2}}\right)^{\frac{\rho_2}{\rho_2-1}} \tag{10}$$

and,

$$\varepsilon_t = \varepsilon_m ax\left(1+exp\left(\frac{t_0-t}{120}\right)\right)^{-1} \tag{11}$$

Constrained to

$$L_{t-1}wt-1+rt-1K_{t-1}^{NEH} = P_{t-1}^{NE}C_{t-1}^{NE} + P_t^E C_t^{E*} + s_{t-1} \tag{12}$$

if

$$K_{t-1}^{NEH} + s_{t-1} < 0 \rightarrow s_{t-1} = 0 \tag{13}$$

With the new energy price, households decide the amount of energy consumption $C_t^E = C_{t-1}^{E*}$ that they consume at time t by comparing the marginal rate of substitution between goods and energy with the ratio between their prices at time t-1

$$\frac{\left(\frac{\partial U}{\partial C^E}\right)_{t-1}}{\left(\frac{\partial U}{\partial C^{NE}}\right)_{t-1}} = \frac{1-A_2}{A_2}\left(\frac{\varepsilon_{t-1}}{\varepsilon_0}\frac{C_0^{NE}}{C_0^E}\right)\left(\frac{C_{t-1}^{NE}}{C_0^{NE}}\right)^{-\frac{1}{\rho_2}}\left(\frac{\varepsilon_{t-1}}{\varepsilon_0}\frac{C_{t-1}^E}{C_0^E}\right) \tag{14}$$

$$\left(\frac{1-A_2}{A_2}\frac{\varepsilon_{t-1}}{\varepsilon_0}\frac{C_0^{NE}}{C_0^E}\frac{P_{t-1}^{NE}}{P_t^E}\right)^{-\frac{1}{\rho_2}}\left(\frac{C_{t-1}^{NE}}{C_0^{NE}}\right)^{\frac{1}{\rho_2^2}}\left(\frac{\varepsilon_{t-1}}{\varepsilon_0 C_0^E}\right)^{-1} \equiv C_{t-1}^{E*} \tag{15}$$

Then, with this new energy consumption quantity, they decide their optimal quantity of goods consumption$C_t^{NE} = C_{t-1}^{NE*}$, for the new goods price that (which was calculated in the last iteraction)

$$\left(\frac{A_2}{1-A_2}\frac{C_0^{NE}}{C_0^E}\frac{\varepsilon_{t-1}}{\varepsilon_0}\frac{P_t^E}{P_t^{NE}}\right)^{-\frac{1}{\rho_2}}\left(\frac{\varepsilon_{t-1}}{\varepsilon_0}\frac{C_{t-1}^E}{C_0^E}\right)^{\frac{1}{\rho_2^2}} C_0^{NE} \equiv C_{t-1}^{NE*} \tag{16}$$

After knowing Q_t^{NE} and C_t^{NE} we can calculate the stocks of non-energy goods at time t

$$\Delta Stocks = Q_t^{NE} - C_t^{NE} \tag{17}$$

$$Stocks_t = Stocks_{t-1} + \delta Stocks_t \tag{18}$$

With C_t^{NE} and Stocks we able to calculate the profits of nonenergy sector

$$\Pi_t^{ex-post} = C_t^{NE}P_{t-1}^{NE} - L_{t-1}w^{t-1} - P_t^{NE}E_t^{NE} - r_t K_{t-1}^{NEH} - \mu Stocks_{t-1} \tag{19}$$

On the other hand the price of non-energy goods of time $t+1$ is equal to

$$P_t^{NE} = P_{t-1}^{NE} - \varepsilon_{stocks} \Delta Stocks_t \tag{20}$$

constrained to

$P_t^{NE} > marginal\ production\ cost$

The households optimal wage is equal to

$$\frac{w_t}{\bar{P}} \equiv \left(\frac{P_{t-1}^{NE} C_t^{NE} + P_t^E C_t^E}{C_t} w_t \right)^{-1} \tag{21}$$

$$\left(\frac{P_{t-1}^{NE} C_t^{NE} + P_t^E C_t^E}{C_t} w_t \right)^{-1} \left(\frac{C_0}{Leisure_0} \right) \frac{1 - A_1}{A_1} \left(\frac{Leisure_t}{Leisure_0} \right)^{\frac{-1}{\rho_1}} \left(\frac{C_t}{C_0} \right)^{\frac{-1}{\rho_1}} \equiv w_t^{H*} \qquad with \qquad w_{t-1} \tag{22}$$

The non-energy sector' labour marginal productivity is equal to

$$\frac{\partial \Pi}{\partial L} = 0 \Rightarrow P^{NE} \left(\frac{\partial Q^{NE}}{\partial L} \right)_t \tag{23}$$

$$= P_{t-1}^{NE} \left(\frac{\partial Q^{NE}}{\partial L} \right)_{t-1} = (Q_{t-1}^{NE})^{\frac{1}{\phi}} (A_{NE} Q_0^{NE})^{\frac{\phi-1}{\phi}} \left(\frac{L_{t-1}}{L_0} \right)^{-\frac{1}{\phi}} \frac{A_L}{L_0} \equiv w_t^* \qquad with \qquad w_{t-1} \tag{24}$$

Wages:

$$w_{t-1} > w_t^{H*} > w_t^{NE} => w_t^{NE} => unemployment \quad increases \tag{25}$$

$$w_{t-1} > w_t^{NE} > w_t^{H*} => w_t^{H*} => employment \quad increases \tag{26}$$

$$w_t^{H*} > w_t^{NE} > w_{t-1} => w_{t-1} => employment \quad increases \tag{27}$$

$$w_t^{H*} > w_{t-1} > w_t^{NE} => w_t^{NE} => unemployment \quad increases \tag{28}$$

$$w_t^{NE} > w_t^{H*} > w_{t-1} => w_{t-1} => employment \quad increases \tag{29}$$

$$w_t^{NE} > w_{t-1} > w_t^{H*} => w_t^{H*} => employment \quad increases \tag{30}$$

Energy sector capital is equal to

$$K_t^E = (1 - \delta^E) K_{t-1}^E + I_{t-1}^{EK} \tag{31}$$

$$\alpha_t^E = \frac{\alpha_{max}^E}{1 + exp \frac{t - t_0}{120}} \tag{32}$$

$$S_t^E = S_{t-1}^E - Q_{t-1}^E + \alpha_t^E I_{t-1}^{ET} \tag{33}$$

Energy production is equal to

$$Q_t^E = Q_0^E \left((1 - \gamma^E) \left(\frac{K_t^E}{K_0^E} \right)^{\frac{\phi^E - 1}{\phi^E}} + \gamma^E \left(\frac{S_t^E}{S_0^E}^{\frac{\phi^2 - 1}{\phi^2}} \right) \right)^{\frac{\phi^2}{\phi^2 - 1}} \tag{34}$$

Energy consumption is contrained by Oil stocks

$$if \qquad O_{t-1} + (Q_t^E - C_t^E - E_t^{NE}) \geq 0 \tag{35}$$

than

$$C_t^E = C_t^{E*} \tag{36}$$

$$E_t^{NE} = E_t^{NE*} \tag{37}$$

$$O_t = O_{t-1} + (Q_t^E - C_t^E - E_t^{NE} \tag{38}$$

$$if \qquad O_{t-1} + (Q_t^E - C_t^E - E_t^{NE}) \leq 0 \tag{39}$$

than

$$C_t^E = \frac{C_t^{E*}}{C^{E*} + E_t^{NE*}}(Q_t^E + O_{t-1} \tag{40}$$

$$E_t^{NE} = \frac{E_t^{NE*}}{C_t^{E*} + E_t^{NE*}}(Q_t^E + O_{t-1} \tag{41}$$

$$O_t = 0 \tag{42}$$

Households optimal interest rate is equal to

$$\frac{\left(\frac{\partial U}{\partial C_t}\right)\beta_H(1 + r_t^{H*})}{\frac{\partial U}{\partial C_{t-1}}} \equiv 1 \tag{43}$$

$$r_t^{H*} = \frac{1}{\beta_H}\left[\left[\frac{(1-A_1)\left(\frac{Leisure_t}{Leisure_0}\right)^{\frac{\rho_1-1}{\rho_1}} + A_1\left(\frac{C_t}{C_0}\right)^{\frac{\rho_1-1}{\rho_1}}}{(1-A_1)\left(\frac{Leisure_t}{Leisure_0}\right)^{\frac{\rho_1-1}{\rho_1}} + A_1\left(\frac{C_t}{C_0}\right)^{\frac{\rho_1-1}{\rho_1}}}\right]^{\frac{1}{\rho_1-1}}\left(\frac{C_t}{Ct-1}\right)^{\frac{-1}{\rho_1}}\right]^{-1} -1 \qquad with \qquad r_{t-1} \tag{44}$$

Non-energy sector optimal interest rate is equal to

$$\frac{\partial \Pi}{\partial K^{NE}} = 0 \Rightarrow P_{t-1}^{NE}\left(\frac{\partial Q^{NE}}{\partial K^{NE}}\right)_t \equiv r_t^* \qquad with \qquad r_{t-1} \tag{45}$$

$$P_{t-1}^{NE}\left(\frac{\partial Q^{NE}}{\partial K^{NE}}\right)_{t-1} = (Q_t^{NE*} - 1)^{\frac{1}{\phi}}(A_{NE}Q_0^{NE})^{\frac{\phi-1}{\phi}}\left(\frac{A_k}{k_{t-1}^{NE}}\right)(1-A_L)\left[(1-A_k)\left(\frac{\varepsilon_t}{\varepsilon_0}\frac{(}{E}{}^{NE}_{t-1}E_0^{NE})^{\frac{\phi_2-1}{\phi_2}} + A_k\left(\frac{K_{t-1}^{NE}}{K_0^{NE}}\right)^{\frac{\phi_2-1}{\phi_2}}\right]^{-\frac{1}{\phi}\frac{\phi_2}{\phi_2-1}} \tag{46}$$

Interest rate is equal to

$$r_t = r_{t-1} + f_3(r_t^{H*} - r_{t-1}) + (1-f_3)(r_t^* - r_{t-1}) \qquad with \qquad f_3 > 0 \quad \Lambda \quad f_3 < 1 \tag{47}$$

Savings are equal to

$$L_t w_t + r_t K_{t-1}^{NE} = P_t^{NE} C_t^{NE} + P_t^E C_t^E + S_t \tag{48}$$

Debt Capital of non-energy sector is equal to

$$K_t^{NEH} = K_{t-1}^{NEH}(1-\delta) + S_t \tag{49}$$

Equity of non-energy sector is equal to

$$Equity_t^{NE} = Equity_{t-1}^{NE}(1-\delta) + \Pi_t^{NE} \tag{50}$$

Capital of non-energy sector is equal to

$$K_t^{NE} = (K_{t-1}^{NEH} + Equity_{t-1}^{NE})(1-\delta) + S_t + \Pi_t^{NE} \tag{51}$$

6.2 Initial Conditions

As annexes we point out the initial conditions of the several equations of the model.

Table 1: Production function non-energy sector initial conditions

Q_0^{NE}	*Mean monthly production of non energy goods*
K_0^{NE}	*Mean capital of the non energy sector*
E_0^{NE}	*Final energy consumption per month by the non energy sector*
δ^2	*Capital depreciation rate*
$\varepsilon_{max}/2$	*Initial 2nd law efficiency from final to useful energy*

Table 2: Utility function initial conditions

C_0^{NE}	*Mean monthly consumption of non energy goods*
C_0^{E}	*Mean monthly consumption of energy by households*
L_0	*Initial labor per month*
$Leisure_0$	*Initial leisure per month*

Table 3: Production function energy sector initial conditions

Q_0^{E}	*Initial monthly production of energy*
K_0^{E}	*Initial capital of the energy sector*
S_0^{E}	*Proven reserves of oil*
O_0	*Stocks of oil*

Table 4: Wage, prices, and interest rate initial conditions

P_0^{NE}	*Mean price of non energy goods*
P_0^{E}	*Mean price of goods*
W_0	*Initial hourly wage*

Table 5: Population initial condition

Pop_0	$1E6 < Pop_0 < 1.5E9$	*Initial population*

6.3 Parameters

We also point out the parameters of the several equations of the model.

Table 6: Utility function parameters

A_1	$0 < A_1 < 1$	*Relative weight of consumption*
A_2	$0.7 < A_2 < 1$	*Share of consumption in aggregate consumption*
ρ_1	< 1	*Elasticity of substitution between leisure and consumption*
ρ_2	< 1	*Elasticity of substitution between leisure and consumption*
ε_{max}	$0.25 < \varepsilon_{max} < 0.50$	*Second law efficiency*
β_H	0.002	*Utility discount rate*

Table 7: Population parameters

σ_{TEEN}	$0.13 < \sigma_{TEEN} < 0.45$	*Fraction of population below* 15
σ	$0.4 < \sigma < 0.85$	*Fraction of active population above* 15
λ	$0.4 < \lambda < 0.85$	*Monthly population growth rate*

Table 8: Utility function non-energy sector parameters

A_k	$0 < A_K < 1$	*Relative contribution of capital*
A_L	$0 < A_L < 1$	*Relative contribution of labor*
A_{NE}	$A_{NE} = 0.48TOPEN + 0.52PCREDIT$	
$TOPEN$	$0.3 - 4$	*Trade openess*
$PCREDIT$	$0.15 - 2$	*Private sector investment*
ϕ	1	*Elasticity of substitution between labor*
ϕ_2	0.65	*Elasticity of substitution between energy*

Table 9: Production function energy sector parameters

γ^E	*Relative importance of the amount of the resources vs.capital*
ϕ^E	*Elasticity of substitution between capital and resources*
δ^E	*Monthly depreciation rate of the energy sector capital*
α^E_{max}	*Conversion of investment into technology available resources*
χ	*Fraction of investment in capital in the energyl sector*

DAY 10 - 14:30		
Room 626 - Environmental and Social Impact Assessment 2		
Sustainability indicators for the portuguese cork industry	Ana Paula Perlin[1]; Gisele Bortolaz Guedes[1]; Manuel Lopes Nunes[1]; Paula Ferreira[1]	[1]University of Minho
Comparative performance of alternative ready-to-use LCIA methods: The case-study of the pulp and paper industry	Margarida S. Gonçalves[1]; Tânia Pinto-Varela[2]; Ana Paula Barbosa-Póvoa[3]; Augusto Q. Novais[1]	[1]LNEG; [2]LNEG, IST; [3]IST
Sustainability Indicators for Electric Utilities: a proposal using PCA	Marta Guerra da Mota[1]; Isabel Soares[2]	[1]FEUP; [2]FEP e CEFUP
Bringing in competing stakeholders: A sustainable management of the Alqueva Reservoir	Amando A. Radomes, Jr.[1]; Camilo Andrés Benítez Ávila[1]	[1]Universidade Nova de Lisboa
Conceptualizing a Credits Trading Approach towards Corporate Social Responsibility Credits	Shantesh Hedea, Paula Varandas Ferreira, Manuel Lopes Nunes , Luis Alexandre Rocha	University of Minho

Sustainability indicators for the Portuguese cork industry

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Abstract

Sustainable development proves to be an important focus of attention from industries once to modern society the impact of humans on the environment in which it operates is becoming increasingly complex. There is a growing concern for the environment and for the scarcity of available natural resources that are frequently related to the negative consequences brought by the industrial manufacturing system. Therefore, a framework incorporating sustainability indicators is an useful tool for decision making, policy formulation and public communication of economic, environmental and social performance of each organization. The present study aims to conduct a detailed study about the cork industry in Portugal, presenting a proposal of a set of sustainability indicators. These indicators are already being used in the industries in general, and can represent a starting point for the development of indicators that measure sustainability for this sector.

Keywords: Sustainable Development, Sustainability Indicators; Cork Industry.

JEL Code: L67; Q01

1. Introduction

Based on the technological changes and growth of organizations, new requirements and standards were created. Nowadays, the importance of existing suitable processes to sustainability in order to ensure social welfare, economic and environmental is evident. The increasing concern of society with the environment in which is the organization operates, points to the negative consequences of production systems and thereby presses the companies to assume their responsibility in sustainable development. It is important, however, to emphasize that sustainability is not dissociated from economic growth, but can be seen as an important factor of competitive advantage and value creation.

According to Silva *et. al* (2009), the concept of sustainability for the business sector represents a new approach to doing business that promotes social responsibility and reduces the use of natural resources, consequently decreasing the negative impacts on the environment and preserving the integrity of the planet for future generations, without neglecting the economic and financial profitable of the enterprise.

Faced with this problem, stand out in this scene companies that respond to sustainable development with environmental actions formulations with new production practices, with the social concern and the deployment of cleaner technologies. These business organizations developed new tools for sustainable management that generated a range of efficient production and best results. In literature sustainability indicators are found for industries such as mining, developed by Azapagic (2004), or for the wine industry (Callado, 2010). These indicators address the economic, environmental and social issues and its relevance into the sector under study. A recent review of indicators that appear frequently in corporate sustainability reports can be found in Roca and Searcy (2012).

Regarding cork industry the sustainability appears to have a strong relationship from the cork oak tree, where the cork is extracted, until the final transformation in cork products. Cork is a raw vegetable with exceptional environmental qualities: it is a renewable resource that is recyclable, non-toxic and durable, besides being a fixer of CO_2 with excellent physical and mechanical properties, such as thermal and electrical insulating, vibration absorber and practically waterproof (Mestre and Gil, 2011).

Therefore, in order to emphasize these properties inherent to this sector, provide progress and make it more efficient in your production it is of great importance the development of sustainability indicators. These indicators may enable the analysis, monitoring and reporting specific to the cork industry.

In this way this work aims carry out a survey of the sustainability indicators already applied in general industries to further development of specific indicators for the cork sector. For instance, the macro indicators, such as the Global Reporting Initiative is used, along with the specific codes in the sector.

2. Cork sector

As a result of the knowledge development and the industry expansion, products used in households and in a simply manner, became valuable to trade and economy. This change also occurred with the cork (vegetable material from the bark of the cork oak tree), in the past, the usage of cork was prevalent in fishing devices and sealing. Later on, after technical studies about its characteristics, it was possible to use the cork in a large amount of products, and nowadays, several countries have yours owns economy linked to these products.

One aspect to justify the study of cork industry is the strong development of the wine industry. Studies have shown that the wine consumption is growing, mainly due to health issues, and as consequence, more cork stopper are being used, as they are the most famous product in cork industry and used to seal the majority of wines. Furthermore, there is a large amount of applications to cork such as in flooring and covering, decorative items for home and office, shoes, automobile gaskets and military and aviation industry.

The cork industry occupies a prominent place in economy and trade of Mediterranean countries such as Portugal, Italy, France, Spain, Morocco, Algeria and Tunisia. According to Pestana and Tinoco (2009), the cork is one of the typical products from Portugal, since the country had been one of the leaders in cork production and exportation in the past decades, in addition to having one of the greatest areas occupied by cork oak trees forest.

The cork oak trees are distributed nearly across the country, isolated or in spontaneous settlements. There are two kinds of existing stands the cork oaks and the assembled. The assembled have a multiple usage, agriculture, forestry and pastoral, which originate a low density of these settlements, and the cork oaks exhibit higher density, being able to have large trees, which the greatest production is allocated to cork exploration (Pestana and Tinoco, 2009).

It can be noticed that Portugal and Spain are both area and production leaders. It can be highlighted that 85.8% of the world production it is located in Europe and only 14.2% in North Africa. In Portugal, the cork is concentrated in south region, having the localities of Alentejo, Lisbon and Tagus Valley as great powers in cork production, extraction and industrialization (Apcor 2012).

3. Indicators of sustainability

There are countless types of sustainability indicators found in the literature and most of these are still under development, discussion, testing and improvement. The research about sustainability indicators generally occurs at two different levels: macro and micro. According to Gray and Wiedeman (1999) macro indicators attempt to measure the sustainability of a city, nation or the world, while the micro indicators generally are related to the lowest level, with local units such as organization of the business and industries.

Regarding the macro indicators, in line with Souza and Lopes (2010), among the initiatives incorporated by principles of governance, related to environmental issues, social and economic, it can be cited: the Un's Global Compact, the Organizational for Economic Cooperation and Development's (OECD) Guidelines for Multinational Enterprises them, and the Global Reporting Initiative (GRI) and so forth. According to the same authors the GRI stands out from the others, because it aims to satisfying the organizations need of having a clear and transparent communication, in order to the sharing of concepts structures have a language that is coherent and global, in other words, proposing a global communication standard over sustainable business actions.

The sustainable development indicators generally reflect sustainability issues into quantifiable measures of economic, environmental and social performance with the ultimate goal of helping to solve the main concerns. For the development of indicators, at the level of companies and organizations, is necessary to identify the relevant issues, which capture the specific features of each type of industry. The stakeholder analysis should help in raising awareness of the general types of questions, however, to identify specific problems, a detailed analysis of each industrial activity is required (Azapagic,2004). Sustainability is based on three dimensions that must be properly structured to develop efficient indicators of sustainability. To Estend and Pitta (2008) actions of sustainable development must seek to act simultaneously in three dimensions: economic, social and environmental.

The model proposed by Azapagic (2004) is composed by economic, environmental, social and integrated indicators. Economic indicators measure the economic impact of the company on its internal and external stakeholders and economic systems at the local, national and global level. The environmental indicators measure impacts of the company on natural systems, including humans, ecosystems, land, air and water. These impacts may be local, regional or global, affecting a wide range of stakeholders. Social indicators assess the aspects, practices often associated with sustainable employment, human rights, society and product responsibility (Kneipp, 2012).

The use of the sustainability indicators for the industry represents a helping procedure to measure the economic, environmental and social performance of an enterprise, providing information on how it contributes to sustainable development (Azapagic and Perdan, 2000).

3.1 Environmental Indicators

The environmental dimension of sustainability covers the organization's impacts on natural systems and living and nonliving relate to performance in respect of raw materials, biodiversity, environmental compliance and other relevant information (Kneipp, 2012).

For Oliveira (2005), environmental sustainability represents the preservation of natural resources and the limitation of use of non-renewable resources, respect for capacity of self-debugging for natural ecosystems and reducing the volume of waste and pollution through energy conservation and recycling. This author argues that some measures are important such as, promoting self-limiting consumption of materials made by rich countries and individuals across the planet, the definition of rules for adequate environmental protection, creating an institutional machinery as well as selecting instruments economic, legal and administrative necessary for their achievement.

However, sustainable development seems to require other approaches, not only covering ecological status quo. A coupled ecological, social and economic system can evolve to maintain a level of biodiversity that will ensure the long-term strength of the system. This ecological perspective replaces the narrow economic objective of protecting only the ecosystems that human activities are directly dependent. Sustainable development seeks compensation for lost opportunities for future generations, because nowadays the economic activity of biodiversity changes in ways that affect the flow of future vital ecological services (Munasinghe, 2007).

3.2. Social Indicators

The social responsibility reveals the organization's ethos in the surrounding environment, incorporating important factors such as the appreciation of the employee and measures that provide quality of life. The impacts of business on society and within the organization may be measured by social indicators.

According Bronn and Vrioni (2001) business involvement in social activities in the community began as voluntary actions of companies, focusing on social issues until reaching the current levels of corporate sustainability.

Social development usually refers to the improvement of well-being and individual comfort and welfare of the whole society, a result of the growth of share capital, usually achieved through the accumulation of skill capacity of individuals and communities to work together (Munasinghe, 2007). The union of people in an attempt to develop can be positive to achieve the objective of the actions (Estender and Pitta, 2008).

For Kanji and Chopra (2010) an enterprise presents social responsibility when: commits to ethical practices in employment and at work, improving the workplace, is involved in build and integrate social projects with local communities and communicates with the communities involved about the consequences of their activities and products; invests in building social infrastructure, contributes to a cleaner environment through its protection and sustainability, and contributes through its corporate governance to economic development in general.

According Glavic and Lukman (2007) social principles are exposed as: social responsibility (the human development in form equitable and egalitarian, contributing to humanity and the environment); health and safety (refer to the workplace including responsibilities and standards); polluter-pay and taxation (whoever causes pollution must pay the costs that this cause, in the form of cleaning taxation).

3.3. Economic Indicators

The economic indicators as opposed to just measure the profit generation must mention the efficient allocation and distribution of natural resources and human capital.

According to Pereira (2009), economics should be evaluated more in terms of macro social that only through specific criteria of corporate profitability, aiming to promote structural changes that act as motivators of human development without compromising the natural environment. The aspects of the economic dimension covered by Krajnc and Glavic (2005) firstly refer to the impacts caused on economic welfare of its stakeholders and the economic system at the local, national and global.

According to Steurer *et. al* (2005) an enterprise economic sustainability is classified by the corporate financial performance, the business competitiveness and the economic impact generated by the company and stakeholders. To Glavic and Lukman (2007) economic principles that should be considered are: eco-efficiency, ethical investments and environmental accounting.

4. Proposal of sustainability indicators of the cork sector

The proposal for sustainability indicators specific to the cork industry is based on the Global Reporting Initiative (GRI), on the indicators already created for industries in various other sectors and on the indicators presented in the sustainability reports of a leading company operating in the Portuguese cork sector.

The GRI provides guidelines to build sustainability reports that demonstrate effectively the sustainable development of the industry. According to Lopes and Souza (2010) the GRI provides a reliable framework for sustainability reporting, and can be used by organizations of all sizes, sectors and localities. To do so it relies on the cooperation of experts from various countries, multistakeholder governance structure that come from companies, consultants, employees, non-governmental organizations, public policy, research institutions, associations and universities.

In essence, the GRI indicators and the indicators classified as essential by this organization and that by authors of this study were considered relevant and adapted to the cork industry. From this initial base, GRI indicators were integrated with the ones proposed by Azapagic (2004), Oliveira (2002) and Erol et. al (2008). Also industry's sustainability report Amorim (2011) was reviewed, as this company already uses indicators for the sector. Then the potential set of sustainability indicators for the cork industry was defined, resulting in a total of 46 indicators being 16 related to environmental performance, 23 related to social performance and 7 related to the economic dimension.

Following the final frameworks with the proposal to sustainability indicators are presented, aiming to support sustainable management of the cork industry.

Environmental Performance Indicators		
Aspect	**Indicator**	**References**
Materials	Materials used by weight or volume.	GRI(2006), Azapagic(2004), Amorim(2011)
	Percentage of materials used that are recycled input materials.	GRI(2006),Azapagic(2004), Amorim(2011)
Energy	Direct and indirect consumption by primary energy source.	GRI(2006),Erol. *et. al*(2008), Amorim(2011)
Water	Total water withdrawal by source	GRI(2006), Erol. *et. al*(2008),Amorim(2011)
Biodiversity	Location and size of land owned, leased managed in, or adjacent to, protected areas and areas of high biodiversity value outside protected areas.	GRI(2006),Erol. *et. al* (2008)
	Description of significant impacts of activities, products, and services on biodiversity in protected areas and areas of high biodiversity value outside protected areas.	GRI(2006)
Emissions, Effluents, and Waste	Total direct and indirect greenhouse gas emissions by weight.	GRI(2006),Erol *et. al*(2008), Azapagic(2004), Amorim(2011)
	Other relevant indirect greenhouse gas emissions by weight.	GRI(2006)
	Emissions of ozone-depleting substances by weight.	GRI(2006), Azapagic(2004)
	NO, SO and other significant air emissions by type and weight.	GRI(2006), Amorim(2011)
	Total water discharge by quality and destination.	GRI(2006),
	Total weight of waste by type and disposal method.	GRI(2006), Azapagic(2004), Amorim(2012)
	Total number and volume of significant spills.	GRI(2006), Amorim(2011)
Products and Services	Quantity and description of initiatives to mitigate environmental impacts of products and services and extent of impact.	GRI(2006), Erol *et. al*(2008), Oliveira(2002)
	Percentage of products and their packaging materials recovered in relation to total sales by product category.	GRI(2006), Erol *et. al*(2008)
Compliance	Monetary value of significant fines and total number of non-monetary sanctions for non-compliance with environmental laws and regulations.	GRI(2006)

Table 1. Environmental indicators for the cork industry.

Source: Developed by the authors.

Social Performance Indicators		
Aspect	**Indicator**	**References**
Employment	Total workforce by employment type.	GRI(2006), Erol *et. al*(2008), Oliveira(2002), Amorim(2011)
	Total number and rate of new employee hires and employee turnover by age group, gender and region.	GRI(2006), Erol *et. al*(2008), Amorim(2011)
Management relations	Percentage of employees covered by collective bargaining agreements.	GRI(2006)
Occupational health and safety	Rate of injury, occupational diseases, lost days, and absenteeism, and total number of work-related fatalities, by region and by gender.	GRI(2006),Erol *et. al*(2008), Amorim(2011)
	Number of hours of training and description of educational programs, training, counseling, prevention and risk control.	GRI(2006), Oliveira(2002), Amorim(2011)
Training and education	Average hours of training per year per employee by gender, and by employee category..	GRI(2006), Erol *et. al*(2008), Oliveira(2002), Amorim(2011)
Diversity and equal opportunity	Composition of governance bodies and breakdown of employees per employee category according to gender, age group, minority group membership.	GRI(2006),Erol *et. al*(2008), Azapagic(2004)
	Proportion of wages between men and women, by position.	GRI (2006), Azapagig (2004) Amorim(2011)
Investment and procurement practices	Percentage and total number of significant investment agreements and contracts that include clauses incorporating human rights concerns, or that have undergone human rights screening.	GRI(2006), Azapagic(2004)
	Percentage of significant suppliers, contractors, and other business partners that have undergone human rights screening, and actions taken.	GRI(2006)
Non-discrimination	Total number of incidents of discrimination and corrective actions take.	GRI(2006)
Freedom of association and collective bargaining	Operations and significant suppliers identified in which the right to exercise freedom of association and collective bargaining may be violated, or at significant risk, and actions taken to support these rights.	GRI(2006)

Child Labor	Operations and significant suppliers identified as having significant risk for incidents of child labor, and measures taken to contribute to the effective abolition of children labor.	GRI(2006), Erol *et. al*(2008), Azapagic(2004)
Communities	Level of effectiveness of programs and practices to manage the impacts of operations on communities.	GRI(2006), Erol *et. al*(2008), Oliveira(2002)
Corruption	Percentage and total number of business units analyzed for risks related to corruption.	GRI(2006), Azapagig(2004)
	Percentage of employees trained in anti-corruption policies and procedures.	GRI(2006), Azapagig(2004)
	Actions taken in response to corruption.	GRI(2006), Azapagig(2004)
Public policy	Number and description of holdings on the public policies of social responsibility, health and safety.	GRI(2006), Erol *et. al*(2008), Oliveira(2002)
Compliance	Total non-monetary sanctions due to noncompliance with laws and regulations and monetary value of existing fines.	GRI(2006)
Customer health and safety	Percentage of products and services that create impacts on the health and safety of customers.	GRI(2006), Erol. *et al* (2008)
Labeling of products and services	Percentage of products and / or services containing information required by procedures.	GRI(2006)
Marketing Communications	Quantity and description of programs for adherence to laws, standards and voluntary codes related to marketing communications.	GRI(2006)

Table 2. Social indicators for the cork industry.

Source: Developed by the authors.

Economic Performance Indicators		
Aspect	**Indicator**	**References**
Economic Performance	Direct Economic value generated: revenues, operating costs, employee compensation, donations and other community investments, retained earnings and payments to capital providers and governments.	GRI(2006), Erol et. al(2008), Amorim(2011)
	Risks, financial implications and opportunities for the organization´s activities due to climate change.	GRI(2006), Oliveira(2002)
	Value and description of the organization´s defined benefit plan.	GRI(2006), Amorim(2011)
	Significant financial assistance received from government.	GRI(2006), Amorim(2011)
Market Presence	Practices, proportion of spending on locally-based suppliers at significant locations of operation.	GRI(2006), Amorim(2011)
	Procedures for local hiring and proportion of senior management hired from the local community at locations of significant operation.	GRI (2006),
Indirect Economic Impact	Value of investment in infrastructure and services for public benefit (health, education, security and the like).	GRI(2006),Azapagic(2004), Amorim(2011)

Table 3. Economic indicators for the cork industry.

Source: Developed by the authors.

5. Conclusion

Through the detailed study of the Portuguese cork industry that was possible understand the working of the sector and observe its dimension and its importance. This study is revealed to be essential for further analysis and definition of the indicators that are best suited to this sector.

The survey of sustainability indicators revealed that there are numerous criteria translated into indicators in the literature being applied to generate sustainability reports. The macro indicators are distinguished from micro indicators, and the main difference is that the former is developed for production or services facilities, and possess the aim to address all key aspects of the production chain involving resources (energy, materials and employees), the natural environment in which it operates and the social and economic development.

The main goal of this study was to conduct a detailed study of the cork industry and to raise sustainability indicators existing in the literature from other sectors confronting them with those already existing in the sustainability reports of companies. From this a framework for possible sustainability indicators for the cork sector was proposed.

The Global Reporting Initiative (GRI) is an international non-governmental organization that demonstrates the guidelines for sustainability reporting and provides support for developing studies of specific indicators. Because it is an organization with credibility and high quality, the essential indicators described in this proposal departed from the GRI sustainability indicators adapted to the specific cork industry.

Therefore these indicators should cover all needs of the cork industry and reveal more clearly sustainable development promoted by this sector. In this way, a total of 46 sustainability indicators were defined, of which 16 related to the environmental dimension, 23 relating to the social dimension and 7 regarding the economic dimension. It is noteworthy that these indicators are a primary study source for subsequent inclusion in industry and verifying the applicability in this industry.

This study is expected thereby to contribute to: (1) possible analysis of sustainability for the sector as a whole, comparable to other sectors, and (2) assessment of companies' sustainability from the cork sector in the national and international level in a unambiguous and impartial manner. Future research targets the proposal of a new tool for supporting the sustainability assessment of the cork industrial manufacturing sector, integrating the full social, environmental and economic cost and benefits (externalities) at local, regional and national levels.

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Comparative performance of alternative ready-to-use LCIA methods: The case-study of the pulp and paper industry

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Abstract

This paper explores the application of four ready-to-use Life Cycle Impact Assessment (LCIA) methods to the pulp and paper industry. A gate-to-gate approach is employed, using the SimaPro 7.3.3 software, with the focus on the individual processes involved.

The methods are the Eco-indicator 99, EPS 2000, IMPACT 2002+ and ReCiPe, with the most significant environmental impacts to be assessed being *resource depletion*, *global warming potential*, *acidification*, *eutrophication*, *photo-oxidant formation* and *toxicity*. An impact assessment and a sensitivity analysis are undertaken to select the most suitable method, in terms of its adequacy as a monitoring tool for process improvement and implementation in a multi-objective optimization procedure.

With this aim a detailed inventory phase of the industrial process was conducted with support in real data and best available techniques for this industry. For all methods a proper sequencing of processing tasks, equivalent to SimaPro layers, was subsequently worked out for the impact assessment up to the point of characterization. Sensitivity tests were conducted on the critical emissions and their effect estimated on the impact categories. Recommendations on the methods suitability is finally presented, together with limitations identified in relation to some impacts.

Keywords: LCA; LCIA; Eco-indicator 99; EPS 2000; IMPACT 2002+; ReCiPe; Pulp and Paper Industry.

JEL classification codes (Q56): Environment and Development; Environment and Trade; Sustainability; Environmental Accounts and Accounting; Environmental Equity; Population Growth.

1. Introduction

The pulp and paper industry is an important driver for the Portuguese economy. Between 2010 and 2011 the paper and cardboard production increased around 7.1%, printing paper representing 71% of the total production (CELPA 2012). Despite the general slowdown in the European economy in the recent years, these industries continuously increase their performance (CELPA 2012), a trend expected to be maintained.

In the last decade, the sustainability concept which embraces economic, environmental and social objectives, became a competitive key challenge in the pulp and paper industries (CEPI 2011). Kloepffer in (2008) stated that sustainability assessment will be provided by the integration of the Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social LCA (SLCA) methodologies, where SLCA aims to assess the social impacts of products and services (UNEP 2009). Despite the scientific community efforts toward the promotion of guidelines for SLCA (UNEP 2009), it still remains a very new and immature field (Jørgensen et al. 2008).

Similarly to other industries, the pulp and paper is also subject to environmental pressures, deriving from statutory emission limits and measures enforced by the European Commission and national governments. The European Commission (EC) in (2001) developed the Integrated Pollution Prevention and Control which is the reference document on Best Available Techniques (BAT) for the pulp and paper industry. It covers a wide range of environmental pollution types and describes the main legal obligations of the industrial operator resulting from the environmental law.

In this context, the Portuguese pulp and paper industries have been making important investments, not only in the production process itself, but also in pollution prevention, such as flue gases, liquid effluents treatment systems, solid waste management and pollution prevention related to energy consumption (CELPA 2012).

In this area in recent years some research work has been undertaken by several authors, with application of the LCA. Lopes et al. (2003) focused their work on the comparison of energy strategies, while Das and Houtman (2004) on process alternatives concerning the environmental performance of the pulping processes. Munoz et al. (2006) dealt with effluent treatment, González-García et al. (2009) with the bleaching processes and Iosip et al. (2012) with recycling and waste management.

Different LCIA methods have been applied, with some being of the ready-to-use type, a concept defined by Brentrup et al. (2004). Based on it some research work appear in the literature that applies these methods, such as EPS by Bystrom and Lonnstedt (1997), Eco-indicator 95 by Fu et al. (2005), IMPACT 2002+ by Gaudreault et al. (2009), TRACI by Gaudreault et al. (2010), Eco-indicator 99 by Moberg et al.(2010) and CML by Iosip et al (2012). There are also pulp and paper LCA studies about methodological choices, such as normalization and weighting techniques developed by Gaudreault et al. (2009) and system boundaries selection by Gaudreault et al. (2010). None of these studies assessed the relevance of the methodological choices of the LCIA methods on the impact results for this particular industry. There are, however, studies for other systems such as: water-based UV-lacquer

(Dreyer et al. (2003)), laundry detergent (Pant et al. (2004)) and house exterior walls (Monteiro and Freire (2012)).

This work explores the application of LCA to an industrial process and assesses the importance of the choice of individual LCIA methods on the impact results and therefore their relevance for decision making. The Eco-indicator 99, EPS 2000, IMPACT 2002+ and ReCiPe LCIA methods will be investigated, using the SimaPro software.

2. Framework

LCA is a technique to assess the potential environmental impacts of products, processes and services throughout their entire life-cycle in the cradle-to-grave concept, or of one value-added process in the gate-to-gate concept (ISO 2006). It is characterized by four phases: goal and scope definition; life cycle inventory analysis (LCI); LCIA, and finally interpretation step. The purpose of the LCIA, characterized by classification, characterization (final mandatory element), grouping and weighting elements, is to evaluate the significance of the potential environmental impacts using the LCI results. The technical guidelines have been standardized by the International Organization for Standardization (ISO 2006).

In the present work the selection of the LCIA methods was based on the ability to calculate the endpoint (or damage) categories, the adequacy of their impact categories to the main environmental impacts, and their European regional validity, acceptance and credibility in the scientific community. Based on these selection criteria, the Eco-indicator 99, EPS 2000, IMPACT 2002+ and ReCiPe LCIA methods were selected. Their main underlying concepts and potential contribution to the case-study impacts are briefly described next.

2.1. Eco-indicator 99

The Eco-indicator 99 is a damage-oriented approach, a.k.a. endpoint approach, considering three fields of damage: human-health, ecosystem and resources (Goedkoop and Spriensma 2000). It comprehends characterization, normalization and weighting phases. The modelling is based on average European conditions. The weighting procedure is based on three different cultural perspectives, namely individualist, hierarchist (H), and egalitarian. The impact results can be assembled into a single-score, measured in Points (Pt).

2.2. EPS 2000

The Environment Priority Strategy 2000 (EPS 2000) developed by Steen (1999) is a damage-oriented approach based on economic assessment. The focus is on the effect on human-health, biodiversity, resources and ecosystems, which are modelled and weighted according to society's willingness to pay (WTP) to avoid such damages. It includes characterization and weighting phases, with no formal normalisation procedure being contemplated. The damage models are based on World averages. The Environmental Load Unit (1 ELU =1 euro) is used as the assessment unit for all the damage categories.

2.3. IMPACT 2002+

The IMPACT 2002+ (Jolliet et al. 2003) is a mid/endpoint damage-oriented approach. The midpoint categories are structured in human-health, resources, ecosystem and climate change damage categories. Like the Eco-indicator 99, this method also includes characterization and normalization steps. Normalisation factors for Europe are available for the year 2000, as annual impact scores for an average European citizen. No specific weighting is developed. As default, the weighting factors can be taken as equal, assuming that the present overall European damage on human-health is comparable to the impact on ecosystems, to climate change and resources impacts.

2.4. ReCiPe

The ReCiPe method, developed by Goedkoop et al. (2012), integrates and harmonises midpoint and endpoint approaches. It allows the user to choose where to end his analysis. In the endpoint level three fields of damage are considered: human-health, ecosystem and resources. It includes characterization, normalization and weighting phases. The modelling can be performed based either on average European or on World conditions. In the weighting step, the method uses a panel approach based on cultural perspectives, like the Eco-indicator 99 method. The results can be combined into a single-score, where one point (Pt) can be interpreted as one thousandth of the annual environmental load of one average European or World inhabitant.

2.5. Environmental impact assessment

The LCA literature identifies that for the pulp and paper production the main environmental impacts are the *resource depletion* (energy consumption as fossil resources), *global warming potential*, *acidification*, *eutrophication*, *photo-oxidant formation* (smog) and *toxicity* (human health and ecosystem impacts) (Lopes et al. 2003; Dias et al. 2007; Vieira et al. 2010). In this work an impact assessment is performed up to the characterization phase based on these environmental impacts, using the four LCIA methods: EPS 2000, IMPACT 2002+, Eco-indicator 99 (H perspective) and ReCiPe Europe (H perspective) for the midpoint and endpoint levels.

Table 1 shows the impact categories of each method assigned to each environmental impact and their units at the characterization phase. Impact categories without a connection to environmental impacts are identified by a hyphen in Table 1, which makes evident that comparisons among methods are not straightforward. Categories are different, as well as their units, because their environmental impacts are converted using different impact assessment models and characterisation factors (CFs). The CF expresses the impact of each substance within its category, in terms of a common unit (Pizzol et al. 2011).

All methods (Table 1) assess the *fossil fuels resources depletion* but with different units. Eco-indicator 99 uses the MJ surplus energy concept that translates surplus energy needed in future to extract lower quality fossil resources. In IMPACT 2002+ the non-renewable energy is expressed in terms of the total primary energy extracted (MJ total primary non-renewable energy/kg used). The ReCiPe *fossil depletion* midpoint factors are given as kg-oil equivalents and endpoint factors are expressed as $/kg extraction. EPS 2000 *depletion of reserves* category includes energy (fossil oil, fossil coal, natural gas) and also mineral resources.

Eco-indicator 99, IMPACT 2002+ and ReCiPe use the IPCC guidelines for *global warming*, although the use of CFs assigns them different units (Table 1). Eco-indicator 99 and ReCiPe's *climate change human health* are measured in Disability Adjusted Life Years (DALY), while ReCiPe's *climate change ecosystem* is in loss of species during a year. Both IMPACT 2002+ and ReCiPe midpoint are expressed in terms of kg CO_2 equivalent (eq.) for greenhouse gases contributing to the impact category *global warming*. EPS 2000 methodology is unsuitable to assess this category.

As also shown all methods assess *acidification* potential impacts but not *eutrophication*. The IMPACT 2002+ method accounts not only for *acidification* but also for *eutrophication* like the Eco-indicator 99. While the former uses a *terrestrial acidification/nutrification* category, the latter uses *acidification/eutrophication* measured as Potentially Disappeared Fraction (PDF). EPS 2000 does not account for *eutrophication* impacts and the *marine eutrophication* category is not present in the ReCiPe endpoint despite being in the midpoint level.

With regard to *photo-oxidation formation* neither the EPS 2000 nor IMPACT 2002+ nor Eco-indicator 99 contemplate it. However IMPACT 2002+ employs the CFs common to the Eco-indicator 99, based on the *respiratory organics* (Humbert et al. 2005) that model *photo-oxidant formation* expressed in DALY. ReCiPe contains this category, with DALY units for the endpoint and kg Non-Methane Volatile Organic Compounds (NMVOC) for the midpoint level.

T*oxicity* categories were grouped, given their diversity (Pizzol et al. 2011; Pizzol et al. 2011). ReCiPe employs the Uniform System for the Evaluation of Substances (USES) model that according to these authors is the most updated, its midpoint levels being expressed in kg of 1,4 dichlorobenzene (1,4-DB). Similarly, Eco-indicator 99, IMPACT 2002+ and EPS 2000 methods also assess *toxicity* impacts. The units are respectively Potentially Affected Fraction (PAF) of species and DALY, kg of vinyl chloride and kg of triethylene glycol (TEG), and lost person-years.

3. Case-study

The pulp and paper manufacturing process will be used as case-study, being divided in two stages: pulp production, followed by paper making. The focus will be centred on the process, thus the gate-to-gate concept will be used.

The pulp manufacture uses the Bleached Eucalyptus Kraft Pulp process (BEKP), involving an Elemental Chlorine Free (ECF) bleaching, and leading to Uncoated WoodFree (UWF) paper as the final product (APA 2012). Figure 1 shows the main process steps, followed by Table 2 where are shown some of the inputs required for pulp and paper production, which is described in greater detail in the next subsections.

3.1. Pulp production

In this stage the pulp is produced by the BEKP process, which involves the Kraft recovery system and the ECF bleaching.

The wood is transformed into chips, whose digestion uses white liquor that reacts with the chips, obtaining pulp suspension and black liquor. The black liquor goes to the Kraft recovery system (the dashed lines in Figure 1), which is a chemical recovery process that also generates energy, leading to white liquor that will be reused in the chip digestion phase. The main process tasks are: evaporation of the black liquor, incineration of the evaporated liquors in a recovery boiler (with energy generation) and causticizing, including lime regeneration (EC 2001). The high energy-intensive requirements of the pulp production stage are provided by the Kraft process (EC 2001). The energy generation is obtained from a Combined Heat and Power (CHP) system.

Table 1 - Impact categories of the LCIA methods.

Environmental impact	**Method**	**Impact categories**	**Units**
Fossil fuels resource depletion	Eco-indicator 99	Fossil fuels	MJ surplus
	EPS 2000	Depletion of reserves	ELU
	IMPACT 2002+	Non-renewable energy	MJ primary
	ReCiPe	Fossil depletion	Endpoint: $ Midpoint: kg oil equivalent
Global warming	Eco-indicator 99	Climate change	DALY
	EPS 2000	-	-
	IMPACT 2002+	Global warming	kg CO_2 equivalent
	ReCiPe	Climate change	Midpoint: kg CO_2 equivalent
		Climate change Human Health	Endpoint: DALY
		Climate change Ecosystems	Endpoint: species year
Acidification	Eco-indicator 99	Acidification/ Eutrophication	PDF m^2 year
	EPS 2000	Soil acidification	H^+ equivalent
	IMPACT2002+	Aquatic acidification	kg SO_2 equivalent
		Terrestrial acid/nutri	kg SO_2 equivalent
	ReCiPe	Terrestrial acidification	Endpoint: species year Midpoint: kg SO_2 equivalent
Eutrophication	Eco-indicator 99	Acidification/ Eutrophication	PDF m^2 year
	EPS 2000	-	-
	IMPACT 2002+	Terrestrial acid/nutri	kg SO_2 equivalent
		Aquatic eutrophication	kg PO_4 P-limited water
	ReCiPe	Freshwater eutrophication	Endpoint: species year Midpoint: kg P equivalent
		Marine eutrophication	Endpoint: - Midpoint: kg N equivalent
Photo-oxidation formation	Eco99	Respiratory organics	DALY
	EPS 2000	-	-
	IMPACT 2002+	Respiratory organics	kg C_2H_4 equivalent
	ReCiPe	Photochemical oxidant formation	Endpoint: DALY Midpoint: kg NMVOC
Toxicity	Eco-indicator 99	Ecotoxicity	PAF m^2 year
		Carcinogens	DALY
	EPS 2000	Life expectancy	Person year
		Severe morbidity	Person year
		Morbidity	Person year
		Severe nuisance	Person year
	IMPACT 2002+	Aquatic ecotoxicity	kg TEG water
		Terrestrial ecotoxicity	kg TEG soil
		Carcinogens	kg C_2H_3Cl equivalent
		Non-carcinogens	kg C_2H_3Cl equivalent
	ReCiPe	Terrestrial ecotoxicity	Endpoint: species year Midpoint: kg 1,4-DB eq.
		Freshwater ecotoxicity	Endpoint: species year Midpoint: kg 1,4-DB eq.
		Marine ecotoxicity	Endpoint: species year Midpoint: kg 1,4-DB eq.
		Human toxicity	Endpoint: DALY Midpoint: kg 1,4-DB eq.

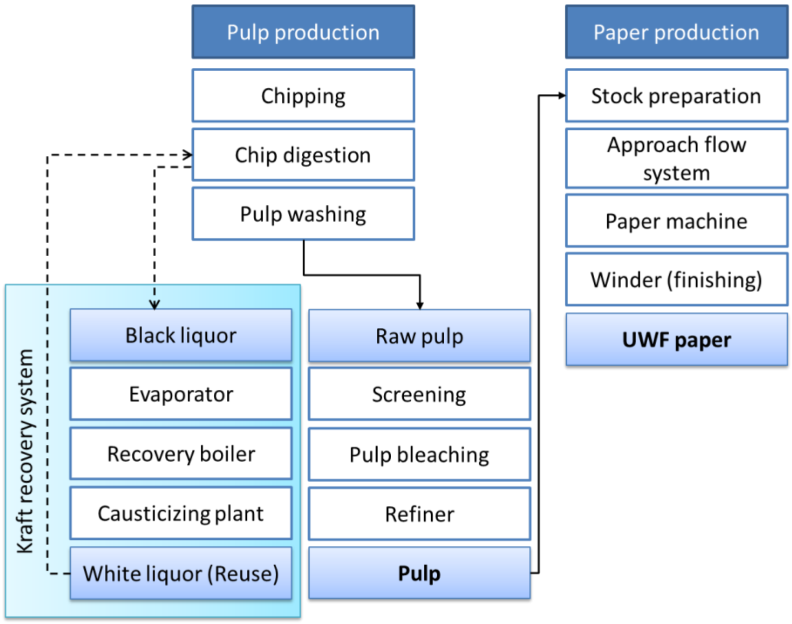

Figure 1 – Pulp and paper process flow.

In the pulp screening task the objective is to separate knots and fibre bundles from the raw pulp (EC 2001). Thereafter, the pulp goes to the bleaching task, in order to produce pulp with certain brightness and to remove residual lignin and impurities (Mark et al. 1982). ECF is a bleaching sequence that uses ClO_2 as bleaching agent (Portucel 2010). It was assumed that some chemicals employed in the bleaching task are produced on-site (APA 2012).

Table 2 - Inputs for the pulp and paper production.

Stage	Task	Compound	Input	Unit
Pulp production	Kraft recovery system	Sodium carbonate (Na_2CO_3)	2,460	[kg/ton of pulp air dry]
		Sodium hydroxide (NaOH)	8,270	
		Limestone ($CaCO_3$)	17,450	
	Pulp bleaching	Hydrogen chloride (HCl)	2,430	
		Sodium hydroxide (NaOH)	42,570	
		Sulphuric acid (H_2SO_4)	30,900	
		Sulphur (S)	10,300	
		Sodium chlorate ($NaClO_3$)	42,320	
		Oxygen (O_2)	2,180	
		Hydrogen peroxide (H_2O_2)	4,890	
Paper production	Stock preparation	Precipitated calcium carbonate (PCC) - Filler	193,000	[kg/ton paper]
		Starch - Sizing agent	11,500	
		Alkyl ketene dimer (AKD) - Sizing agent	0,740	
	Approach flow system	Retention aids – Retention agent	2,100	
		Optical brighteners - dyes	0,176	
	Paper machine	Starch surface - Sizing agent	32,400	
		Salt - Strength agent	4,600	

3.2. Paper production

The paper production comprehends stock preparation, approach flow system, paper machine and winder, after which the UWF paper is obtained.

Stock preparation and approach flow system tasks (Figure 1) convert the pulp suspension into stock for the paper machine. These tasks are based on the removal of impurities and water, the improvement of the strength properties of the fibres and the addition of chemicals to aid the process and fix the final quality of the paper sheet (Table 2). In the paper machine task (adding up of additives and steam drying (APA 2012)) the paper is formed and most of the properties of the paper are determined (Table 2). In the last task, winder reels the paper web into a roll (APA 2012) and the final product UWF is obtained.

In an integrated pulp and paper mill, as in the current case, the heat produced on-site in the CHP system, covers most total energy consumption for paper production. The additional energy requirement of about 2.200 MJ per ton of UWF paper is obtained using an auxiliary gas turbine operated by fuel. The average amount of pulp required to produce 1 ton of UWF paper is 0.61 ton (EC 2001), assuming an integration of 100%.

4. Results

Based on the four previous LCA methods, a comparison analysis is made between the two production stages, i.e. pulp and paper. All the environmental impacts are quantified, based on the functional unit of 1 ton of UWF paper, and compared among the four methods as shown in Figures 2 to 7. Sensitivity tests are subsequently performed taking into account these results, using again SimaPro 7.3.3 version. The inventory data used on the pulp and paper production was obtained from the literature (EC 2001; Portucel 2010; APA 2012) and on energy generation from the database Ecoinvent system processes 2.2 (Ecoinvent 2010).

4.1. Environmental Impact Analysis

Figures 1 to 3 show the *global warming*, *photo-oxidation formation* and *eutrophication* impacts for the four LCA methods. As can be seen, the EPS 2000 is not included, because it uses a different environmental impact characterization (Table 2).

For *global warming* slight differences can be found between methods, with paper production being the most problematic stage. This is a result of burning natural gas, since this combustion is responsible for almost all the paper stage impact due to the associated fossil CO_2 emissions. Pulp production impacts are related mainly to N_2O and CH_4 emissions from the combustion of renewable fuels at the CHP.

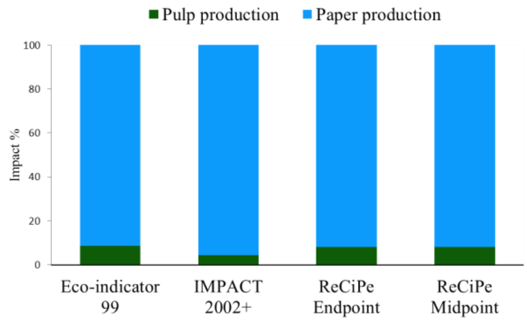

Figure 1 – Global warming.

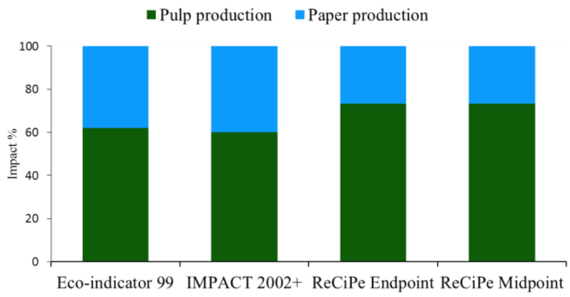

Figure 2 – Photo-oxidation formation.

As can be seen in Figure 2, there is no agreement in the impact percentage obtained for *photo-oxidant formation*. The Eco-indicator 99 and IMPACT 2002+ reach similar results, with the pulp production presenting an environmental impact of about 60%. For the ReCiPe mid and endpoint the pulp production stage exhibits a higher impact (73%).

The results of these first two methods are related to the CHP emissions, which contribute largely to the total impacts for both stages (paper and pulp), i.e. 96% for Eco-indicator and 89% for IMPACT 2002+. The consumption of H_2O_2 at the bleaching task contributes with 2% to the Eco-indicator 99 and with 4% to the IMPACT 2002+ for the pulp production impacts. For both methods the natural gas combustion also contributes to the paper production stage impacts (about 6%).

Table 3 - Main emissions and tasks for photo-oxidation formation assessment.

		Eco-indicator 99	IMPACT 2002+	ReCiPe
Tasks (%)	CHP system	96	89	68
	Pulp bleaching	1	4	25
	Gas turbine	2	7	2
	Chip digestion	0	0	5
Emissions (%)	NMVOC	9	27	≃0
	Hydrocarbons	66	21	≃0
	NO_x	0	0	92

Both ReCiPe levels have similar impact results. The most relevant tasks are CHP (68%), bleaching (25%) and chip digestion (5%). These tasks are responsible for the NO_x emissions, which represent 92% of the total. Differences in impact results are related mainly to different emissions and the CFs considered in the LCIA methods, but also to the NO_x emission (only considered in ReCiPe) and hydrocarbons (*aliphatic, unsaturated* in Eco-indicator 99 and *aliphatic, alkanes unspecified* in IMPACT 2002+).

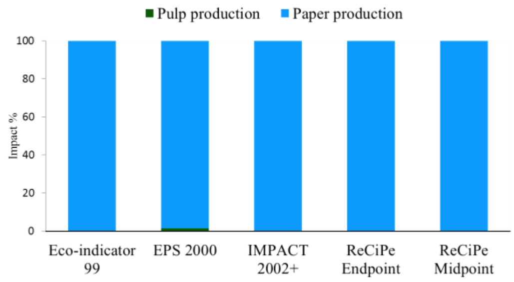

Figure 3 - Fossil resource depletion.

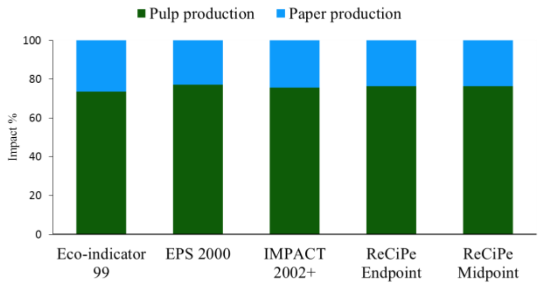

Figure 4 - Acidification.

Like *global warming,* the *fossil resource depletion* (Figure 3) identifies the paper production stage as displaying the greatest environmental impact. This is due to the fuel consumption at the auxiliary gas turbine. However, the EPS still identifies a small impact for the pulp stage (1.4%), which might be explained as a result of its environmental category, i.e. *depletion of reserves*, also considering the consumption of raw materials (e.g., sulphur) at the bleaching chemical on-site preparation. It can be concluded that all methods seem reliable for *fossil resource depletion* except EPS, since it considers other resources in its impacts. Despite this good agreement, different results may be expected when other energy flows are added on account of different CFs.

As to the *acidification* impact, all methods present similar results, as can be seen in Figure 4, although the Eco-indicator 99 and the IMPACT 2002+ account not only for *acidification* but also for *eutrophication* potential impacts (Table 1), hence their characterization differing from the other methods. A fairer comparison should aggregate Eco-indicator 99 with IMPACT 2002+ and the EPS 2000 with the ReCiPe. Also in the present case-study both ReCiPe levels reach exactly the same result, which is also common to EPS (Table 4). In other cases however they might show less agreement due to the difference in their CFs, since ReCiPe assigns a higher importance to ammonia, while the EPS to SO_2. For these two methods *acidification* quantification comes mainly from sulphur dioxide (SO_2) and nitrous oxides (NO_x) emissions (Table 4) in the bleaching and CHP tasks (pulp production), and in the natural gas turbine (paper production stage). Both methods Eco-indicator 99 and IMPACT 2002+ seem to be reliable for the *eutrophication* and *acidification* phenomena as a single indicator, while strictly for *acidification* a better choice are ReCiPe and EPS, both leading to a single indicator but with different units (Table 1).

Table 4 – SO_2, NO_x, and ammonia impact percentage for the ReCiPe and EPS.

Method	Emission (impact%)			
	Pulp production		Paper Production	
	SO_2	NO_x	NO_x	Ammonia
ReCiPe	16	54	21	2
EPS 2000	12	53	21	≃0

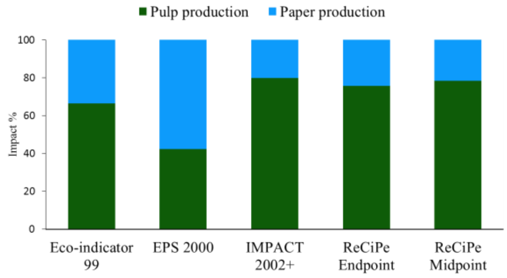

Figure 5 – Toxicity

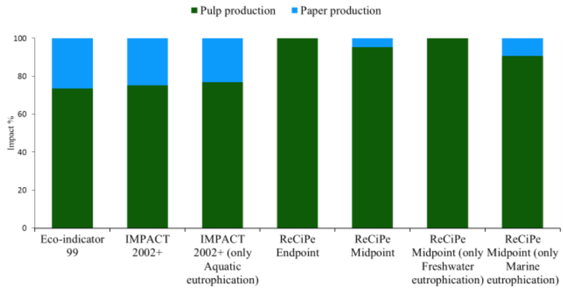

Figure 6 – Eutrophication.

Toxicity and *eutrophication* are those impacts presenting a higher variability, not only between the several methods but also between the two process stages (Figures 5 and 6). Figure 6 contains the two ReCiPe midpoint categories (last two bars) to illustrate the differences between ReCiPe mid and endpoint results, and also for the former *eutrophication in aquatic freshwater systems* with *aquatic eutrophication* of IMPACT 2002+.

The *toxicity* impact shows differences among the various methods, more marked in the case of EPS that presents a higher contribution of paper production. For the others the main contribution comes from the pulp production stage. These differences are related to the different impact categories (Table 1) employed by the LCIA methods, which make comparisons difficult. The ReCiPe mid and endpoints differ by 5%, as a consequence that at the pulp stage the copper emitted to the water in the bleaching task being considered in the midpoint *freshwater eco-toxicity* category (CF is 101 kg 1,4-DBeq) but not in the endpoint (without a CF). The same happens for *marine ecotoxicity*.

As examples of the *toxicity* results discrepancy, it is found that Eco-indicator 99's *ecotoxicity* is mainly related to zinc, copper and lead metal emissions (not shown), which are absent in *carcinogen*. In ReCiPe all the indicators consider these emissions, while in EPS only the lead is included in *severe nuisance*, and in IMPACT 2002+ they are present in all categories except in *carcinogen*. It is obvious that this and similar situations lead to different results and explains why there is no consensus for the *toxicity* assessment results. It is therefore difficult to point out a suitable LCIA method for the *toxicity* assessment based only on the impact assessment results.

In Figure 6 can be seen that *eutrophication* presents a high variability of results among methods, with EPS not even considering it. All the methods present the pulp as the most pollutant process stage, ranging from 70% to 100%. For the same reason mentioned in the *acidification* analysis, both Eco-indicator 99 and IMPACT 2002+ *eutrophication* results are assessed together (Figure 6). The main difference between them is related to their CFs and emissions considered, in particular the Chemical Oxygen Demand (COD) only assessed in IMPACT 2002+.

IMPACT 2002+ and ReCiPe have a similar category for *eutrophication* in aquatic freshwater systems, however results differ as can be seen in Figure 6. While both address the aquatic freshwater impacts, ReCiPe neglects those on the paper production stage, since it excludes COD emissions. In ReCiPe the main impacts come from the pulp production, while for IMPACT 2002+ they result not only from pulp but also from paper production, because once again COD emissions are only considered in the latter. Both methods, given their high impact scores, point out to phosphorus emissions at the pulp bleaching and chip digestion task as offering greater potential for further environmental improvement. In addition, the IMPACT 2002+ also points out to the chipping and pulp washing tasks.

In order to elucidate why results between the two ReCiPe levels differ, the ReCiPe midpoint is broken down in two contributions, also shown in Figure 6. ReCiPe mid and endpoints differ by 5%, because while both levels have the *freshwater eutrophication* category, the midpoint has in addition the *marine eutrophication*, thus accounting for other compounds, mainly NO_x and ammonia.

From this analysis, it was not possible to identify a suitable method for *eutrophication* impacts quantification. The ReCiPe method may be fit to model the *eutrophication* impacts as a single phenomenon, although it does not consider the COD emissions. The *eutrophication* and *acidification* impacts are jointly modelled in the IMPACT 2002+ but this method also incorporates the COD emissions.

4.2. Sensitivity analysis

In the present case, the critical emissions based on the EC (2001) document refer to the water, air and waste emissions, and it is therefore important to identify how sensitive the impact categories (output result) of each method are to a perturbation in these emissions. Water emissions include COD, biological oxygen demand (BOD), absorbable organic halides (AOX), nitrogen, phosphorus, chlorine dioxide and chlorate. Air emissions include NO_x, nitrogen dioxide (NO_2), SO_2, carbon monoxide (CO), CO_2, particulates, hydrogen sulphide and chlorine**.** Solid waste emissions include slags, ashes and green liquor sludge (metals).

Since the SimaPro software has a linear relationship between inputs (emissions) and outputs (impacts), for each impact category, one single test was investigated through the application of a variation of 10%, as expressed by equation 1.

$$SA\ Impact\ category_i = \frac{\dfrac{1{,}10 * Impact\ category_i - Impact\ category_i}{Impact\ category_i}}{10\%} \quad (1)$$

The results obtained for each impact category are presented in Table 5, in the form of environmental and impact categories reflecting the SA results. A graphic is added showing the intensity of the impact category for each method, thus allowing to identify those methods with the highest SA index for each environmental impact. Table 6 sums up these findings and shows in the first row the percentage of critical emissions assigned to the environmental impacts, and in the remainder the sensitivity categories deducted from Table 5, by expressing as percentage the number of impact categories with non-zero sensitivity coefficients.

Table 5 - Sensitivity analysis (SA) results.

Environmental impact	Method	Impact categories	SA Value
Global warming	Eco-indicator 99	Climate change	2,19
	EPS 2000	-	-
	IMPACT 2002+	Global warming	2,30
	ReCiPe	Climate change Human Health	2,21
		Climate change Ecosystems	2,21
Acidification	Eco-indicator 99	Acidification/ Eutrophication	1,28
	EPS 2000	Soil acidification	1,38
	IMPACT 2002+	Aquatic acidification	1,40
		Terrestrial acid/nutri	1,29
	ReCiPe	Terrestrial acidification	1,34
Photochemical oxidation formation	Eco-indicator 99	Respiratory organics	0,00
	EPS 2000	-	-
	IMPACT 2002+	Respiratory organics	0,00
	ReCiPe	Photochemical oxidant formation	1,30
Eutrophication	Eco-indicator 99	Acidification/ Eutrophication	1,28
	EPS 2000	-	-
	IMPACT 2002+	Terrestrial acid/nutri	1,29
		Aquatic eutrophication	1,48
	ReCiPe	Freshwater eutrophication	1,65
Toxicity	Eco-indicator 99	Ecotoxicity	0,01
		Carcinogens	0,00
	EPS 2000	Life expectancy	0,62
		Severe morbidity	1,40
		Morbidity	2,03
		Severe nuisance	0,00
	IMPACT 2002+	Aquatic ecotoxicity	1,28
		Terrestrial ecotoxicity	0,00
		Carcinogens	0,00
		Non-carcinogens	0,87
	ReCiPe	Terrestrial ecotoxicity	1,00
		Freshwater ecotoxicity	0,50
		Marine ecotoxicity	0,15
		Human toxicity	0,06

Table 6 – Critical emissions and sensitivity categories of the LCIA methods.

	Eco-indicator 99	EPS 2000	IMPACT 2002+	ReCiPe
Critical emissions considered (%)	41	71	59	53
Global warming sensitivity categories (%)	100	-	100	100
Acidification sensitivity categories(%)	100	100	100	100
Photochemical oxidation formation sensitivity categories (%)	0	-	0	100
Eutrophication sensitivity categories (%)	100	-	100	100
Toxicity sensitivity categories (%)	50	75	50	100

Having in mind the objectives set for this work, the most suitable method should be the one that presents higher sensitivity for most of its impact categories.

The EPS despite considering 71% of the critical emissions is the method with the lowest number of impact categories (identified with a hyphen in Tables). It only assesses *acidification* and *toxicity* emission impacts, with SAs respectively of 100%, and 75%.

The Eco-indicator 99 has apparently four sensitive environmental impacts, namely *global warming*, *acidification*, *eutrophication* and *toxicity*. However, two of them, i.e. *acidification* and *eutrophication*, are achieved through the same impact category (i.e., *acidification/eutrophication*), thus reducing its adequacy because the number of sensitivity categories is less than for the other methods. Furthermore this method only considers less than half of the critical emissions and is not suitable to model the wastewater impacts.

The IMPACT 2002+ and the ReCiPe consider slightly more than 50% of the critical emissions. The *photo-oxidant formation* indicator of the IMPACT 2002+ bears no sensitivity to a change in the critical air emissions and some of the indicators of the *toxicity* impacts are not sensitive to a change in the inputs.

The ReCiPe is the method with a higher number of sensitivity impact categories. All the environmental impacts are completely characterized by the corresponding environmental categories, as can be seen in Tables 4 and 5.

5. Conclusions

Eco-Indicator 99, EPS 2000, IMPACT 2002+ and ReCiPe (mid and endpoint levels) methods were applied and tested to a pulp and paper case-study. To investigate their adequacy, *fossil resources*, *global warming*, *acidification*, *eutrophication*, *photo-oxidation formation* and *toxicity* impacts were assessed. It should be noted that even for methods with the same trend, the ranking results might not always relate to the same tasks and compounds, due to the application of different characterization factors.

As a general conclusion it is found that impact results differ among methods for some environmental categories, mainly for *eutrophication*, *photo-oxidation formation* and *toxicity* impacts.

Eutrophication is contemplated in the ReCiPe and IMPACT 2002+ methods, however the former does not consider COD emissions and the latter models jointly the *eutrophication* and *acidification* impacts.

For *photo-oxidant formation*, and according to EPA (1998), the NO_x is a contributor, thus the ReCiPe is a good choice since it is the only method that takes this emission into account.

Concerning *toxicity*, due to the difficulty in interpreting results of this category the criteria selection should attend to the sensitivity analysis and to the methods that use the most updated *toxicity* models, which according to Pizzol et al. (2011) is the USES model employed by ReCiPe.

From the sensitivity tests it was possible to conclude that compared to the other methods the EPS 2000 is not suitable to the current case-study, given the number of environmental impacts assessed and sensitivity categories obtained. Conversely, ReCiPe is the method with more sensitivity impact categories and with all environmental impacts being completely characterized by its impact categories.

Based on the impact assessment and the sensitivity analysis undertaken, the most suitable of the four ready-to-use methods are the ReCiPe (mid and endpoint levels) and the IMPACT 2002+, given the expected most significant environmental impacts in the pulp and paper industry. Despite the two ReCiPe levels differing slightly in some impact results there are advantages to model both. This is because the midpoint has environmental impact units easier to understand and allows the identification of the categories related to the single-score value achieved with the endpoint level.

The widespread general concern with sustainability requires that an industrial process may only run for profit with due measures related to the environmental impact of its operation. A process optimization study which addresses simultaneously economic and environmental criteria will not only be instrumental in achieving this goal but can in addition demonstrate the added business benefit of a proper handling of the environmental issues. This will be the next step in our work following the present analysis on the selection of adequate ready-to-use LCIA methods and the exploration of the integration of social impacts.

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Sustainability Indicators for Electric Utilities: a proposal using PCA

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Abstract

This article presents a proposal to address the environmental, social, economic and financial information, generically reported by European electric utilities, to concentrate that information on a limited set of indicators, capable of widespread application. These indicators represent the activities and contributions of selected companies for internal and external sustainability. European electricity utilities were chosen as the object of the present study, both because having a large impact on social, economic and environmental issues and because integrating a regulatory and market specific context. However, the evolution of their global performance is hardly compared, once it is still hampered by the use of a very broad set of indicators, some of them with a qualitative character. Consequently, the focus of the present work is the application of multivariate techniques, in order to condensate a large amount of data into a set of electricity industry representative indicators, with the minimum loss of information. The use of Principal Components Analysis technique allowed identifying, from a large set of indicators, those with a stronger explanatory power, which act as representatives of all the other. The methodology, which presents a quite innovative character when applied to sustainability indicators, proved to be adequate and provided valuable outputs.

Keywords: Sustainability reporting, European electricity industry, principal components analysis, industry performance indicators.

JEL classification codes: L94; M14; Q56

1. Introduction

The concept of sustainability applied to business may be faced from two interconnected and interdependent perspectives. An inner vision, which refers to the company's ability to survive on a long-term and an broader vision, which refers to the company's contribution for the sustainability of the planet. The aforementioned, results into a systemic, interactive and holistic vision, whereby companies integrate a grid of relationships that they influence as economic agents, but in turn they are conditioned by the context in which they move.

The energy sector is fundamental for sustainability. The sector's contribution both for the depletion of natural resources, for the pollutant emissions and for the creation of social well-being is undeniable (Azapagic and Perdan 2000; Azapagic 2003). The electricity industry in Europe plays a central role in European sustainability scenario because the production is still largely based on fossil fuels and on nuclear generation, which implies long-run impacts mainly associated with green gas emissions and waste management.

Consumers, investors, managers and regulators are looking for credible, reliable, relevant, usable and comparable data, to use for the decision making, the definition of strategies, the evaluation of performance or benchmarking (Edvardsen and Førsund 2003), (Jamasb and Pollitt 2003). In this field Sustainability Reports (SR´s) and Corporate Social Responsibility Report (CSRR) are assuming an increasing importance both at corporate level and business overall concerns. However, those Reports seem to contain many hard-to-verify or incomplete statements. A close survey of the available models of disclosure and reporting proved to be unreliable: the term "sustainability reporting" is being used in a partial way, once it refers only to deliberately exposed issues. In these cases, it subverts the aim and misleads the readers (Gray et al. 1997; Gray 2001; Kolk 2004; Meehan 2006; Adams 2004; 2007; 2008; Adams and Evans 2004; Larrinaga-Gonzalez and Bebbington 2001; Bebbington et. al. 2007; Owen et al. 2000, Hess and Dunfee 2007, Martins et al 2007, Doane 2005; Arnold 2008; Hubbard 2009; Rahman and Post 2011). That makes difficult to discern and to make a proper judgment of what is being actually reported. There is a mosaic of approaches and methods that can lead to different results and therefore can induce to distortions on the evaluation and pursuit of corporate sustainability. The definition of a methodology to identify industry specific issues to report is leading to legitimate decision-making and ultimately to improve the overall level of industry performance (O'Dwyer and Owen 2005; Adams 2008, Kolk 2004; Bebbington et al. 2007; Ilinitch et al. 1998; Hubbard 2009; Arnold 2008; Azapagic 2003; Lydenberg et al.2010).

Meanwhile, on the peculiar case of electric public utilities there are few academic papers that address the key issues of CSR reporting. Public Utilities by their own nature and scope are intended to be accountable to various stakeholders. Because of providing a public service and for presenting large-scale impacts, electricity-producing companies have accrued responsibility for reporting to their stakeholders. Therefore, disclosed information is subject to careful scrutiny and analysis. Electric utilities are a good example having to deal with challenges emerging on a global scale. Yet, most of these companies have been carefully preparing non-financial reports for the early years, they move between vast borders, enabling them to decide what to report or not. Even from the same industry, reports still miss from homogeneity of information along time and between peers. The lack of comparability makes it difficult to identify best practices and to markup the best results.

In general, standards for sustainability reporting are still missing. The submission of information relating to sustainability and corporate performance suffers from the lack of standardization and comparability (Krajnc and Glavic 2005; Kolk 2004; Gasparatos and al 2008). Key questions regarding frameworks, measurement and empirical methods have not yet been settled. Dozens of frameworks for assessing corporate sustainability performance have been proposed, using a large amount of indicators. However, the heterogeneity of measures hinders the analyses over time and the comparisons between companies (Krajnc and Glavic 2005). By other hand, it is important to realize to what extent the indicators will be used, since their collection requires effort and resource use. It is a fact that the assessment of such a complex concept as sustainability demands the use of several indicators (Krajnc and Glavic 2005; Kolk 2004; Gasparatos and al 2008), chosen and analyzed under certain criteria to better describe such intricate systems. Accordingly, the choice of tools and indicators must be carried out in accordance with the context and settings to show (Gasparatos and al 2008). The main limitations on a representative and meaningful report are aggregated in three main groups (*Figure 1*).

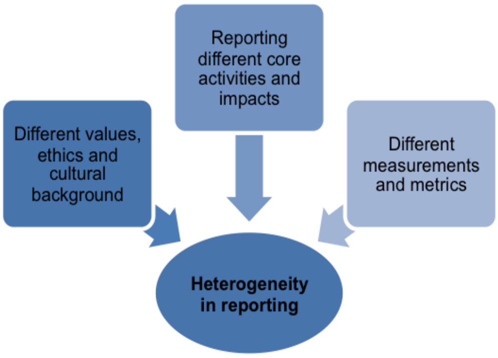

Figure 1 Main limitations on sustainability reporting

A monitoring system based on comparable, relevant and representative indicators for industry critical issues, it is assumed as an important contribution to assure accountability, to improve transparency, provide comparability and increase completeness on reporting. The present work intended to test a methodology to signal key issues in terms of corporative sustainability and identify a small set of indicators, obtained, as far as possible, free from bias and subjectivity of values, representing material contributions from European electricity producers to sustainability.

2. Methodology

The use of a not very extensive set of representative indicators of sustainability performance is relevant to understand and to relativize the performance of each company regarding the industry. Given that each sector has specific characteristics that influence the definition of relevant indicators (Ziegler 2011), this research focused on the production and commercialization of electricity. To handle this problem it was decided to use a Factor Analysis technique (FA), since it allows the identification of the most representative indicators from a vast available set and it provides the summarization of the information in smaller groups of components. As far the survey of literature allowed to conclude, the use of factor analysis is quite innovative in addressing the corporate sustainability issues, especially in the case of non-dichotomous variables use. In the present study the technique was applied to non-dichotomous variables, collected from European companies in the energy sector. The analysis was performed upon a database constructed by the author using: publicly available data from company reports and websites, industry reports and other open access sources.

The present study is mainly focused on European Union member countries, once they fall under the umbrella of global policies and goals for energy and under a common energy regulatory framework. Yet, some companies based in other European countries but outside the EU, were also included in the study once the scope of its activities with EU member states fall necessarily under the guidance of the Community rules. Select energy firms integrated both public and private entities, but also investor owned and cooperatives. The selection criteria were:

- Companies with headquarters in Europe, in order to limit the study to those firms with greater role in European territory

- Companies with core business related to electricity production, although they may distribute their activities for a variable range of business areas (e.g., electricity production, distribution and transportation of gas and / or electricity, oil and gas exploration and production, sanitation and water supply, environmental services and others).

- Availability of non-financial information, disclosured in published corporate reports (sustainability, citizenship, corporate responsibility or annual reports), or posted on the companies website.

The application of selection criteria resulted on the following list (Table 1):

Table 1 Selected companies

Name	Headquarter	Installed capacity (MW)	Name	Headquarter	Installed capacity (MW)
Acciona	Spain	7 587	ENEL SA	Italy	97 281
BKW FMB Energy Ltd.	Switzerland	2 532	EON AG	Germany	68 475
Cêntrica	UK	4 672	ESSENT	Netherlands	4 048
CEZ GROUP	Czech Republic	15 018	EVN	Austria	1 787
Dansk Olie og Naturgas	Denmark	6 654	Fortum Corporation	Finland	14 113
Drax	UK	4 000	Gas Natural Fenosa	Spain	17 305
Edison	Italia	12 586	Hafslund	Norway	0
Eesti	Estonia	n.a.	Iberdrola SA	Spain	44 991
Electrabel	Belgium	11 233	International Power	UK	70 196
EDP SA	Portugal	21 990	NUON	Netherlands	3 645
EDF SA	France	140 100	Rwe AG	Germany	52 214
Electricity Supply Board	Ireland	5 600	Scottish Southern Energy	UK	11 330
EnBW Energie Baden-W.	Germany	15 489	Statkraft	Norway	16 010
Endesa SA	Spain	40 141	Vattenfall AB	Sweden	39 923
Eneco	Netherlands	2 200	Verbund AG	Austria	8 638

After selecting the sample (Table 1), a set of generic relevant issues for the industry was presented. These issues were decomposed in themes applying the recognized framework Global Reporting Initiative (GRI). For each theme, several indicators were proposed. The relevance of indicators for sustainability was rooted on the characteristics of the industry. After knowing the depth and relevance of electric utilities real impacts, the most relevant issues arising from their activities as economic agents were defined, without neglecting the social and environmental externalities (Table 2).

Table 2 Industry key issues for corporate sustainability dimensions:

Economic	**Environmental**	**Social**	**Financial**
• Installed capacity	• CO_2 Emissions and other GHG emissions	• Employment conditions and professional development	• Sustained increase in the company value
• Distributed vale added	• Renewable energy sources	• Health and safety	• Ability to meet the long run commitments
• Generation and end-use efficiency	• Water use	• Community support	• Long-term profitability
	• Biodiversity	• Corruption and bribery	
	• Residuals • Nuclear waste		

Hereafter the criteria for selection of indicators was defined and applied: qualitative variables were rejected; indicators reported for a small number of companies (less than 33%) were eliminated, given their low representativeness in terms of the sample; indicators with less than 50 observations were eliminated given their low representativeness in terms of the issue. The remaining amounted to a total of 64 variables, which were used for the construction of composite indicators. Finally, the data needed for composed indicators was collected and treated so that the defined multivariate technique could be implemented.

This way, based on available data and on industry key issues was constructed a panel of mixed physical and monetary indicators covering the environmental, social, economic and financial issues for corporate sustainability on electric utilities. The use of absolute indicators make difficult to accomplish comparisons between companies with very different scales and may induce distortions in the results. The relativization of indicators enables to control several problems that could arise during data analysis. In this study, we used a set of 52 composite indicators, relativized according to the dimension (size and production capacity) and referring to environmental, economic, social and financial issues. It was intended they could provide an adequate benchmarking for the companies under study regardless their differences.

A very vast set of variables, although providing large information usually ends up presenting a difficult and complex interpretation by users. However, some variables are naturally associated presenting similar behaviors. For example, it is expected that increases in production's capacity be accompanied by a revenue variation in the same direction. The overlapping of some variables is much likely to occur among a large set of variables, than between few variables, which may remain distinctive and different. This way, a large number of variables that expresses a particular reality, can be replaced by a smaller group, which maximizes the explanation of the entire data set.

Factor analysis techniques allow to understand the structure and interrelationships of a wide number of variables addressed in multivariate techniques, in order to determine underlying patters, that may support the condensation of large amount of information into a smaller set of factors or components (Hair 2009). It has been widely used in business related research. The present study used one of FA techniques, which is the Principal Components Analysis (PCA). In PCA it is assumed that all variability in an item should be used in the analysis. Factors are based on the total variance[1] (common, unique and error variance). The method is primarily used to summarize most of the original information (correlated variables) into a minimum number of factors (principal components), which account for the maximum portion of total variance of the original set of variables. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible.

3. PCA Results

PCA was primarily used for each dimension of sustainability. From the initial 52 variables used in former PCA, those 19 with higher loadings, were then mixed on a joint set of variables, representing the four dimensions of corporate contribution for sustainability (Table 3) and (Table 4) and then applied the PCA for the second time. From the 19 possible components to extract, the use of the eigenvalue allowed to select the first seven Principal Components (PC´s), which apprehend 83% of the total variance. The contribution for the explanation of total variance assumes a decreasing importance from component one (PC1) to component seven (PC 7). For aggregated variables in Table 3, the principal component PC1 explains about 21% of all the variance for the original set of variables and 25% of the variance explained by the solution of the seven principal components. The following components explain successively lower amounts of the residual variance.

Table 3 PCA for aggregated variables

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	
IWA	- 0,295865	0,354307	- 0,104866	- 0,215608	0,103184	- 0,038489	0,361657	Econ
IH_GENTH	-	-	0,453500	-	0,04568	-	0,19301	Econ

[1] Variance is a value (i.e. the square of the standard deviation) that represents the total amount of dispersion of values for a single variable about is mean (Hair 2009).

	0,126872	0,324914		0,294518	3	0,144196	1	
IGENT_SAL	-0,073257	0,110542	0,215481	0,362014	0,208333	0,080756	-0,041984	Econ
IEVD_LEN	-0,248748	-0,117262	-0,067649	0,229041	-0,163599	-0,103377	0,491131	Econ
IEVD_TAX	-0,253883	-0,107099	0,206514	0,259951	0,007433	0,079893	-0,030853	Econ
IBYPRO	0,099482	0,004441	-0,439389	0,307673	0,306264	-0,083183	0,356834	Econ
IGENRE_T	0,276099	0,204758	0,330411	0,062170	-0,003132	-0,211200	0,140402	Environ
IGENRENU_T	0,235950	0,094323	0,436251	0,259552	0,143329	-0,132825	0,171635	Environ
ICO_TH	0,306249	0,110704	-0,161537	-0,022131	-0,250504	0,182302	0,022926	Environ
IWST_ZREC	-0,013248	0,400759	0,253548	-0,298454	-0,164994	0,205972	-0,011791	Environ
E_PS	-0,109028	0,162367	-0,028712	-0,039816	0,140024	-0,399368	-0,468929	Financ
IDBT	0,423486	0,108044	-0,092375	-0,153910	-0,235780	0,009293	-0,115440	Financ
ROA	0,060087	-0,020483	0,017121	-0,159847	0,640255	0,140792	-0,010016	Financ
ROE	0,146037	0,016828	-0,026150	-0,214110	0,437892	0,428839	-0,286949	Financ
IEMP_ABS	-0,122885	-0,283774	0,200828	-0,044786	-0,132539	0,481334	-0,014010	Social

IEMP_ACC	-0,257146	0,364911	-0,109476	-0,101049	-0,073909	0,174247	0,010579	Social
IEMP_FTC	-0,387496	-0,368354	-0,089898	-0,018249	-0,040914	0,060572	0,015334	Social
IEMP_TURN	-0,284979	-0,288687	-0,179569	-0,089375	-0,056332	0,060733	0,028900	Social
IEMP_WOMB	-0,012238	0,190525	0,061447	0,492969	-0,089258	0,420238	0,034721	Social
Proportion	**0,205000**	**0,150800**	**0,134400**	**0,119400**	**0,093100**	**0,071300**	**0,054800**	**0,8288**
Corrected proportion	**0,247346**	**0,181950**	**0,162162**	**0,144064**	**0,112331**	**0,086028**	**0,066120**	**1,0000**

Table 4 Summary of aggregated variables

Variables	**Description**	**Variables**	**Description**
IWA	Cooling water used per unit of electricity generated	E_PS	Earnings per share
IH_GENTH	Weight of heat generation on the total electricity generation	IDBT	Weight of net debt on the total assets
IGENT_SAL	Weight of electricity generation on the total electricity sales	ROA	Return on assets
IEVD_LEN	Weight of payments to lenders on the Economic Value Distributed	ROE	Return on equity
IEVD_TAX	Weight of taxes (income and others) on the Economic Value Distributed	IEMP_ABS	Employee absenteeism rate
IBYPRO	Share of recovered by-products (gypsum and ash)	IEMP_ACC	Average accidents per one hundred employees
IGENRE_T	Share of renewable sources in electricity production	IEMP_FTC	Share of employees with full-time contract
IGENRENU_T	Share of CO2 free electricity production	IEMP_WOMB	Share of women in the management board
ICO_TH	CO2 relative emissions from electricity generation (Kg per kWh)	IEMP_TURN	Share of employees replaced within the company, excluding retirements
IWST_ZREC	Share of recovered hazardous waste		

After signaling the variables with a loading above 35%, we identified the variables with higher weight in each component. In component 1 (PC1) variables with the highest loadings are: weight of net debt on total assets (IDBT) and share of employees with full-time contract (IEMP_FTC). In the first component (PC1) issues assuming greater relevance are those relating both to debt to assets, type of labor contracts and labor stability. The increase in debt relative to assets implies greater accountability to lenders, which often leads both to precarization of labor contracts and to use of part-time work as a way to reduce staff costs. CO_2 emissions from thermal also present higher loadings, which may indicate that this situation is linked to those heavy technologies, which demand larger investments. PC1 reflects the equilibrium between the commitments assumed toward lenders and employees.

In component 2 (PC2) variables with the highest loadings are: (IWST_ZREC), average accidents per 1000 employees (IEMP_ACC), share of employees with full-time contract (IEMP_FTC) and cooling water used for electricity generation (IWA), In the second component (PC2) issues assuming greater relevance are those relating both to occupational and environmental safety and staff retention. The precarious nature of employment contracts affects the individual's professional training and potentiates the occurrence of accidents. The company concerns with the proper routing of hazardous waste and water consumption reflect some accountability with the impacts of its own activities and with the fulfillment of its legal obligations. PC2 reflects the concern with labor and environmental safety.

In component 3 (PC3) variables with the highest loading are: weight of heat generation on the total electricity generation (IH_GENTH), share of recovered by-products (IBYPRO) and share of CO_2 free electricity production (IGENRENU_T). In the third component (PC3) issues assuming greater relevance are those relating both to production efficiency on: using renewable sources, valuing heat production and marketing byproducts. It relates the electricity production sources with the technology used for electricity production. PC3 reflects the efficiency on resource use from CO_2 free technologies

In component 4 (PC4) variables with the highest loading are: share of women in administration board (IEMP_WOMB), weight of electricity generation on the total electricity sales (IGENT_SAL). In the forth component (PC4) issues assuming greater relevance are those relating both to Component 4 refers to the share of woman in board with electricity sales. PC4 reflects the influence of women on commercial management.

In component 5 (PC5) variables with the highest loading are: return on assets (ROA), return on equity (ROE). In the fifth component (PC5) issues assuming greater relevance are those relating both to return on assets and equity. PC5 reflects the balance between assets and the financing structure of the company.

In component 6 (PC6) variables with the highest loading are: (IEMP_ABS), share of women in administration board (IEMP_WOMB), return on equity (ROE) and earnings per share (E_PS). In the sixth component (PC6), issues assuming greater relevance are those relating both to motivation of employees, return on equity and women in management board. The absenteeism rate has been appearing associated with the percentage of women in the labor force. However, the participation of women in top management contributes to higher returns on equity, albeit, in the present case, with lower ability to generate revenue for each title of ownership. PC6 reflects the commitment of senior management.

In component 7 (PC7) variables with the highest loading are: weight of payments to lenders on economic value distributed (IEVD_LEN), earnings per share (E_PS), cooling water used for electricity generation (IWA). In the seventh component (PC7) issues assuming greater relevance are those relating both to weight of debt in the company's profitability, efficiency on water use and earning per share. Water use appears once again associated with loans obtained and earnings from ownership. Usually water use is higher on those technologies, which demand larger investments on facilities, personnel and equipment (thermal or nuclear facilities). These units incur in high costs both for startup and for infrastructure maintenance, usually demanding large amounts of borrowed capital. Before increased liabilities, earnings per share may decrease. The trade-off of returns on equity and debt is, in this component, linked to the technology chosen for electricity production. PC7 reflects the influence of the production technology on capital remuneration.

Considering the descriptions and interpretation previously performed, it is proposed the following naming for the components (Table 5).

Table 5 Aggregated Principal Components - summary

Principal component	**Component proposed name**	**Share of explained variance**
PC1	Commitment to lenders and employees	25%
PC2	Environmental and labor safety	18%
PC3	Efficiency on resource use from CO_2 free technologies	16%
PC4	Impact of women on commercial management	14%
PC5	Return on assets and equity	11%
PC6	Commitment of senior management	9%
PC7	Distribution of value between shares and debt	7%

From all components, there is a valuation of the issues related to the commitment with lenders and employees, which explains almost 25% of variance. Environmental and labor safety, represents almost 18% of the explained variance, while efficiency on resource use from CO2 free technologies explains 16% of variance. The sum of the three first components accounts for approximately 59% of the total variance of the aggregated issues. The remainder relates to others themes such return on assets and equity, senior management commitment and distribution of value between shares and debt. Knowing that the obtained Principal Components (PC´s) summarize the behavior of the sample, the PCA for the aggregate dimensions of the corporate contribution for sustainability, may be synthesized in the previous seven perspectives, which jointly characterizes the sector of electricity production.

After the application of the methodology, the dimensions of corporate sustainability were characterized in terms of the established indicators. In the case of the European electricity production, these dimensions are highlighted comprehensively by:

- Return on assets, equity and debt capital (economic and financial dimensions).
- Efficiency of production technologies (economic and environmental dimensions)
- Efficient use of resources (economic and financial dimensions)
- Equity in the distribution of economic value generated by the stakeholders (economic and social dimensions)
- Working conditions, relating to the contract of employment and health and safety (social dimension)
- Contribution of women on production and management (economic and social dimensions)
- Pollution (environmental dimension)

3. Conclusions

The identified components highlight the most relevant issues derived from the information collected in the sample for this analysis. However, other sustainability issues also relevant for the sector were not included due to insufficient workable data. The present research was based on non-experimental data, gathered from the companies in the sample. Although collected with great care and rigor, it is recognized that it still lack of higher quality. Errors may occur from the measurement of the variables, both due to problems of heterogeneity of concepts, measures and metrics and due to the fact that there is many missing data for the selected sample. Thus, some care is needed in the analysis and application of the obtained results. Besides, as previously noted, some areas relevant to the industry of electricity are rarely reported.

The analysis is thus limited by the unavailability of data, which are not uniformly presented by the sample. It is advisable a stronger homogenization of concepts and metrics to enhance greater soundness of the analysis and to allow more reliable results. In the presence of information gaps the partial answers obtained may register selectivity bias and thereby not represent exactly the general sample. Moreover, another problem encountered is that the use of indicators composed by two or more variables, implies the potentiating of the lack of information (if the value for one variable is missing the indicator can not be calculated). This way, the use of indicators in some cases similar and complementary is intended to overcome the missing data and to cover the industry critical issues as broadly as possible. Regarding the performed Principal Components Analysis there is a loss of information in two ways:

- The information contained on components that are not considered in the analysis, those beyond the eigenvalue. Excluded components can be more discriminating in regard to the sample and present less homogeneous information.

- The information excluded by the use of surrogates variables. As only one variable is selected to represent a complex result (component), there is always a risk of over-simplifying the complexity of the components previously calculated.

Moreover, some concepts of corporate contribution for sustainability are exclusively associated with few variables. If none of them is assumed as surrogate variable the concept does not appear at the aggregated level analysis.

To end this section, it can be concluded that apart from these limitations, the methodology revealed a set of relevant information to the knowledge of the electricity production sector in Europe and the corresponding contribution to sustainability. It is also expected that a clear disclosure of corporate sustainability performance may provide a better understanding about corporate externalities and the respective actions undertaken for internationalization of costs, as also the resulting successes or failures. The methodology proved effective in selecting a group of indicators, sufficiently small but representative of corporate contribution for sustainability, covering the most relevant issues to the sector. The ascertained indicators represent a summary allowing an assessment of sustainability performance between companies and in the long run.

As new data is being collected and made available, expectedly in the near future, the methodology developed may be applied to sweep the extended set of indicators and to select the most relevant new ones. The set of ascertained indicators is representative of corporate sustainability, given the basic information that we managed to collect. The definition of homogeneous methodologies for data collection and its effective implementation among companies, may allow the integration of new data and indicators, enabling a more accurate perspective for the corporate sustainability performance.

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Bringing in competing stakeholders:
A sustainable management of the Alqueva Reservoir

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Abstract

Alqueva Reservoir is one of the largest of irrigation systems in Europe. This system supports the agricultural production in the Alentejo region in southern Portugal. The area receives a little rainfall and thus artificial irrigation system is needed to sustain the industry. To address this, the Alqueva Multipurpose Project (AMP) was specially created. This venture is centrally managed by the Empresa de Desenvolvimento e Infrastruturas do Alqueva, SA, (EDIA). The mission of AMP goes beyond supporting irrigation; it also provides water for domestic consumption to over 20 counties, produces hydropower electricity from several dams spread throughout the region, and eventually support for a growing local tourism. This study seeks to model the dynamic behaviour of the AMP through the interaction of these sectors. System dynamics approach is used to evaluate the sustainability of the reservoir amidst the competing goals of its stakeholders. The three subsystems – Alqueva, Pedrogao, and Ardila – are modelled. Sensitivity analyses are done to show different scenarios that result from varying levels of water supply (river input, precipitation, evaporation), demand (irrigation, domestic consumption, tourism), and price elasticity.

Keywords: Alqueva Reservoir, sustainability, sustainable management, system dynamics, Alqueva, Perdogao, Ardila

JEL Classification code: Q56 - Environment and Development; Environment and Trade; Sustainability; Environmental Accounts and Accounting; Environmental Equity; Population Growth

1. Introduction

The Alentejo region occupies almost a third of mainland Portugal. This area has low demographic density, accounting for only 5 percent of the population. The scarcity of water in the region has been one of the main restraints to development, impeding the modernization of agriculture and the sustainability of public water supply services (EDIA, 2012). The Alqueva Multipurpose Project (AMP) was conceived as a regional development project, formulated to meet the needs of a strategic water reservoir for the Alentejo, a semi-arid region in southern Portugal (Videra, 2002). Promotion of efficient use of water through better management of water resources is important under the conditions of severe water shortage (Shangguan et al., 2002). Without adequate irrigation, the Alentejo region in Portugal faces desertification. Damming the Guadiana River enabled the Alqueva Multipurpose Project to be implemented to tackle the problem. The project is succeeding in providing a guaranteed supply of water to the population and industry in the region, while coping with fluctuating water demands (World Pumps, 2011).

The following are the goals of the AMP: (1) The establishment of strategic water reserve, with a capacity sufficient to meet all the needs of at least three successive years of drought; (2) guarantee water supply to the population, industries, and agriculture within the project intervention area; (3) amendment of the Cultural Agricultural Model, with the gradual introduction of new irrigation areas; (4) the production of non-polluting electrical energy using renewable sources; (5) the preservation of the environment, monitoring and actively participating in the improvement of the same; and (6) promotion of quality tourism by means of cooperation with public and private entities, the execution of Land Use Plans and systematic efforts to ensure the sustainability of the interventions (EDIA, 2012). The AMP is centred on the Alqueva Dam, built on the Guadiana Rriver and the main infrastructure of the project. This enables the creation of a reservoir with an inter-annual regulation capacity from which water may be distributed throughout the region. Complementing the dam, which is equipped with a hydroelectric plant, is the Pedrogao Dam, located 23 kilometres downstream from Alqueva beside the settlement of the same name and also equipped with a min hydroelectric plant. The purpose of the Pedrogao Dam is the creation of a downstream reservoir in Alqueva for the recovery of flows, also serving as a source of water for the Ardila and Pedrogao water supply subsystems (EDIA, 2012).

2. Objectives of the study

The study seeks to address the following issues:

1. How can the Alqueva water reservoir be managed in a sustainable way given the fluctuating water demand of the three subsystems, namely: Alqueva, Pedrogao, and Ardila?
2. How will a sustainable water supply be guaranteed for the following conflicting stakeholders under periods of long drought?
   - Agricultural demands for irrigation

- Energy production
- Domestic consumption
- Tourism

3. Review of Literature

3.1. Agriculture, irrigation, and hydropower generation

Generally, irrigation water amount is negatively correlated to the precipitation amount, and could also be very high when the precipitation is abundant (Liu et al., 2010). In Africa, where irrigation is a major problem, sustainable irrigation has been the interest of some researchers. For instance, Urama (2005) developed a framework for assessing the sustainability of an irrigation scheme in South-eastern Nigeria. In Morocco, Schilling et al. (2012) analyzed the impacts of climate and adaptation options and found out that agricultural incentives used in the past are inadequate to buffer drought effects. Chebud et al. (2009) used a mass balance approach to estimate the hydrological balance of Ethiopia's Tana Lake, where the level fluctuates annually and seasonally following the patterns of changes in precipitation. Water influx from four major rivers, subsurface inflow from the floodplains, precipitation, outflow from the lake constituting river discharge and evapotranspiration from the lake were taken into consideration. The Dong Nai River Basin in southern Vietnam has been thoroughly studied by Ringler et al. (2007), who focused on the development, application, and selected policy analyses using an integrated economic hydrologic river basin model. The model framework depicted the sectoral structure and location of water users (agriculture, industry, hydropower, domestic, and the environment) and the institutions for water allocation in the basin. On the other hand, a methodology has been developed for predicting the future growth in demand for irrigation in countries with supplemental irrigation such as England and Wales (Weatherhead, 2000). Over-exploitation of groundwater resources has even intensified with the shift to higher value-added but often more water intensive crops (Yang et al., 2003). Liu (2010) showed that the averaged annual irrigation for all crops over the study area was the highest under the full irrigation scenario and much lower under the scheduled irrigation scenarios. Worthington et al., (2008) provided best-practice estimates of price and income elasticities, quantifying the impact of non-price water restrictions and gauging the impact of non-discretionary environmental factors affecting residential water demand. A methodology was developed by Gómez-Limón et al (2004) for the different types of farm in an arable area. They analyzed the differential impact that a pricing policy for irrigation water would have.

3.2. Drought and water scarcity

Drought is a nature-produced but temporary imbalance of water availability and corresponds to the failure of the precipitation regime, causing disruption of the water supply to the natural and agricultural ecosystems as well as to the human activities (Pereira et al., 2002). Past historical evidence indicates that droughts have had great impacts on human life. It is assessed based on two key factors, namely, the estimated water demand, and the expected water supply (Kumar et al., 2007). Alarm has been raised concerning the growing demands, yet limited supplies, for potable water, as well as the increasing rate of energy consumption for pumping water from aquifers (Jaber et al., 1997). Molle at al. (2010) showed that increasing water withdrawals for urban, industrial, and agricultural use have profoundly altered the hydrology of many major rivers worldwide. In northern China, where water scarcity is becoming an increasing constraint to food production, Yang et al. (2003) proposed pricing-based water policies in addressing challenges facing irrigated agriculture under current water management institutions. Molle at al. (2010) emphasized the implications of overexploitation of water resources in terms of increased interconnectedness between categories of users and between societal processes and ecosystems in different parts of a river basin. According to Massarutto (2003), water prices have an impact on irrigation more because of their absolute level (provided it is high enough to compensate the differential margin that water allows to farmers) and not because of the marginal reaction of water users to marginal variations.

3.3. Tourism sustainability

Many island destinations are struggling with tourism’s water demands (Cole, 2012). While it is true that tourism is one of the main driving forces behind economic growth in several world regions, it is also true that tourism can have serious negative environmental impacts, especially with regard to water resources (Tortella et al., 2011). A research conducted by Forsyth (1995) in northern Thailand showed that the adoption of tourism by agricultural communities may increase or decrease environmental degradation by affecting the frequency of cultivation or perceived value of soil conservation. A model was created by Tortella et al. (2011) to analyze hotel water consumption. It included a set of different hotel variables associated with physical, seasonal and management-related factors. Hydrological issues of tourism in Indonesia were studied by Cole (2012). From a political-ecological perspective, he sought to understand how social power and ecology come together and result in inequitable and unsustainable water distribution on the island of Bali.

3.4. Approaches to studying the system

There have been several methods employed by researchers in studying this domain – both qualitative and quantitative. Expert Systems has been used by Mohan et al. (1997) provide decision support in irrigation management. Linear programming was used by Flinn (1969) to estimate irrigation water demand functions at the farm level, integrating both seasonal and intra-seasonal demand schedules. He et al. (2009) provided a computational, positive mathematical programming model that integrated both irrigation decisions and specific crop choices when characterizing agents' optimal responses to moderate water scarcity. Shangguan et al. (2002) used dynamic programming for optimizing crop irrigation scheduling applied to the combined optimal allocation of multiple water resources in Yangling, a semi-arid region of the Loess Plateau, China. A nonlinear discrete-time dynamic model was developed Georgiou et al. (2006) to describe the operation of a single-purpose reservoir during the irrigation season. The impact on crop yield due to water deficit and the effect of soil moisture dynamics on crop water requirements are taken into account by an integrated soil water balance model. Gómez-Limón et al. (2004) studied the impact of a water pricing policy on a representative area in the Duero Valley in Spain via Multi-Attribute Utility Theory (MAUT) mathematical programming models.

3.5. System dynamics approach

Ford (1996) designed a computer simulation model of the Snake River in the greater Pacific Northwest. The model simulated the annual flows in the Snake at key points of interest to agricultural groups, environmental groups and the electric power industry. Ford (1997) also used SD methodology in resource planning in the electric power industry, a study that was honoured with Jay Forrester Award in 1996. Analysis of intensive irrigated lands and water management in Spain was conducted by Fernández et al. (2004). They developed a dynamic model to study the key socio-economic and environmental factors driving the whole system. The model included five sectors: irrigated lands, profitability, available space, water resources and pollution.

4. Scope of the study

The following provides the framework from which the extent of the study is built upon: (1) *Simulation period is 100 months (8 years and 4 months).* This simulation temporal horizon was chosen long enough to see any mid-range change in the behaviour in the structure. Some shifts in feedback dominance were seen within the 50th to 70th month range; so some extension of months were included until such that the behaviour. (2) *Optimizations of variables are not done; scenarios are proposed.* The simulation runs are used not to optimize the values of variables, for instance: the best value of reservoir level, the largest amount of agricultural production that can be sustained, the best price of water, and so on. Instead, various values are inputted into the variables; their corresponding effects to the dynamics of the system structure are observed; and policies are made based on the scenarios. (3) *No feedback between population dynamics and tourism.* The same reasons (i.e. time limitation and absence of data) made the linkage between the community and tourism not viable. (4) *Agriculture, energy production, and community are the main sectors.* These three sectors are the focus of the current system being modelled. However, the actual model is not divided into sectors but rather into subsystems (i.e. Alqueva, Pedrogao, and Ardila). (5) *Tourism and pumping back system are currently not implemented.* As had been confirmed with EDIA, these two systems are not currently in place. These have been included in the policy model to see what the effects of these systems may be in the context of eventual water scarcity. (6) *Price system and quotas regulate water consumption seasonal variation for inflows and water required by economic activities.* Price elasticity and quota are assumed to control the behaviour of the demand of agriculture, community, and tourism.

5. Research Environment

The AMP includes implementation of around 120,000 hectares of newly irrigated crops in the Alentejo region in southern Portugal. The area of direct influence of the AMP covers over 20 counties in the districts of Beja, Évora, Setúbal, and Portalegre (EDIA, 2012). AMP encompasses three main irrigation subsystems: (1) *Alqueva subsystem:* This guarantees the distribution of water to the whole of eastern Beja and central Alentejo. Fanning out from the Alqueva Reservoir at the Alamos pumping station, this subsystem is made up of a group of hydraulic circuits which guarantee the connection to the main reservoirs in the region. This is responsible for the distribution of water to 63,900 hectares of land and for domestic consumption to ten municipalities with population of 104,000 (2010). (2) *Pedrogao subsystem:* This is the smallest among the substations. Beginning at the Pedrogao/ Right Bank pumping station, this group of pipelines covers the region of east of Beja on the right bank of the River Guadiana. This is responsible for the distribution of water to 24,500 hectares of land and for domestic consumption to two municipalities with population of 17,000 (2010). (3) *Ardila subsystem:* Fanning out from the Pedrogao/Left Bank pumping station, this subsystem is responsible for public supply to the counties of Mertola and Serpa. This also distributes water to 38,700 hectares of land and for domestic consumption to a municipality with population of 22,000 (2010) (EDIA, 2012).

6. Model Boundary

In SD modelling, parameters may be classified as endogenous, exogenous, or excluded. Endogenous variables are those that change as the value of other variables change over time. These create the dynamics of the structure of the system. Exogenous variables are those constant values set by the modeller or that are obtained from historical data. Excluded variables, practically not existing in the model, are variables the modeller emphasizes that are not included or are beyond the scope of the model. **Erro! A origem da referência não foi encontrada.** shows the model boundary.

Table 1. Model boundary

Sector	Parameters		
	Endogenous	**Exogenous**	**Excluded**
Alqueva Reservoir	Alqueva Reservoir Pedrogao Reservoir Quota Desired turbine flow Electricity production Flow turbined Pump-back flow	River input Minimum ecological flow Power energy multiplier Optimal water level Wind power for pumping back	Competition
Agriculture	Arable land Agricultural production Desired yield	Time to convert arable land Land productivity Harvest period Land productivity Irrigation requirement	Cost Benefit Analysis Export
Community	Population Change in population	Population growth rate Water consumption per person	Immigration Aging chain Economic well-being
Tourism	Tourists Infrastructure Attraction perception Water consumption Investments	Revenue per tourist Elasticity of water price	Competition

7. Dynamic Problem

The study seeks to explore the structure of the AMP that causes the dynamics of the system. Figure 1 shows the actual historical data on the Alqueva Reservoir water volume taken from EDIA. A more important graph in the figure is the blue one, which corresponds to the volume of water in the reservoir in hectometres. It should be noted that the observations plotted are not in regular intervals from February 2002 until April 2012. During the closing of the dam gates in 2002, water volume was zero. The volume steadily increased until it peaked on April 2004. It then plunged down around 2,500 hectometres by end of 2006. Then it increased and fluctuated thereafter. A central interest of SD methodology is to model a structure that will explain the behaviour of the system over time. After a steady increase, the water level fluctuated over the years. What parameters might have caused the system to behave such? What are the parameters in the system that can be used as leverage points in order to propose policies? These questions will be addressed in the succeeding sections.

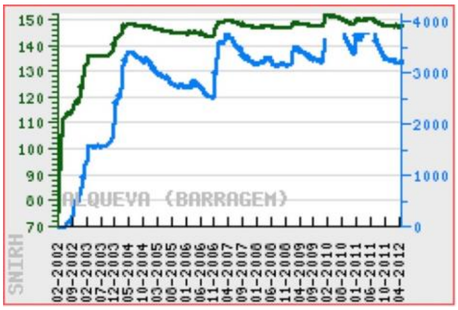

Figure 1. Alqueva Reservoir reference mode. Green scale on the left represents height of water (meters); while the blue scale on the right is the corresponding volume (cubic hectometres). Source: EDIA website (2012)

8. Model Structure

8.1 Causal Loop Diagram

The model aims to address allocation water resource problems along a number of competing sectors including energy, agriculture, households' consumption, and tourism. The causal-loop diagram in Figure 2 portrays the main dynamics of Alqueva and Pedrogao Reservoirs.

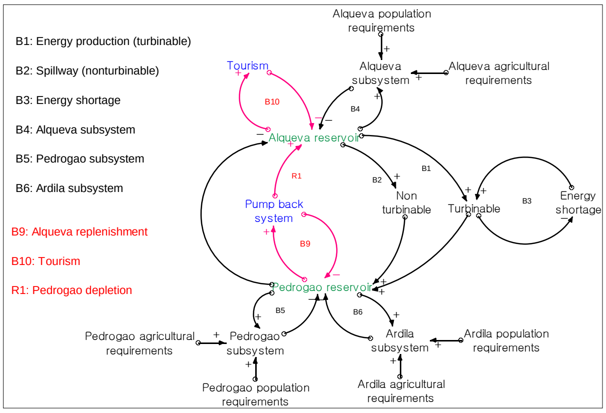

Figure 2. Causal-loop diagram of AMP

The more water available in the Alqueva Reservoir, more water flow availability in order to produce energy. After being released, water flow increases Pedrogao Reservoir at the bottom of the dam, and consequently reduces Alqueva Reservoir water volume (B1). There is an alternative mechanism for releasing water from Alqueva without producing energy, in order to regulate Pedrogao subsystem at its desirable level (B2). Energy production is a balancing loop, seeking to reduce energy shortages (B3). On subsystem, they increase their water demand according water availability, households' consumption and agriculture requirements, whereas they decrease the level of either Alqueva Reservoir (B4) or Pedrogao Reservoir (B5) and (B6). Additional loops (in red) represent prospective policies. The first one is an eventual implementation of a pumping back system from Pedrogao Reservoir to Alqueva Reservoir, using idle turbines (B9, R1). The second one is the implementation of additional economical activity (Tourism), which might require farther amount of water for its operation (B10).

Price mechanism (Figure 3) seeks to balance water demand from the subsystems, in order to guarantee reservoir sustainability. Assuming that either Pedrogao or Alqueva Reservoir level is decreasing, it leads to an increase in the price of water. Therefore, there is a decrease of the water demanded by subsystem, as long as the marginal cost of producing goods and service increases as well. The lower the amount of water demanded, the higher the reservoir volume over the time.

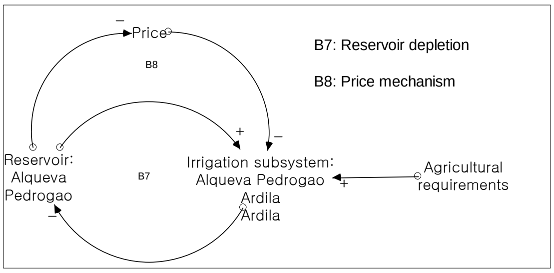

Figure 3. Price mechanism causal-loop diagram

8.2 Stock and Flow Diagram

8.2.1 Explanatory model (current structure)

In the model, dam and reservoir are used interchangeably. The main inflow of *Alqueva Dam* (or Reservoir) is the River Guadiana. The rate of water per month is set exogenously and it is affected by seasonal raining/evaporation. In order to manage the reservoir level, it is possible release water either through turbines valve or spilling valves. In both cases, water goes to *Pedrogao Dam*. In the first case, water is released in order to produce energy; in the second case water is released in order to keep the reservoir level below its maximum capacity (upper spillways) or to balance *Pedrogao Reservoir* in its optimal volume (medium spillways). Refer to Figure 4 for the stock-and-flow diagram of the system.

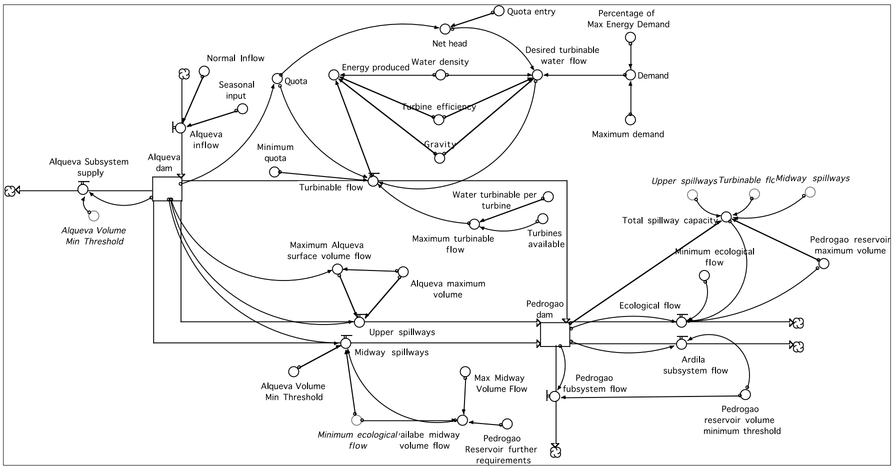

Figure 4. Stock-and-flow diagriam of the current system in Alqueva and Pedrogao Reservoirs

Turbinable flow depends on the *desired turbinable water flow*, the *quota*, the *maximum turbinable flow*, and the *minimum quota*. *Quota* is the vertical distance between the surface and the bottom of the dam. It is model as a second order equation derived from given reservoir level, taken from data provided by EDIA. The *maximum turbinable flow* available is defined according *water turbinable per turbine* and *turbines available*. *Energy* is produced at a certain *turbinable flow* level and *net head*, taking into account a number of additional parameters like *turbine efficiency*, *density of water* and *gravity*. *Net head* is the vertical distance between the surface and the intake *(Quota entry)*. When the dam level overtakes the maximum threshold, spilling mechanism is activated at the rate of the maximum volume of flow available. There is a second spilling mechanism, which is activated in order to fulfil *minimum ecological flow* and further *Pedrogao Dam* uses. Further *Pedrogao Dam* flow demand could be met if actual Alqueva volume is higher than its *minimum threshold*. Water is released from the *Pedrogao Dam* in order to guarantee a *minimal ecological flow*. Additionally, if *Pedrogao Dam* reaches its maximum capacity, water is spilled. In this case of water surplus, spilling policy takes into account previous information on total Pedrogao inflow from Alqueva.

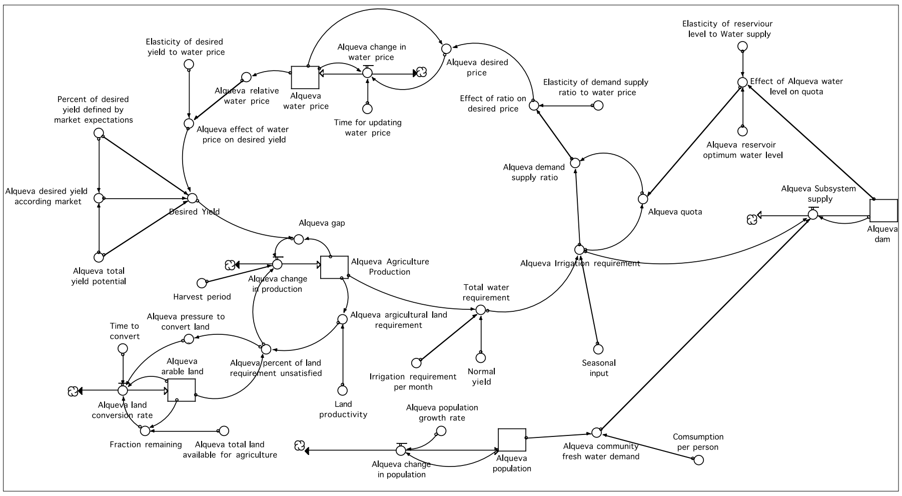

Figure 5. Stock-and-flow structure of the agricultural and local community

There is an additional outflow from *Alqueva Dam* to Alqueva agricultural subsystem (Figure 5). This rate depends on irrigation requirement, taking into account the total water requirement and the proportion supplied by weather conditions along different year seasons. Total water required is depends on the agriculture production, water required per month and normal yield. *Alqueva agricultural production* balances desired yield and depends on the dynamics of land acquisition. A higher percent of land requirement unsatisfied, the more the pressure to convert land, given the availability of suitable land for agriculture. The user, setting a percentage of the total yield potential, defines desired yield. Additionally, there is an effect of water price on the desired yield. The higher the price, the lower the desired yield.

Effect of water prince on desired yield is determined by a negative inelasticity, given the change of relative water price over time. Alqueva water price is a first order-balancing loop. The loop is closed when the water desired priced is set according the ratio between irrigation requirement and Quota of water flow for Alqueva system. This Quota is defined according the demand of water flow and the actual level of Alqueva dam comparing to its optimum level (supply). If the actual level of the reservoir is higher that its optimum level, the water quota for Alqueva is going to be above the desired water flow required by the subsystem. Otherwise, water quota is going to be below the desired flow required by the subsystem.

Price mechanism was taken from Yamaguchi 2011, adapting its general model on setting price by inventory availability. According Yamaguchi, the effect of inventory ratio on price can be model as:

$$p' = p(t)\ g\left(\frac{x(t)}{x}\right)$$

Where (p') is the desired price, g is function which describes the effect of inventory ratio on price, (x) the current water availability and (x*) water demand. In turn, function g could be mathematically represented as:

$$g = \frac{1}{x^e}, where\ x = \frac{x(t)}{x^*}$$

Elasticity of the function g can be calculated as:

$$Elasticity \ \equiv \ -\frac{\frac{dg}{g}}{\frac{dx}{x}} = -\frac{dg}{dx}\frac{x}{g} = -\left(-\frac{e}{x^{e+1}}\right)\frac{x}{g} = e$$

Finally, water demand from the Alqueva subsystem includes fresh water demand from households. In this model, households demand only depends on population growth rate. *Alqueva Dam* will supply agricultural requirements only if it is not below its minimum threshold. In the case of people demand the system will supply water nevertheless the actual level of the reservoir. On the other hand, *Pedrogao Dam* has two additional outflows, which supply water to Pedrogao Subsystem and Ardila subsystem. Pedrogao and Ardila replicate the same agricultural and fresh water structure.

8.3 Simulation results

Tourism and pumping back system were not implemented. Simulation versus reference mode is shown in Figure 6.

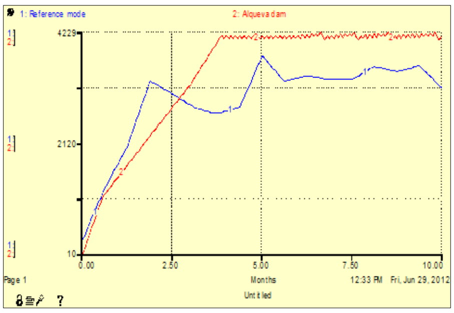

Figure 6. Actual versus simulated data

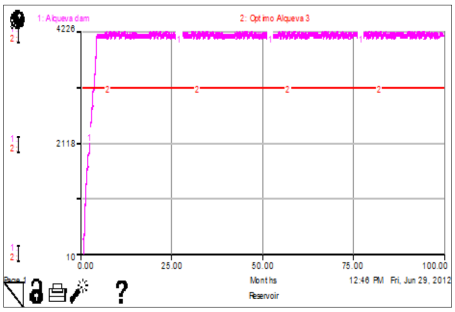

Figure 7. Alqueva dam water level scenario 1

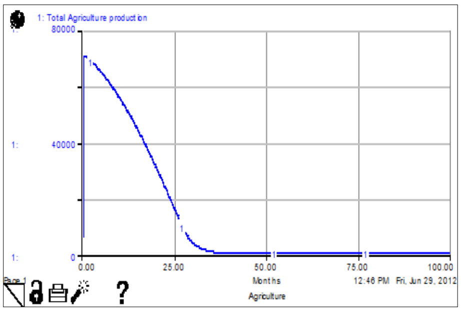

Figure 8. Agricultural production scenario 2

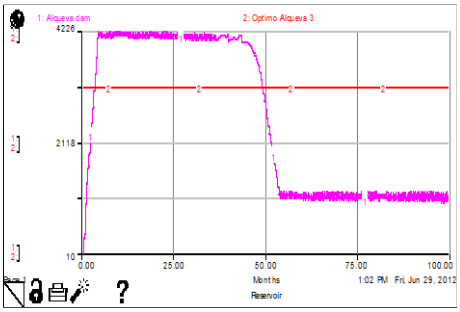

Figure 9. Alqueva reservoir water level scenario 1

Initial parameter setting assumes strong elasticity of reservoir level to water supply to agriculture (Initial value = 2). In other words, a change in water supply has a more than proportional in the water available for subsystems and its trend is raising water price. In this scenario, reservoir sustainability is guarantee over the time and energy supply (Figure 7), but agriculture production is highly constrained (Figure 8). On the other hand, if there is no effect of reservoir level to water supply to agriculture (Value = 0), reservoir level will be compromised in the long run (Figure 9), but agriculture may not have any constraint for increasing its production (Figure 10). In other words, a change in water supply has a more than proportional in the water available for subsystems and it trend is raising water price. In this scenario, agriculture production is highly constrained, but reservoir sustainability is guarantee over the time; moreover, there will be shortages in energy supply (Figure 11).

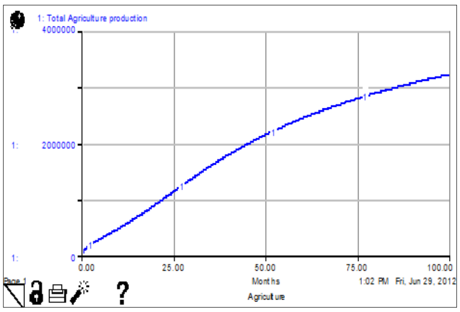

Figure 10. Agricultural production scenario 2

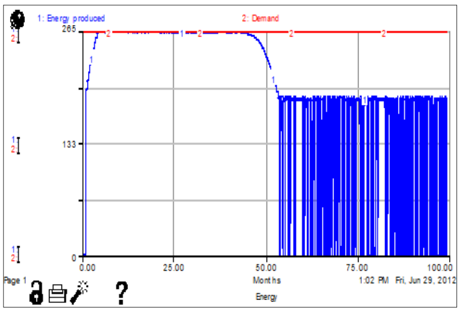

Figure 11. Energy shortages scenario

8.4 Policy model (proposed structure)

Pumping back system (Figure 12) uses idle turbines and is activated when *Alqueva Dam* level is below to its optimal and *Pedrogao Dam* level is above its maximum. Energy from wind power might be use.

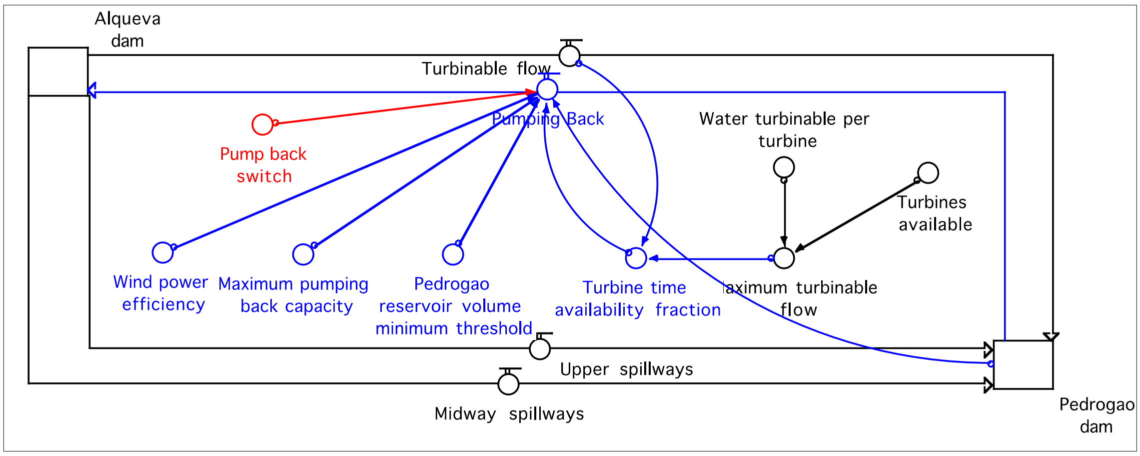

Figure 12. Pumping-back system implementation

Implementing tourism sector implies a new outflow from *Alqueva Dam* (Figure 13). Tourism water requirement depends on current number of tourist and their consumption per capita. It is assumed that tourist consume 10 times more water than an inhabitant. Tourist gain depends on the effect of attractiveness of the place. In turn, the level of saturation given a certain infrastructure capacity defines attractiveness. Tourism business loop closes when investment in new infrastructure depends on profitability for each additional tourist. However, it is assumed an initial investment in order to start operations. Water price has an additional effect on tourism costs. The mechanism emulates the price set to agriculture. However, the user can modify the reference threshold in order to represent a higher cost per hectometre consumed in comparison to Agriculture sector. When prospective policies where implemented, and testing with different parameters, they did not show any visible effect on Alqueva Reservoir during the simulated time (Figure 14). However, the number of tourist attracted will vary depending on amount of water available for this sector (Elasticity of reservoir level to Tourism –Blue= 08; Red 1.6).

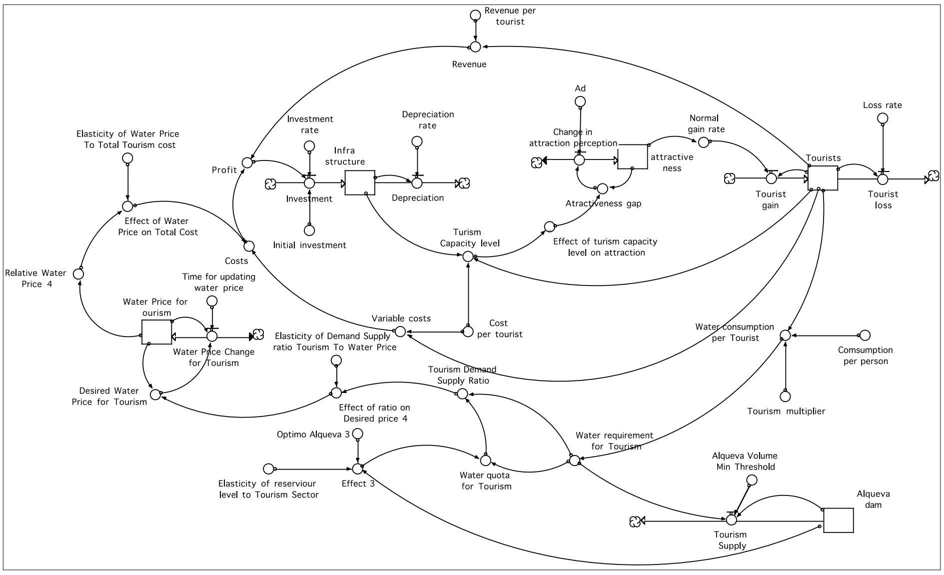

Figure 13: Tourism sector implementation

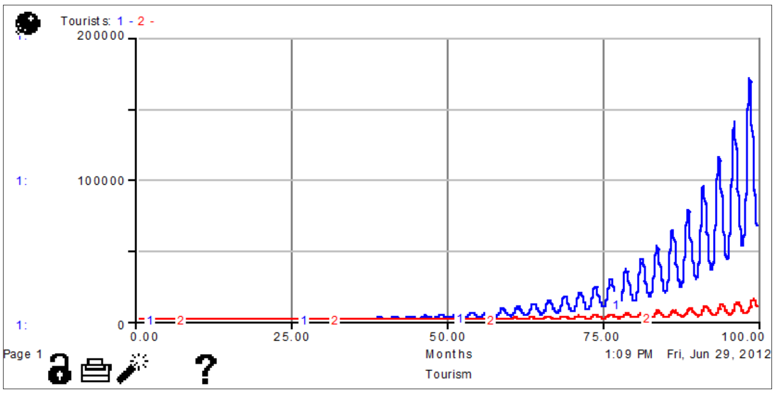

Figure 14: Comparison tourist attracted in scenario 1 and scenario 2

9. Discussion and conclusions

The following are the insights from the construction of the model of AMP:

- Model is highly responsive to exogenous variables. However, the model represents trades-offs between sectors and represents information feedbacks on water scarcity/availability.
- The model could be a valuable tool for setting scenarios given uncertainties about exogenous variables. Parameters should be improved through involving clients and stakeholders in the modelling process.
- Model could be improved by integrating different times scales. However, the modelling tool chosen (iThink) does not permit this kind of integration. Unreal values might be the product of inappropriate time scale (Pedrogao Reservoir).

- Modellers gained better understanding of the dynamics of water irrigation. This pedagogical value might be replicated among stakeholders interested in investing on different kind of economic activities in the Alentejo Region.

The model may be used to experiment with policies to deal with these problems in the future. The unique feature of the model is its ease of use by a diverse group of individuals who are familiar with it but may not be experts in computer simulation (Ford, 1996). The results can help identify potential future water resource problem areas, and should be useful for water resource planning by individual farmers as well as by the government, regulatory authorities and others (Weatherhead, 2000). Increased reliance on demand-side management policies as water consumption management tool has stimulated considerable debate among economists, water utility managers, regulators, consumer interest groups and policymakers (Worthington et al., 2008). Reduced demand can be achieved by adopting improved farm irrigation systems and deficit irrigation (Pereira et al., 2002). Tourist water demand can generate big problems of sustainability, mainly in those regions where water is scarce, as occurs in most coastal and small island destinations where a large part of world tourism is concentrated (Tortella et al., 2011). Future studies may focus on the dynamics of the tourism industry to environmental degradation. Lastly, the improvement of irrigation systems is closely related with higher irrigation uniformity. This implies better design, appropriate selection of irrigation equipment, careful maintenance, and the extended use of field evaluation (Pereira et al., 2002). Agricultural policies should shift from maximizing agricultural output to stabilizing it to increase resilience against climate change (Schilling et al., 2012).

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Conceptualizing a credits trading approach towards corporate social responsibility credits

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Abstract

Life Cycles of both products and services significantly consume renewable and non-renewable resources across a worldwide scale. Thus, eliciting an enormous environmental impact, that is known to disproportionately instigate crises into the socio-economic and political domains of our civilization. Therefore, Creation of Shared Value and Corporate Social Responsibility (CSR) have been considered by Policy makers, Public and Private Institutions. In addition to Corporate Philanthropy, CSR practices also encompass a wide spectrum of activities, including Stakeholder safety/welfare, designing sustainable products and ecological restoration to name a few which are ascertained to capital and knowledge intensive in nature. Therefore, this paper primarily structures the scope of CSR and proposes a mechanism for trading Corporate Social Responsibility credits in order to incentivize stakeholder centered business practices. Furthermore, the CSR credits trading methodology would entail similar mechanisms used by its remotely successful predecessors namely, tax incentives, tradable credits/certificates and flexible mechanisms for implementing sustainable projects. The CSR credits trading methodology is envisioned to entail a more holistic approach towards overall Sustainability when compared to Carbon Offsets/Renewable Energy Certificates which are more focused towards reducing the environmental footprint.

Keywords: Sustainability, Corporate Social Responsibility, Credits Trading.

1. Introduction

A Corporate Social Responsibility (CSR) endeavor(s) in an Enterprise is to accommodate social, environmental and ethical considerations towards its Stakeholders within the Business Operations and Strategic Initiatives. Stakeholders include and are not limited to the Enterprise's human resources, end-users, customers, regulatory bodies, suppliers, distributors, manufacturers, development collaborators, shareholders, remote/distant communities, Government(s).

The underpinnings of contemporary Economic Principles authored by Alfred Marshall which is further founded upon Adam Smith's seminal works, The Theory of Moral Sentiments (1759) and The Wealth of Nations (1776). Smith's advocacy of the 'Invisible Hand' which realizes the self regulatory nature of markets, when Businesses act in their self interests only in favor of their shareholders resonated with Freidman's description of Free Market Economy. In contrast, Joseph Stiglitz, 2008 stated that in the era of Globalization where environmental, social and economic externalities of business activities are more systemic in nature, which would eventually lead to a 'Tragedy of the Commons' scenario. Moreover, as discussed in Adam Curtis' BBC Documentary, the century of Self in 2002 about the rise in consumerism and commodification in recent decades has not only posed ethical questions on their social impacts; nevertheless has resulted in exploitation of natural and non-renewable resources leading to environmental degradation and instigating geo-political crises (Parenti, 2011). This aspect has been re-iterated by Mathis Wackernagel et al. from the Global Footprint Network that the global ecological stability is the fundamental underlying wealth which upholds other forms of wealth generation activities.

Presently, the standards of social sustainability (SA8000 standard); Environmental Management (ISO 14000); Life Cycle Analysis (ISO 14043)and Economic performance (ISO 9000 family) remotely encompasses Corporate Social Responsibility. Moreover, the ISO 26000 only offers guidelines for CSR without any requirements and certification. Similarly, the United Nations has established Triple Bottom Line and Intergovernmental Working Group of Experts on International Standards of Accounting and Reporting (ISAR) guidelines. The major impediment in formulating robust legislations and standardization norms is owing to the scope of CSR endeavors that encircles a wide spectrum of intricately detailed activities ranging from ecological restoration, employee engagement, community welfare programs and philanthropic donations. These diverse paradigms entail metrics that are inter-related either by strong or weaker co-relations posing a major impediment in order to specifically outline the CSR endeavors. For instance, the impact of releasing toxic emissions (environmental) on the health of a community (social) and income distribution at state-level (economic).

Corporate Social Responsibility has been identified by critics as more of a window dressing and lip service by Corporations to project a positive public image. From the critics' perspective, they essentially referred to Businesses of substantial profitability with controversial social impacts, which include but not limited to the Tobacco Industry, Weapons Manufacturing, Retail Giants, Large sized Agro Businesses and Processed Food Industry.

Porter and Kramer, 2006 stated that Enterprises focusing towards Creating Shared Value Approach that emphasizes the significance of human capital, replenishment of resources and efficient government.This approach is anticipated to improvise income distribution and eventually leading towards wealth generation. Moreover, detailed studies have proved a positive correlation between Corporate Social Responsibility and the aforementioned outcomes (D'Alessandro et al., 2009). For instance, over 40 years Nestle by virtue of technology transfer developed infrastructure in the Moga region of Northern India. The infrastructure resulted in the establishment of many local dairies and substantial growth in milk collection under expert guidance. The outcome was a steady supply of basic commodity, improved income distribution and overall standard of living.

The objective of the paper is to recommend Enterprises, to venture beyond the 'Marketing Strategy' and 'Cheque Book Philanthropy' attribute of Corporate Social Responsibility, so as to engage with the society and the ecosystem for a long term sustainable future.

2. Shortcomings of Carbon Offsets and Renewable Energy Certificates Trading

a) Reduction in emissions or switching to renewable energy alone does not lead to climate change mitigation. Meanwhile, stabilization of the biogeochemical cycles (eg: water and oxygen cycles) and restoration of damaged ecosystems is ascertained to be far more effective (Fischer, 2011; Costanza et al., 1993). Moreover, critics have pointed out the 'quick fix approach' of Enterprises participating Clean Development Mechanism (CDM) Projects which ultimately has not demonstrated a convincing magnitude of tangible outcome (Smith, 2007 Carbon Neutral Myth). On the contrary certain emission offset projects have excluded the role of the stakeholders in developing nations and in certain cases have even encroached on their means of subsistence.

b) The CDM initiative does not explicitly outline socio-economic sustainability and fails to address environmental stability in a holistic manner due to its complex nature (Costanza et al., 1993). On the other hand, there are stringent regulations and rigorous monitoring techniques that could discourage parties in developing nations; mainly owing to their lack of infrastructure and expertise to materialize CDM collaboration. As mostly the poorest of the nations (eg: Haiti) encounter these problems and hence are excluded because parties from developed nations choose their counterparts in host nations that provide lower costs for operation and implementation (eg: China and India). Moreover, determining the baseline scenarios or alternative baseline scenarios for evaluating additionality is considered as an exhaustive procedure, eventually leading to substantial transaction costs (Gillenwater & Seres, 2011). Concurrently, the risk of "leakage" and "permanence" has always required strict vigilance and commitment of more technical resources.

c) There exists the factor of perverse incentives which could be either in the form of creating more emissions to be destroyed later for gaining credits and 'rent seeking' in the regulatory framework for eliciting additionality.

3. Co-relating Corporate Social Responsibility and the Credits Trading Approach

In early 2010, the Corporate Affairs Minister of the Indian Government, Mr. Salman Khurshid discussed the importance of quantifying Corporate Social Responsibility initiatives to enable a credits trading approach. Moreover, the aforementioned shortcomings denote the need for a more holistic approach towards delivering socio-economic and environmental sustainability (to be referred as Sustainability here onwards) within the framework outlined as per the market economy approach. As illustrated in Figure 1, Corporate Social Responsibility is categorized into three levels.

The projects that address Class 1 measures are identified to be intensive on the frontiers of knowledge, financial capital, material, human, technological and planning. Therefore, in order to mitigate the resource intensive nature for encouraging investors, only the Class 1 measures are to be considered for the credits trading approach. The authors intend to clarify that the approach is more on the similar lines of Renewable Energy Certificates (RECs) that provides a production and installation subsidy as opposed to Carbon Offsets (EPA, 2010). For instance, a retail store cannot purchase CSR credits to offset the poor working conditions and maltreatment of its employees. Accordingly, parties interested in purchase-sale of CSR credits are required to adhere to Class 2 measures.

Meanwhile, Class 3 measures such as philanthropy possess minimal credibility of tangible contribution towards stakeholders’ well-being and hence are assigned in the lowest rank of Figure 1.

Class 1 Corporate Social Responsibility (Applicable for issuing credits/certificates):

a) Sustainable Business Practices that contribute to socio-economic growth and ecological stability.

b) Forming partnerships with Government(s), Non-Profit Entities and Non-Governmental Organizations via engagement with stakeholders in order to build and improve Infrastructure.

c) The endeavors promoting and maintaining Ecological Integrity should include and are not limited to the implementation of robust technologies for stabilizing bio-geochemical cycles.
For example: Carbon Capture and Utilization, Large scale Industrial Ecology and Ecological Restoration Programs, Waste Treatment throughout Life Cycle.

Purchasers: Universities, Private Enterprises, Governments, Public Institutions, Individuals, Non-Profits

Outcome: Creation of new knowledge, growth in quality/quantity of human capital, ecological stability, improvement in income distribution and employment statistics, easier access to natural and renewable resources, long term strategic and competitive advantage coupled with enhanced reputation.

Class 2 (Compulsory and Pre-requisite for buying and selling Credits/Certificates):

a) Risk Management via Regulatory Compliance for Safety and Welfare of Stakeholders

b) Adherence to Human Rights (Universal Declaration of Human Rights) and Acknowledgement for Democratic framework of the Host nation.

c) Tangible contribution towards a Nation's Social and Economic Rights Fulfillment Index.

d) Access to information and transparency between Enterprise and Stakeholders.

e)Engaging and rewarding employees for in devising sustainable business practices.

f) Avoiding participation or supporting any form of Genocide, including cultural. For example: United Nations Declaration on the Rights of Indigenous Peoples)

g) Upholding the Ethics for the Freedom of Press.

Outcome: Strengthening relation with Value Chain Partners, increase in positive image, reducing Operational Risk, Employee loyalty, reduced probability of litigation.

Class 3: Philanthropy and Medium Scale Community Welfare Programs

SOURCE: Business Leaders Initiative on Human Rights- A Guide for Integrating Human Rights into Business Management.
Committee of Sponsoring Organizations of the Treadway Commission, Enterprise Risk Management-Integrated Framework, 2004.

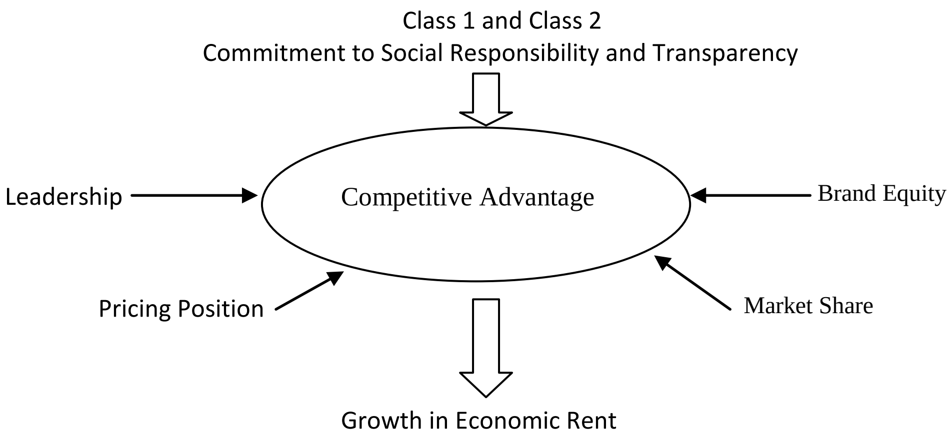


Figure 1: Categorizing Corporate Social Responsibility

The RECs and Carbon Offsets are quantified in terms of their units in megawatt-hours and tones of emissions, respectively. However, as discussed previously, the comprehensive nature of CSR cannot be quantified to a singular unit and accordingly, the credit or certificate valuation could be inspired from the valuation technique used for stock prices. Moreover, in addition to an Enterprises' financial performance, the price of the CSR credit would be governed by the Enterprises' adherence towards Class 2 measures, scope of the selected Class 1 measures, supply and demand of the credits and the sustainability related outcomes of the selected Class 1 measures.

The valuation methods should also consider approaches stated in domains of Ecological Economics(Costanza et al., 1998; Xepapadeas, 2008), Social Accountability, Cost Benefit Analysis and Thermoeconomics (Valero et al., 2010; Gutowski et al., 2009) to name a few. Although, assigning a financial value to CSR outcomes is inherently myopic in nature; nevertheless, these are 'most suited' methods of analytical tools to reconcile dynamics of a market economy approach towards Sustainability which is centered on mainstream economics and the complex dynamics of our ecosystem (Ramjerdi, 2008).

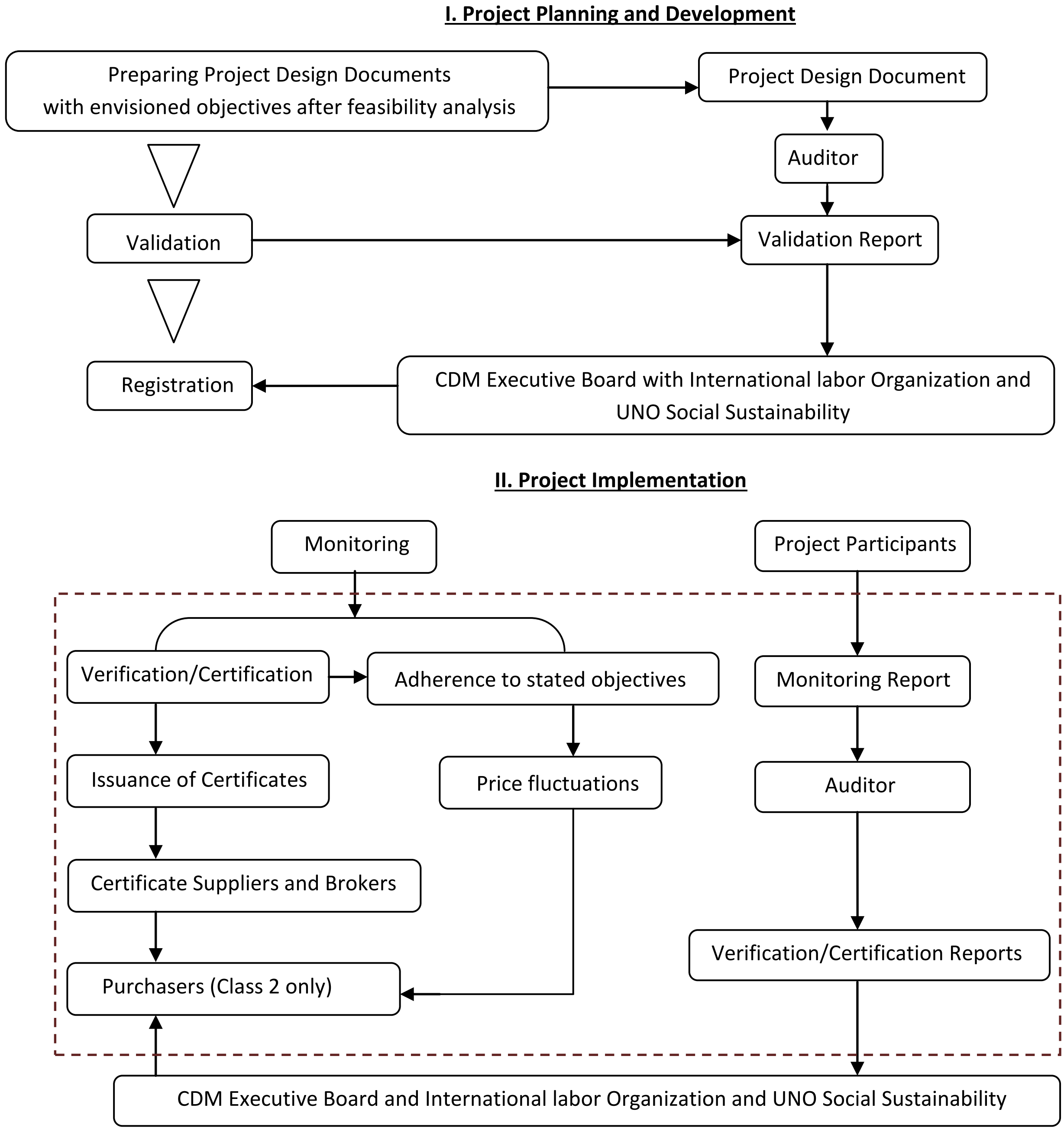
4. Structuring the Trading Mechanism for Corporate Social Responsibility Credits

The authors recommend that the Credits Trading Approach of Corporate Social Responsibility should commence as an Initiative under the Clean Development Mechanism Executive Board of the Kyoto Protocol and United Nations Framework on Climate Change. These institutions possess comprehensive experience in project planning/finance and diversified learning curves for implementing rigorous evaluation techniques; thus leading to higher certainty of investments.

Firstly, a majority of the Class 1 measures for Ecological Stability bears some resemblance with the emission reduction CDM projects. Secondly, the CSR credits initiative would need to collaborate with the International Labor Organization and UNO's Social Sustainability initiative to effectively monitor the adherence of Human Rights at the premises of the Projects as well as the Enterprises (Figure 2). A remarkable example is the ILO initiated Garment Sector Project in Cambodia to monitor human rights of workers and managers as a part of the US-Cambodia textile Agreement. Furthermore, it is essential that the participating Enterprises and institutions should conform to the highest form of ethical and moral standards; wherein an Enterprise from a developed nation should not intimidate a developing nation by virtue of economic strength, technological prowess and geo-political clout. As this would constitute of 'rent seeking' via 'resources and information asymmetry' (Klein, 2007).

5. Prospective Challenges and Roadblocks in implementing the Credits Trading Approach for Corporate Social Responsibility

There exists a risk of implementing vague and ambiguous guidelines for the each of the three facets of Sustainability for the various Class 1 projects occurring simultaneously; thus leading to repeated revisions in the guidelines. Moreover, the CDM would entail additional burden of monitoring of socio-economic facet of Sustainability which would eventually result into a more multiple-step rigorous evaluation procedure further skyrocketing the transaction costs (Gillenwater & Seres, 2011). Furthermore, there can be lengthy legal proceedings for assigning the liabilities between various participants and the grey debatable areas may result in a harmful status-quo for the stakeholders (Sacconi, 2004). The inclusion of CSR credits within CDM would not exclude it from the inherent incompatibilities of CDM with international trade agreements namely, GATS (General Agreement on Trade in Services) and GATT (General Agreement on Tariffs and Trade).



Enumerating the Best Practices for success in Class 1 CSR Projects

- Planning attainable schedule and time horizons
- Empowering local governments for transparency and effective administration
- Using the Land resources as an integrative planning tool
- Developing robust monitoring systems with an ecological approach
- Considering risks pertaining to natural disasters, political crises, market dynamics, price fluctuations of essential commodities and civilian problems.
- Vendors and Contractors should be evaluated for their Performance History, Expertise, Certifications/Licenses and Pre-existing Financial/Legal Liabilities.

Figure 2: Class 1 CSR Projects under CDM and Kyoto Protocol

As Gunawansa & Kua, 2011 discussed, even though these trade agreements do not permit discrimination of enterprises based on their nationality; nonetheless, the Kyoto Protocol does segregate on the basis of history of compliance with emission standards and nationality. Similarly, a collaboration may not occur between potential enterprises from developed or developing nations solely on the basis of their WTO (definition) memberships, acceptance of Kyoto protocols and diverse geo-political objectives. Moreover, a developing nation may exclude investment from an enterprise of a developed nation by the monopoly exclusion stated in GATS, so as to maintain the monopoly of its domestic player(s). Thus delaying the introduction of new technology which could have actualized some form of economic progress in the recipient nation.

Owing to the two laws of thermodynamics, the projects encompassing ecological restoration, stabilization of biogeochemical cycles and Industrial Ecology may not result in 100% effectiveness (Valero et al., 2010). Therefore, resulting in entropy (waste heat and unusable matter) that would threaten the ecological integrity. Furthermore, the adjustments of the baseline scenario by the Kyoto Protocol due to limitations in technology, materials and expertise of the participating enterprises may result in these enterprises profiteering from the trading activities, while the integrity of the ecosystem would continue to be compromised (Gutowski et al., 2009). In contrast to financial debt crises, the irreversible ecological debt might be almost impossible to pay-off (Srinivasan, UT et al., 2008). This facet exemplifies the disparity between the dynamics of mainstream economics and ecological stability, further explaining the diminished ability of market economy to explicitly accommodate Sustainability owing to its complex nature (Costanza et al., 1993).

The experts, who provided their feedback, unanimously agree to the aforementioned challenges and impediments, in addition to the ethical and philosophical facets of credits trading approaches in general. Similarly, exerts pointed out at the potentially un-surmountable challenge of evaluating overall Sustainability and simultaneously harmonizing a diverse set of social and ecological sustainability activities, which could range from building sanitation facilities in villages and stabilization the nitrogen cycles. Moreover, the experts raised concerns on the voluntary and mandatory nature of CSR measures by certain governments; as in their experience the CSR regulations are identified to possess a multitude of loopholes. As a result, some experts recommend eliminating the concept of a private corporation. Meanwhile, other experts strongly feel that CSR measures are ‘window dressing endeavors’ and credits trading approaches are usually futile attempts towards sustainability and in some cases are far more destructive.

6. Concluding Points

The resource intensive nature and long project cycles of Class 1 measures may encourage Small Medium Enterprises and Large companies to profit solely from trading CSR credits. This would lead to Class 1 project participants to label such parties as ‘free riders’. Moreover, the Class 1 project participants would eventually gain substantial knowledge and tangible resources (monetary and material); thus leading to an Oligopoly structure that disproportionately favors them, competitively and strategically.

Unfortunately, the CSR credits trading approach is also vulnerable to an economic crises as in the case of RECs, to lose tax rebates and other government subsidies. Moreover, Businesses with negative social externalities could indirectly offset their social externalities by virtue of sponsoring R&D projects concerning Class 1 measures. Thus, ironically contributing towards Sustainability. For instance, The United States Department of Defense has started a Climate Change Rebate Program for Fuel Cells which encourage ventures in renewable energy (EPA, 2010).

Scholars and Intellectuals throughout the globe are aware of the time consuming nature for the transition of our global economy from a non-sustainable linear system to a more sustainable closed loop economy that honors the ecosystem dynamics and social welfare. Although, as discussed in the previous sections on the challenges encountered while evaluating the complex nature of ecology and economics; nonetheless these impediments should not deter policy makers and institutions of advanced research to devise robust economic models for attaining overall sustainability.

Furthermore, Emissions and RECs Trading despite shortcomings has provided an Administrative and Legislative (including Enforcement) Frameworks that could act as a scaffold for propagating a series of novel Sustainability programs. Therefore, with respect to the authors’ stated objective of this paper, the proposed CSR credits trading is considered as complementary to its two predecessors and views itself as a important juncture within the transition phase of our economy towards a Sustainable Future.

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DAY 10 - 14:30		
Room 642 - Energy Modelling 2		
Oil abundance and economic growth – a panel data analysis	Nuno Torres[1]; Óscar Afonso[2]; Isabel Soares[2]	[1]CEFUP and Universidade Lusíada Porto; [2]FEP and CEFUP
Potential of CO2 taxes as a policy measure towards low-carbon Portuguese electricity sector by 2050	Hana Gerbelová[1]; Filipa Amorim[1]; André Pina[1]; Christos Ioakimidis[2]; Paulo Ferrão[1]	[1]MIT|Portugal Program - Sustainable Energy Systems, Instituto Superior Técnico; [2]Deusto Institute of Technology, DeustoTech
Methodology to develop integrated scenarios for electricity demand, mix electricity supply, price and GDP	Mário Brito[1]; Tânia Sousa[1]	[1]Department of Mechanical Engineering and IN+, Instituto Superior Técnico
Modelling the Hungarian energy system – the first step towards sustainable energy planning	Fanni Sáfián[1]	[1]Eötvös Loránd University, Hungary

Oil abundance and economic growth – a panel data analysis

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Faculdade de Economia, Universidade do Porto Portugal, CEFUP.

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Abstract

Our panel estimation shows that higher oil abundance does not hinder crude producers' growth. This sample controls for specificities of oil economies, but the usual cross-section 'curse' result is found – it disappears allowing for unobserved effects. Our model controls for a potential (but unconfirmed) oil curse working through institutions, and for other growth factors such as education, which is considered by deriving real wage growth as the dependent variable. We measure the oil growth-effects through labor and capital efficiency, and as a factor of production. They are all insignificant for oil production, but rig productivity benefits growth through capital efficiency. However, oil concentration only fosters growth (by reducing the capital necessary to oil exploration) significantly if there is fiscal responsibility, and in developing countries, where institutions are weaker and there is a broader scope for factor-efficiency and technological improvements arising from the oil sector.

Keywords: Economic growth, Institutions, Oil curse, Panel data.

JEL classification: C23, O13, O47, O50, Q00, Q40.

1. Introduction

After Sachs and Warner (1995, 1997, 2001) established an association between countries' natural resource abundance and lower economic growth, several theories were brought forward to explain this unexpected empirical result,[1] known as the resource 'curse'. *A priori*, the access to abundant natural resources should instead benefit economic growth, and we do find several exceptions to the curse – countries that have benefited from those resources, such as Norway. What is more, the curse remains elusive in the literature; thus, the search for its validity, causes and how it can be avoided remains of interest, especially for policy makers in developing commodity-producing countries and producers of point-source resources (such as oil) in particular, since several studies relate the curse to these resources, as shown below. Therefore, we deem pertinent to re-evaluate the possibility of an oil curse (especially in the present context of rising oil prices), and propose a new approach.

The first explanations for the resource curse, based on the structuralist theses of the 50s and Dutch Disease theories,[2] were not unequivocally confirmed by empirical studies (e.g., Dawe, 1996). The case study led by Auty (2001a) also dismisses these explanations by showing the complexity and diversity of cases among resource-abundant countries, including exceptions such as Norway, which has benefited from its oil abundance to become a rich country. Another thesis stresses the negative effect of rent-seeking activities related to natural resources (e.g., Torvik, 2002), but the concern applies to other rent sources, such as foreign aid and monopoly power (Lederman and Maloney, 2008).

The importance of institutions in explaining the resource curse has received wider acceptance (e.g., Hartford and Klein, 2005). Mehlum *et al*. (2006), for example, show that better institutions can avoid the resource curse, but they admit that natural resources can affect institutional quality. This is identified by recent endogenous-institutions explanations, where the kind of natural resources affects institutional quality (e.g., Auty, 2001a, b), which benefits growth (e.g., Acemoglu *et al*., 2005). Isham *et al*. (2005) and Sala-i-Martin and Subramanian (2003) sustain that natural-resource abundance penalizes growth only indirectly, through institutional quality, in the case of geographically-concentrated resources, such as oil.

Several studies focus more specifically on the challenges of fiscal policy in dealing with the high volatility of natural resources (e.g., Davis, 2001; Atkinson and Hamilton, 2003; Bleaney and Halland, 2009).

Following Sachs and Warner (1995), most studies on the resource curse measure natural resource abundance as the share of exports or GDP. Other studies, which explore more direct measures of mining production or reserves, find different results regarding the impact of point-source resources: for example, the mining share in GDP is a robust growth regressor in Sala-i-Martin *et al.* (2004), and Nunn (2008) finds a positive effect of *per capita* gold, oil and diamonds production growth between

[1] The structuralist theses of the 1950s already expressed concern regarding the natural resource sector and its few linkages to the rest of the economy. The concern goes even further back to Adam Smith, as he considered mining to be a bad use of labor and capital.

[2] In Dutch Disease arguments the non-resource sector, assumed as the growth engine, is hindered by the resource sector, namely through real exchange rate appreciation or the absorption of factors of production. Other explanations for the resource curse, often presented autonomously, can also be partly considered as symptoms of the Dutch Disease crowding-out logic, such as decline of entrepreneurs in industry (Sachs and Warner, 2001).

1970 and 2000 on *per capita* GDP in 2000. Brunnschweiler (2008) and Brunnschweiler and Bulte (2008) show a positive impact of *per capita* subsoil wealth on growth, but van der Ploeg and Poelhekke (2010) claim that the effect is insignificant after dealing with several issues. Therefore, as Lederman and Maloney (2008) point out, the cross-section econometric evidence remains weak, with results changing depending on the resource proxies that are used. Moreover, a rare panel study by Manzano and Rigobon (2006) dismisses the curse by controlling for fixed effects.

In this paper, we examine the impact of oil abundance on the economic growth of crude producers by using an original approach that broadens the scope of the literature. We use a panel factor-efficiency growth accounting model to test an eventual oil curse working through institutions by (we hypothesize) hindering labor and capital efficiency, which may be boosted by the oil sector otherwise, especially in (developing) countries where this sector is more likely to have a productivity advantage over the rest of the economy. In this way, we admit the possibility of an oil-growth bonus through factor efficiency and, at the same time, control for a potential curse arising from the eventual negative impact of oil windfalls on institutional quality and, in turn, on labor and capital and efficiency,[3] and thereby on economic growth.

The use of a growth-accounting model also allows us to test the significance of the oil impact as a factor of production. Outside the resource curse literature, the effect of natural resources as a factor of production is seen by many authors as not decisive to long-run growth (*e.g*., Nordhaus, 1992; Meier and Rauch, 2000),[4] considering the important growth records achieved by several resource-poor countries, such as Japan. However, the oil impact as a factor of production may be positive in our panel of crude producers. If this is the case and the potential curse materialises through institutions by hindering labour and capital efficiencies, as we conjecture, then the curse impact has been undervalued so far, since the distinction of those effects does not exist in previous studies.

In our growth study, we choose oil production as a measure of oil abundance. It is a direct proxy of the oil stock included as an input in our production function, since we assume, for simplicity, a (optimal) constant extraction rate (e.g., Crabbé, 1982) over the estimation period (the choice of the oil proxy is presented in Section 3)[5] – the assumption can be slightly relaxed as it only needs to be verified on average for each country at each time.[6] We consider this approach to measuring the oil stock is preferable to using oil known reserves, as they are difficult to measure (thus reducing the

[3] The rationale is that low institutional quality leads to an inefficient use of labor and capital, as implied by curse explanations based on institutions (e.g., Isham *et al*., 2005) and rent-seeking theses (e.g., Torvik, 2002).

[4] The idea is that scarcity of resources, along with pollution, can be overcome through technological progress, forces of substitution and structural change when natural resources have market prices (Meier and Rauch, 2000); if there is open access to those resources, then adequate policies and institutions should force economic agents to consider their social value. This is disputed namely by ecological economists. Indeed, environmental effects related to climate change are much more difficult to reverse, posing tremendous immediate challenges to avoid aggravated future economic costs (e.g., Stern, 2008). However, this kind of analysis relies on the social discount rate and climate changes are difficult to predict despite science advances; thus, in this study, they are excluded.

[5] Under this assumption, the evolution of the oil stock in our final estimation form corresponds to the (log) growth rate of oil production. The oil stock thus defined represents the amount of oil resources that, at each time, are economically available for extraction, and its evolution relies on, e.g., structural trends in demand (assumed as exogenous) leading prices, and technological advances (also assumed as exogenous) determining extraction costs. Depending on these conditions, the phase when the extraction rate declines towards the end of the oil field is prolonged or anticipated at each time, and the exploration of new wells may or not be economically viable.

[6] This means we allow oil fields with declining extraction rates provided they are compensated for by production from new wells at each moment, in order to maintain a constant average extraction rate.

number of observations),[7] and the possible effects through which the curse takes place cannot be expected to happen until the resources are extracted – thus, reserves are not adequate to assess a potential curse, which we evaluate by including oil (interpreted as an oil windfall that may affect institutions) in labor and capital efficiency specifications. The above assumption also allows us to draw conclusions for both oil production and the oil stock regarding the growth effects by labor and capital efficiency.

In addition, we conduct a deeper analysis of the oil growth-effects by breaking down oil production into rig productivity (and size, if we consider the oil stock) and the number of rigs, in order to assess the separate growth-impacts (on labor and capital efficiencies, and also as a factor of production),[8] thus providing further results and conclusions. Therefore, we not only assess the potential growth-effects of oil abundance, but also of oil concentration (in space). We would expect a higher oil concentration (size and pressure of a reservoir) to allow a more efficient oil exploration, using less capital and labor.

Furthermore, the eventual significant oil effects are analyzed with dummy variables dividing countries according to income level and inequality, technological progress and geographical areas. We would expect the oil growth-effects to be more relevant in less advanced countries either in the case of an oil curse (due to worse institutions) or an oil-growth bonus (because of higher productivity in the oil sector).

The impacts of the most important growth factors (labor, capital, investment, trade, institutional quality, infrastructures and R&D), our control variables, are also estimated.[9] Human capital is considered inside the real wage growth, which is derived as the dependent variable to allow the estimation of all coefficients. This approach also preserves our single-panel estimation strategy (annual data on education is unavailable for all the estimation period), which was chosen to take into account the variability of oil windfalls and the consequent difficulty of managing those resources (e.g., Davis, 2001) in our assessment of a potential curse working through institutions.

By choosing a panel of crude oil producers, we also control for specificities of oil economies that may not be addressed by cross-section studies showing an oil curse, which usually include resource-poor countries and do not control for unobserved effects. We stress, however, that the usual cross-section curse plot (shown in Section 4) is confirmed inside our panel of crude oil producers for the chosen oil abundance indicator (oil production), thus the curse hypothesis must be dealt with inside our framework.

Our approach and estimation strategy require several assumptions based on previous studies: (i) for simplicity of analysis, we choose a production function with constant returns to scale in labor and capital (e.g., Denis *et al*., 2002) and test the significance of the oil impact as a factor of production; (ii) the conjectured labor and capital efficiency specifications are close to Coe and Helpman (1995); (iii) our model uses the real wage as a proxy for labor productivity, as derived from the labor first-order condition, but the estimations only require that these variables present similar log growth

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[7] See Lederman and Maloney (2008) for a theoretical debate on resource proxies and the drawbacks of reserves.

[8] A similar breakdown analysis was tested with wells, but these results are hampered by a significant decrease in the number of observations; therefore, they are not presented in this study.

[9] Bleaney and Nishiyama (2002) show the resource curse result found by Sachs and Warner (1997) is robust to the inclusion of other explanatory variables from growth models.

rates. We allow for further labor-market idiosyncrasies by controlling for unobserved effects within our panel models. Moreover, we admit linear efficiency wage contracts (e.g., Akerlof and Yellen, 1986); (iv) however, we exclude nonlinearities at an aggregate level, as few labor market segments use nonlinear wage contracts (cf. Demougin and Helm, 2009, for example); (v) we consider a constant oil extraction rate (only on average), as mentioned above; (vi) for simplicity of analysis, assume no impact of economic growth on energy use (evidence of bi-directional effects can be found, e.g., in Soytas and Sari, 2003); (vii) we also exclude the environmental impact of energy use on economic growth (highlighted by, e.g. Stern, 2008).

Data requirements, high for developing countries regarding a few proxies, reduce the number of observations for developing countries (namely African), but we achieve diversity of situations to carry estimations, which include up to 402 observations from 1980 to 2003.

The paper is structured as follows. After the introduction (Section 1), we present the model setup, which is derived in Section 2. In Section 3 we explain the estimation strategy and the main proxies. The results are shown and discussed in Section 4. Here, we highlight the significant oil growth-effects, and then disaggregate and analyze those effects by using dummy variables. Finally, Section 5 provides the concluding remarks.

3. Model setup

This section presents the model specification used to estimate the oil growth-effects and the impact of the control variables.

3.1. Growth-accounting model

Production function with factor efficiency

We consider the following neoclassical Cobb-Douglas production function with constant returns to scale,[10] at each time *t* (Table A1 in Appendix A shows the sources of all proxies):

$$Y(t) = \left[L(t) f(t)\right]^{\alpha} \left[K(t) g(t)\right]^{\beta} \left[Oil(t)\right]^{\gamma} \text{, where:}^{11} \tag{1}$$

(i) Y is the real aggregate output; (ii) L is the labor level; (iii) K is the capital stock; (iv) f (g) is the labor (capital) efficiency; (v) Oil represents oil abundance (the oil stock, in this case); (vi) α, β, γ are, respectively, constant elasticities of L, K, Oil in relation to Y; and (vii) Lf (Kg) measures labor (capital)

[10] The Cobb-Douglas production function with constant returns to scale (only in labor and capital, as we assume below) is chosen for simplicity of analysis in line with other studies (e.g., Denis et. al, 2002). Our approach differs from the classic production function with exhaustible resources in Dasgupta and Heal (1980).

[11] The multi-sector approach (e.g., Matsuyama, 1992) is not used, thus Dutch Disease or rent-seeking theses, which do not account for the diversity of cases among natural-resource abundant countries (Auty, 2001a), are not tested in a curse scenario. As we focus on a sample of crude oil producers, the Dutch Disease thesis is excluded.

in efficiency units, whereas *L* and *K* are expressed in conventional units. Thus, quality advances in *L* and *K* are captured by *f* and *g* in (1).

We stress the oil abundance variable *Oil* is included as factor of production (the oil stock) in *Y*, and as a windfall inside *f* and *g* (presented below), where we control for an eventual curse running through institutions and affecting labour and capital efficiency. The measurement of the *Oil* variable is discussed in the end of Section 3.

From (1), we reach the following expression for the product real growth rate:

$$\hat{Y}(t) = \alpha\left[\hat{L}(t) + \hat{f}(t)\right] + \left(\beta\right)\left[\hat{K}(t) + \hat{g}(t)\right] + \left(\gamma \hat{Oil}(t)\right), \tag{2}$$

in which the circumflex accent expresses the log growth rate. Since *f* and *g* are unobserved, they are considered a function of several variables, including *Oil*. Equations for *f* and *g* allow us to evaluate Total Factor Productivity (TFP), and are in line with Coe and Helpman (1995). Thus, they are also built on endogenous growth models based on R&D (e.g., Barro and Sala-i-Martin, 2004) and on human capital (e.g., Mincer, 1993).

Specification for labor efficiency

Assuming the functional forms with constant elasticity, we propose the following expression for labor efficiency *per* worker at each time *t*:

$$f(t) = F\left(\frac{I(t)}{L(t)}\right)^{a_1}\left(\frac{T(t)}{L(t)}\right)^{a_2} e^{\int_{t-1}^{t}\left(a_3 IQ(t) + a_4 \frac{Oil(t)}{L(t)}\right)dt}, \text{ where:} \tag{3}$$

(i) *F* is a scale factor; (ii) *I* is investment; (iii) *T* is international trade; (iv) *IQ* is institutional quality; (v) a_1 and a_2 are constant elasticities of *f* in relation to $\frac{I}{L}$ and $\frac{T}{L}$; (vi) a_3 and a_4 are constant semi-elasticities of *f* in relation to *IQ* and $\frac{Oil}{L}$; as *f* refers to the labor-unit efficiency, variables are divided by *L*, except *IQ*. The variables are based on empirical studies, e.g., Englander and Gurney, 1994 (*I*); Frankel and Romer, 1999 (*T*); Acemoglu *et al*., 2005 (*IQ*), Isham *et al*., 2005 (*Oil*). From (3), the growth rate of labor efficiency is:

$$\hat{f}(t) = a_1\left[\hat{I}(t) - \hat{L}(t)\right] + a_2\left[\hat{T}(t) - \hat{L}(t)\right] + a_3\, IQ(t) + a_4\,\frac{Oil(t)}{L(t)}. \tag{4}$$

From the labor first-order condition (FOC), $\frac{\partial Y(t)}{\partial L(t)} = w(t)$:

$$\alpha\left[L(t)\right]^{\alpha-1}\left[f(t)\right]^{\alpha}\left[K(t)g(t)\right]^{\beta}\left[Oil(t)\right]^{\gamma} = w(t), \tag{5}$$

where w is the real wage *per* worker. Then, in order to obtain separate estimates for all coefficients (not possible by substituting $\hat{f}$ and $\hat{g}$ in (2)), we derive $\hat{f}$ as a function of $\hat{w}$, $\hat{L}$, $\hat{K}$, $O\hat{i}l$ and $\hat{g}$ (which, in turn, depends on a set of other variables, as shown below):

$$\hat{w}(t) = (\alpha - 1)\hat{L}(t) + \alpha \hat{f}(t) + \beta \hat{K}(t) + \beta \hat{g}(t) + \gamma O\hat{i}l(t). \quad (6)$$

The omission of human-capital advances in (3), and thus in (4), is justified by the use of the labor FOC,[12] since (to some extent) wages reflect human capital,[13] in line with endogenous-growth models (e.g., Romer, 1990) and with empirical studies supported by them (e.g., Englander and Gurney, 1994). However, as previously mentioned, the use of the labor FOC is only required in a more flexible (log) growth version. Indeed, since the estimation forms are derived from (6), the assumption can be relaxed in (5) by considering that wages are not paid their marginal productivity (i.e., the expression is satisfied with inequality) if the differential is constant over time or averages to zero.

The assumption is further relaxed if we consider that the differential is explained in part by unobserved effects (e.g., labor market idiosyncrasies, crucial for developing countries; measurement errors), which we control below with our panel estimation models. Moreover, we do not require a unidirectional relation from labor productivity (and output) to wage growth in line with the marginal productivity theory – we allow for linear efficiency wages and make the assumption that nonlinearities can be excluded for the whole economy.

In addition to human capital, R&D is also crucial to long-run productivity growth (e.g., Romer, 1990; Englander and Gurney, 1994), and is included below in the specification of g.

Specification for capital efficiency

We again assume constant elasticity, and propose the following form for g, at each time t:

$$g(t) = G\left(\frac{RD(t)}{K(t)}\right)^{b_1}\left(\frac{Inf(t)}{K(t)}\right)^{b_2} e^{\int_{t-1}^{t}\left(b_3\frac{Oil(t)}{K(t)}\right)dt}, \text{ where} \quad (7)$$

(i) G is a scale factor; (ii) RD is R&D; (iii) *Inf* measures infra-structures; (iv) b_1 and b_2 are elasticities of g in relation to RD and *Inf*; (v) b_3 is a semi-elasticity of capital efficiency in relation to $\frac{Oil}{K}$; as g refers to the capital-unit efficiency, variables (based on several studies, e.g., Coe and Helpman, 1995 (*RD*); Roller and Waverman, 2001 (*Inf*).) are divided by K.

We note that RD is measured by patent applications from both residents and non-residents. Thus, it measures the effect of applied domestic and foreign R&D on internal capital efficiency, and thus

[12] This justified our preference over the capital FOC.

[13] This allowed us to preserve a single-panel estimation approach (see Section 3), as yearly education indicators are unavailable for the entire period, and determined the exclusion of *Oil* as a pure additive windfall in (1), in order to avoid differences between wage and productivity growth. A limitation of assuming factor prices reflect their quality is that it relies on markets working properly and, in turn, on good institutions, which, as stressed by recent-curse theses, may not be present in all natural resource abundant countries. However, we should expect low levels and improvement in education and wages in those countries if institutional quality remains low.

multiple counting is not a problem. Regarding infrastructures, we use the number of telephone lines and subscriptions for cellular telephone services as a measure of the telecommunications infrastructure, which benefits growth (e.g., Roller and Waverman, 2001). We stress that the direct impact of physical infrastructures on growth is already captured by *K*. Here, we evaluate the effect on overall capital efficiency.

Moreover, all explanatory variables in *f* could also be used in *g* and vice-versa. We included variables other than *Oil* where they are expected to have the greatest impact, in order to preserve the usual functional form of constant elasticity. Indeed, due to perfect collinearity, this functional form does not allow a separate estimation of the variables' effects in *f* and *g*, as will become clear below. Since we want to analyze oil effects in *f* and *g*, coefficients are included as semi-elasticities to avoid collinearity problems. The *IQ* coefficient is included as semi-elasticity in *f*, as we consider that the curse explanation that is tested, working through institutions (e.g., Isham *et al.*, 2005), is mainly caused by a decrease in labor efficiency.[14]

From (7), the capital-efficiency growth rate is:

$$\hat{g}(t) = b_1\left(R\hat{D}(t) - \hat{K}(t)\right) + b_2\left(In\hat{f}(t) - \hat{K}(t)\right) + b_3\,\frac{Oil(t)}{K(t)}\,. \tag{8}$$

Substituting $\hat{g}$ in (6), we have:

$$\begin{aligned}\hat{w}(t) = {}& \delta_1\left[\hat{I}(t) - \hat{L}(t)\right] + \delta_2\left[\hat{T}(t) - \hat{L}(t)\right] + \delta_3 IQ(t) + \delta_4\,\frac{Oil(t)}{L(t)} + \delta_5\hat{K}(t) + \delta_6\hat{L}(t) + \\ & + \delta_7\left[R\hat{D}(t) - \hat{K}(t)\right] + \delta_8\left[In\hat{f}(t) - \hat{K}(t)\right] + \delta_9\,\frac{Oil(t)}{K(t)} + \delta_{10}O\hat{i}l(t) + u(t),\end{aligned} \tag{9}$$

where: $\delta_j = \alpha\, a_j$ if $j = 1,2,3,4$; $\delta_5 = \beta$; $\delta_6 = \alpha - 1$; $\delta_j = \beta b_{j-6}$ if $j = 7,8,9$; $\delta_{10} = \gamma$; *u*(*t*) is white noise. Equation (9) allows us to obtain estimates for α, β, γ, a_1 up to a_4, and b_1 up to b_3. Since the wage equation is based on the labor FOC, it expresses labor-productivity growth. Hence, we assess directly in (9) whether there is an oil curse or an oil growth bonus, since the estimates also evaluate the impact of those variables on growth.

In the analysis we assume constant returns to scale in *Lf* and *Kg* $(\alpha + \beta = 1)$, and test if the oil impact as a factor of production is significant (*i.e.*, if $\gamma = 0$), as several authors argue that natural resources are not crucial to growth (e.g., Meier and Rauch, 2000).[15] Then, we can aggregate $\delta_5\hat{K}(t) + \delta_6\hat{L}(t) = \beta\hat{K}(t) + (\alpha - 1)\hat{L}(t)$ into $(1-\alpha)\left[\hat{K}(t) - \hat{L}(t)\right]$ in (9). We lose the $\hat{L}$ coefficient in (9), and it becomes $\delta_5 = 1 - \alpha$; $\delta_j = \beta b_{j-5}$ if $j = 6,7,8$; $\delta_9 = \gamma$.

[14] An eventual impact through *g* is also captured – the effects are not separable, since *IQ* is not divided by *L* or *K*.
[15] There is also little empirical evidence of substantial decreasing/increasing returns (e.g., Burnside *et al.*, 1995).

Panel estimation model

Panel data improves estimation efficiency through variability across time and countries, and allows the control of unobserved individual heterogeneity (Wooldridge, 2002).[16] The panel estimation models require several assumptions to deal with the possibility of an unobserved individual element, which, in our case, can be a country and/or a time effect. Considering constant returns in *Lf* and *Kg*, our vector of variables can be represented as

$$X_j = \left\{ \left[\hat{I} - \hat{L}\right], \left[\hat{T} - \hat{L}\right], IQ, \frac{Oil}{L}, \left[\hat{K} - \hat{L}\right], \left[R\hat{D} - \hat{K}\right], \left[In\hat{f} - \hat{K}\right], \frac{Oil}{K}, O\hat{i}l \right\}.^{17}$$

Then, expression (9) in a panel form with constant δ_0 becomes either (10), in the case of the Pooled OLS and the random effects model (REM) with time and country effects, or (11) for the fixed effects model (FEM) with time and country effects, where c_i (d_t) is the country (time) effect, and ω_{it} is white noise:[18]

$$\hat{w}_{it} = \delta_0 + \sum_{j=1}^{9} \delta_j \left(X_j\right)_{it} + \varphi_{it}, \; \varphi_{it} = c_i + d_t + \omega_{it} \tag{10}$$

$$\hat{w}_{it} = \rho_{it} + \sum_{j=1}^{9} \delta_j \left(X_j\right)_{it} + \omega_{it}, \; \rho_{it} = \delta_0 + c_i + d_t \tag{11}$$

The analysis of the oil growth-effects using dummy variables

Finally, we decompose the oil growth-effects (impacts through labor and capital efficiency, and also as a factor of production) by using multiplicative dummy variables, in order to analyze the eventual significant effects on growth (see Section 4) either in the case of an oil curse or an oil growth bonus. We include dummies for all categories, since we are interested in directly assessing the significance of each category:[19]

- Income: *HIC*=1(0) and *LIC*=0(1) for High (Low and Middle) Income Countries (World Bank classification, 2007). Thus, we asses if the oil coefficients are significant for both rich and low/middle-income countries. If there is a resource curse, rich countries may not be affected by oil abundance in the presence of strong institutions. On the other hand, if the oil effect is positive, it may only be significant in poor countries, with lower efficiency levels, and where the oil sector can have a crucial effect on the overall economy;
- Technology Clubs: *A*=1(0) and *FM*=0(1) for Advanced (Follower/Marginalized) countries. The empirical analysis of Castelacci (2008) identifies the three technology clubs aforementioned, all

[16] The presence of unobserved effects dismisses the resource curse in Manzano and Rigobon (2006) study.

[17] We also tested the inclusion of lagged variables, not present in vector *X*, but only *RD* lags produced significant results (see Section 4), besides the use of a two-year lag as an instrument for the budget balance.

[18] The FEM asks how group and/or time affect the intercept, while the REM analyses error variance structures affected by group and/or time. In both, slopes are assumed unchanged. The pooled OLS is based on the idea that countries would react in the same way to changes in explanatory variables, and that intercepts are the same for all countries. The choice of the adequate estimation model is made in view of proper test statistics.

[19] Thus, we do not study the usual differential effect with respect to a reference category. The choice also allows an easier interpretation of estimates when crossing categories between distinct dummies (see Table 3, Section 4).

showing markedly different levels of technological-knowledge development. Considering the possibility of a resource curse working through institutions, stronger institutions should prevent a probable negative impact of oil abundance on R&D effort. On the other hand, if we find positive growth-effects of oil, it is more probable that they occur in countries with low levels of technological-knowledge development;

- Geographic groups (for *LIC* and *FM*): *EAP*/*ECA*/*LAC*/*MNA*/*SAS*/*SSA*= 1(0) if country *i* is from East Asia & Pacific/Europe & Central Asia/Latin America & the Caribbean/Middle East & North Africa/South Asia/Sub-Saharan Africa (otherwise). These groups follow the World Bank (2007) area classification for *LIC*, but we also apply this geographical division to *FM* countries in the analysis of results (Section 4). In interpreting the significance of the oil impact across our area dummies, we must bear in mind differences in income, technological-knowledge levels, and also distinct exploration conditions associated with local crude oil characteristics (e.g., Law, 1957; Grace, 2005);
- Inequality: *GL*=1(0) and *GH*=0(1) if Gini Index$_i$ <(≥)40. In the case of a resource course through institutions, the negative impact of oil may only arise in high inequality countries, as low institutional quality leads to a bad distribution of oil wealth. If, however, there is a positive effect of oil, it may originate in countries where the sector can induce wage inequality due to a productivity advantage over the rest of the economy, typically in developing countries (e.g., Sachs and Warner, 2001). The usual threshold of 40 is used to split high from low/medium-inequality countries.

Consequently, the vector X_j in our panel specifications (10) and (11) is redefined to include the multiplicative dummy variables (which are combined as shown in Section 4):

$$X_j = \left\{ \begin{matrix} \left[\hat{I}-\hat{L}\right], \left[\hat{T}-\hat{L}\right], IQ, \frac{Oil}{L}, \left[\hat{K}-\hat{L}\right], \left[R\hat{D}-\hat{K}\right], \left[In\hat{f}-\hat{K}\right], \frac{Oil}{K}, O\hat{i}l; \\ \left[O\hat{i}l, \frac{Oil}{K,L}\right] \times \left[\begin{matrix} HIC, LIC\ (EAP, ECA, LAC, MNA, SAS, SSA); \\ A, FM\ (EAP, ECA, LAC, MNA, SAS, SSA); GH, GL \end{matrix} \right] \end{matrix} \right\}.$$

2. Estimation strategy, choice of the main proxies and their interaction

Regarding the estimation approach, the use of a single panel with annual data follows from the need to control for an eventual oil curse, as explained below, and it also increases the data. By controlling for institutional quality, we can assess if the most recent explanation of the curse in cross-section studies (e.g., Isham *et al*., 2005) is valid in our panel of oil producers.

We follow the interpretation of institutions as reflecting policies (e.g., Dodrik *et al.*, 2004; Brunnschweiler and Bulte, 2008), an approach that proves more adequate in a single-panel estimation like ours than the usual approach of "deep and durable" features of societies followed by cross-section studies (we also test this approach using the Polity and Freedom House indicators),[20] as it allows more time variability. In line with, e.g., Acemoglu *et. al.* (2003), we consider that macroeconomic policy reflects the quality of institutions and focus on fiscal policy,[21] as several cases

[20] We choose the Polity and Freedom House indicators because they are available for many countries and years, but estimation is only possible in some cases (to reduce potential endogeneity problems, we used one-year lags of these proxies, and also tested values in 1979, prior to the estimation period).

[21] Fatás and Mihov (2003, 2005) challenge the claim of Acemoglu *et al*. (2003) that macroeconomic policy is just a transmission mechanism for institutions, by showing that fiscal policy volatility hinders growth after controlling for

(such as Norway) suggest it may be crucial in avoiding the curse (e.g., Davis, 2001, Atkinson and Hamilton, 2003).[22] We use the budget balance as a percentage of GDP to measure fiscal policy, in line with, *e.g*., Burnside and Dollar (2000). The budget balance is the only regressor that tests positive for endogeneity in our study (with the Durbin-Wu-Hausman test), but the problem disappears by instrumenting this proxy with a two-year lag and then following a 2SLS approach.[23]

The use of yearly observations is preferred to period aggregation traditionally used in growth studies (to account for economic cycles), in order to reflect fiscal policy and the variability of resource revenues. In our view, the contemporaneous differences in electoral cycles across countries (reflected on budget balances), which are lost through period aggregation, are crucial in assessing the state management of oil revenues. There is also evidence that volatility has a significant negative effect on long-run growth (e.g., Martin and Rogers, 2000), and that it may be crucial for the curse result (e.g., van der Ploeg and Poelhekke, 2010). These factors may explain unexpected results we find with five-year panels, due to loss of information (see Section 4).

We must also consider the geographic concentration of oil-proved reserves is crucial in terms of investment flows. Much of the international investment in capacity has been made in countries where foreign direct investment has serious restrictions or faces political risk. Indeed, political risks and concerns about security of supply are among the main causes of lack of investment in oil (and gas) exploration and production (Osmundsen *et al*., 2006). This means that, unless there is a full change in policies and institutions, a greater part of the oil producers' cash flows will be redirected to oil re-investment (Greenspan, 2005).

Thus, poor institutional quality may reduce the flow of international oil investment and, indirectly, the total amount (and composition) of national investment. In this study, the oil growth-effects are estimated and analyzed by taking into account national investment and institutional quality (along with other control variables), as mentioned before.

The possibility of an oil curse working through institutions and affecting labor and capital efficiency is evaluated by the sign and significance of these oil growth-effects when we remove the proxies for institutions from estimation forms (10) and (11). In particular, we focus on fiscal policy to assess the importance of public management of oil windfalls. If there is oil growth bonus, good institutions may be determinant by lowering oil exploration risks.

Regarding the measurement of oil abundance, we find oil production to be the appropriate proxy for the oil stock included as a factor of production in the production function (preferable to oil reserves, as mentioned in Section 1) by assuming an optimal constant extraction rate (following Campbell, 1980; Crabbé, 1982) over the estimation period. As we show below, this assumption allows us to preserve the analysis of the oil impact as a factor of production and, at the same time, draw

institutional variables. Bleaney and Halland (2009) find that this negative effect is explained by changes in natural-resource export shares (the curse result is reduced and affects both diffuse and concentrated resources) as institutional variables become insignificant. Following Bleaney and Halland (2009), we deem that the access to natural-resource revenues may distort fiscal policy and assess this thesis in our case.

[22] Additionally, we can assume the quality of policies and institutions is correlated. According to Mauro (1995), the measures of corruption and various aspects of bureaucratic efficiency are highly correlated. Moreover, Stein *et al.* (2005) associate the quality of legislative capabilities, in general, to the quality of policies, namely fiscal.

[23] This proxy only reflects the main issue of excessive indebtedness by governments (it excludes proper countercyclical policies in recessions), thus assessing - past and present, due to instrumentation - fiscal diligence.

conclusions for both the oil production and the oil stock regarding the analysis of the effects through labor and capital efficiencies.

Denoting $Oil_P(t)$ as the oil production at time t and $Oil_S(t)$ as the remaining oil stock at t (included in (1)), the assumption of a constant (positive) extraction rate E is represented by:

$$Oil_P(t) = E\, Oil_S(t) \Leftrightarrow Oil_S(t) = \frac{1}{E} Oil_P(t) \cdot \tag{12}$$

From (12), we also find the log growth rates of the two variables are the same:

$$O\hat{i}l_S(t) = O\hat{i}l_P(t) \,. \tag{13}$$

Therefore, the oil variables $O\hat{i}l(t)$ and $\frac{Oil(t)}{L,K}$ in our final estimation forms (10) and (11) can be directly replaced by the corresponding expressions with oil production (in (12) and (13)) without changing the analysis. The only difference in using oil production as a proxy for the oil stock under the referred to assumption is that the coefficients of oil impacts on efficiencies $\frac{Oil(t)}{L,K}$ become divided by the positive extraction rate E (which we do not need to estimate separately), but the analysis of results in terms of sign and significance is similar, thus we can draw conclusions for both oil variables regarding these impacts. In the curse assessment, oil production may be (in theory) a more appropriate measure (being a flux) of variable oil windfalls affecting institutions and, in turn, labor and capital efficiency.[24]

In terms of interpretation, the oil stock $Oil_S(t)$ represents, under the constant extraction rate assumption, the remaining amount of oil resources that are economically available for extraction at each time, and its evolution relies on, e.g., structural trends in demand (assumed as exogenous) leading prices, and technological advances (also assumed as exogenous) determining extraction costs. Depending on these conditions, the phase when the extraction rate declines towards the end of the oil field is prolonged or anticipated at each moment, and the exploration of new wells may or not be economically viable. Therefore, our assumption of a constant extraction rate only needs to be satisfied on average for each country at each time, i.e., we can allow oil fields with declining extraction rates provided they are compensated for by production from new wells at each time.

As mentioned in Section 1, we conduct an additional analysis of the oil growth-effects by breaking down oil production between rig productivity (thereafter denoted as *RP*) and the number of rigs (thereafter denoted as *Rigs*), as oil concentration may allow a more efficient oil exploration and thus be a significant variable. The oil growth-impact as a factor of production associated with $O\hat{i}l(t)$ in estimation forms (10 and (11), is decomposed between the impacts $R\hat{P}$ and $Ri\hat{g}s$. We break down the oil growth-effects on labor and capital efficiencies $\frac{Oil(t)}{L,K}$ between $\frac{RP(t)}{L,K}$ and $\frac{Rigs(t)}{L,K}$,

[24] Notice that oil windfalls should also incorporate oil price variations, which are absent in our analysis given the chosen proxy, However, we would expect oil production variations to be positively correlated with international price changes as corresponding to optimal decisions to increase oil receipts in an oligopolistic market.

respectively.[25] Thus, the vector of variables X_j in estimation forms (10) and (11) is again redefined to include $R\hat{P}$, $Ri\hat{g}s$, $\frac{RP(t)}{L,K}$ and $\frac{Rigs(t)}{L,K}$.

3. Results

Table 1 – descriptive statistics of main variables (1980-2005)

	Mean	S.D.
$GDPpc$ growth	0.971	7.280
$\hat{w}$	0.431	8,411
$(\hat{I} - \hat{L})$	1.530	17.628
$(\hat{T} - \hat{L})$	4.166	12.317
IQ: budget balance in % of GDP	-2.570	4.961
IQ: Polity [a)]	1.243	7.940
IQ: Freedom [b)]	4.229	2.117
Oil: crude production (thousand barrels a day)	1059.621	1609.555
Oil: number of oil rigs	84.120	325.574
$\hat{L}$	1.718	4.939
$\hat{K}$	3.109	3.406
$(In\hat{f} - \hat{K})$	9.846	14.205
$(R\hat{D} - \hat{K})$	-1.771	25.559

Notes: percent values, except for *Oil* and *IQ* indicators; results based on non-missing observations; [a)] Revised combined Polity score (Polity IV), ranging from -10 (strongly autocratic) to +10 (strongly democratic); [b)] Freedom classification (from The Freedom House) combining average ratings for Political Rights and for Civil Liberties – countries rated 3 or less are classified as Free, between 3 and 5 (5,5 since 2003) are Partially Free, and between 5 (5,5 since 2003) and 7 are Not Free. Data sources in Appendix A – Table A1.

[25] This division would be more precise if we used logs instead of absolute values, but the conclusions are similar.

Table 1 above shows descriptive statistics of the data for the main variables in our unbalanced panel of 48 oil producers from 1980 to 2005.[26] We stress the high standard deviations of most variables, namely oil indicators, thus expressing a diversity of situations among oil producers.

Figure 1 below depicts a negative correlation between crude oil production in 1979 and real GDP *per* capita growth of 48 crude oil producers from 1979 to 2005, thus illustrating an oil curse. Similar results were found using real wage *per* worker growth, our dependent variable, instead of real GDP *per* capita growth.

Figure 1 - GDP *per capita* average growth rate from 1979 to 2005 and crude oil production in 1980

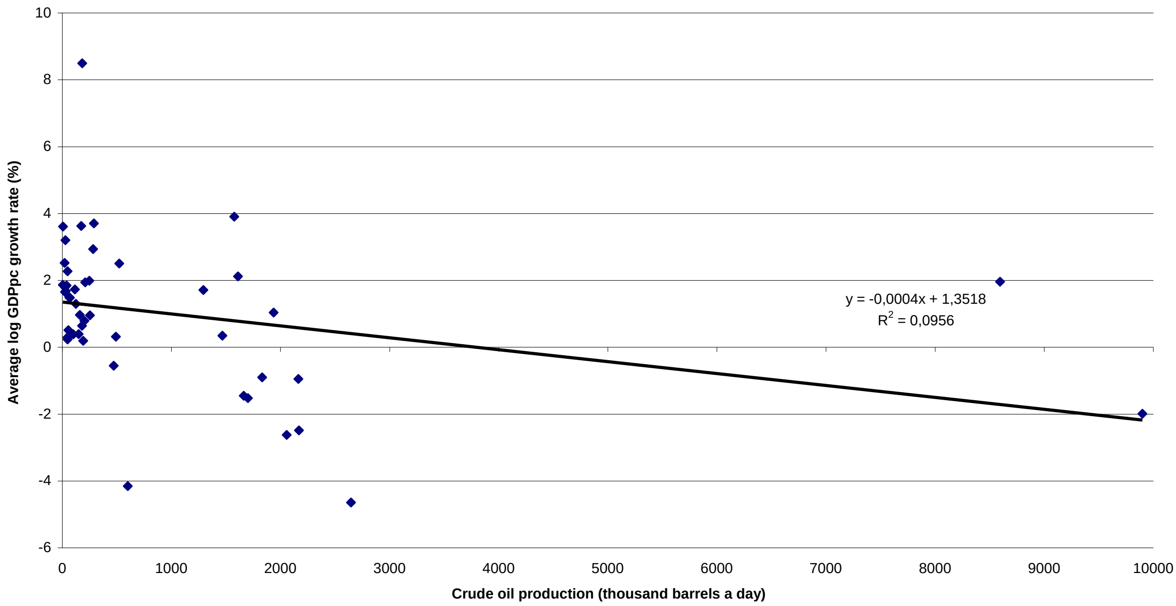

Table 2 shows estimations of panel form (10), since the REM is the appropriate model in all cases, according to test statistics. The regressions present the growth-effects of our oil indicators, in addition to the impact of the control variables. The dummy variables are excluded in this first set of estimations (the effect of these variables is shown in Table 3). The estimation period ends in 2003 and not in 2005 due to the instrumentation of the budget balance (our proxy for fiscal policy and the overall quality of policies and institutions) with a two-year lag to dismiss endogeneity concerns, as previously mentioned – this means the main regressions are estimated with a 2SLS approach.[27] Regarding the other proxies for institutions, only $Polity_{-1}$ showed enough variability to be included in all estimations,[28] but results with the Freedom indicator are similar when the effect can be estimated. The introduction of lags in other explanatory variables only produced significant results for *RD*.

[26] Our panel excludes oil producers from former USSR and Yugoslavia because they are aggregated in OPEC data, and the same does not happen in the remaining data. Data requirements reduce the number of estimated countries to 21 in our final estimations, but we achieve diversity of situations (see analysis of Table 2).

[27] However, we note that instrumentation does not appear to significantly influence the main results, which are similar using the uninstrumented balance budget.

[28] We tested one-year lags and values in 1979 with Polity and Freedom indicators, to reduce potential endogeneity problems.

Table 2 – Wage equations (1980-2003)

Regression	1	1a	2	2a	3	4	4a
Sample (comparison)		Regr.3		Regr.1			Regr.3
Model	REM G&T [(a)]	REM G&T	REM G&T	REM G&T	REM G&T	REM G&T	REM G&T
F [(b)]	2.151	2.393	1.571	2.214	2.393	2.711	2.514
LM [(b)]	17.17	14.01	11.17	18.50	10.86	15.52	15.66
Hausman [(b)]	4.39	6.68	6.87	2.28	9.65	8.26	8.60
Dependent variable, $\hat{w}$							
Constant	-0.846	-0.630	-0.198	-0.466	-0.256	0.239	-0.116
	(-0.622)	(-0.431)	(-0.202)	(-0.454)	(-0.157)	(0.160)	(-0.070)
$(\hat{I} - \hat{L})$	0.093*	0.070**	0.093*	0.093*	0.070**	0.070**	0.073**
	(3.382)	(2.425)	(3.918)	(3.450)	(2.447)	(2.553)	(2.535)
$(\hat{T} - \hat{L})$	0.048	0.037	0.093**	0.052	0.047	0.062	0.037
	(0.735)	(0.499)	(2.137)	(0.797)	(0.616)	(0.875)	(0.492)
IQ: Fiscal Policy	0.224	0.385***			0.407***	0.401***	0.385
	(1.066)	(1.676)			(1.715)	(1.772)	(1.630)
IQ: Polity$_{-1}$	0.134	0.175			0.121	0.049	0.094
	(1.310)	(1.628)			(0.820)	(0.389)	(0.637)
$O\hat{i}l$	0.302	-0.611	0.756	0.014			
	(0.160)	(-0.276)	(0.380)	(0.007)			
$R\hat{P}$					-0.899		
					(-0.404)		
$Ri\hat{g}s$					-1.787		
					(-0.777)		
$\frac{Oil}{L}$ (c)	-0.002	-0.002	-0.002	-0.001			
	(-0.902)	(-0.890)	(-0.881)	(-0.587)			
$\frac{RP}{L}$ (c)					-0.013	-0.007	-0.009
					(-0.729)	(-0.440)	(-0.538)
$\frac{Rigs}{L}$ (c)					0.032	0.037	0.039
					(0.673)	(1.117)	(0.818)
$\frac{Oil}{K}$ (c)	0.278	0.205	0.209	0.274			
	(1.348)	(0.888)	(1.134)	(1.289)			
$\frac{RP}{K}$ (c)					0.145***	0.150***	0.155***
					(1.791)	(1.913)	(1.901)
$\frac{Rigs}{K}$ (c)					-2.273	-2.596	-2.854
					(-0.590)	(-0.998)	(-0.737)
$(\hat{K} - \hat{L})$	0.340*	0.306*	0.333*	0.352*	0.297*	0.292*	0.301*
	(5.960)	(5.388)	(5.822)	(6.292)	(5.284)	(5.496)	(5.355)
$(In\hat{f} - \hat{K})$	0.128*	0.138**	0.046	0.127**	0.140**	0.126**	0.141**
	(2.567)	(2.478)	(1.102)	(2.544)	(2.514)	(2.415)	(2.547)

$(\hat{RD}-\hat{K})$	0.010	0.015	0.006	0.010	0.020	0.022	0.021
	(0.783)	(1.000)	(0.441)	(0.839)	(1.329)	(1.600)	(1.424)
$(\hat{RD}-\hat{K})_{-1}$	0.022***	0.009	0.023***	0.023***	0.009	0.014	0.011
	(1.698)	(0.558)	(1.764)	(1.758)	(0.604)	(0.992)	(0.694)
$(\hat{RD}-\hat{K})_{-2}$	0.012	-0.018	0.014	0.013	-0.016	-0.015	-0.016
	(0.821)	(-1.058)	(1.011)	(0.899)	(-0.985)	(-0.948)	(-0.976)
Observations	336	267	402	336	267	284	267
R^{2} (d)	0.458	0.503	0.369	0.452	0.522	0.523	0.518
Adjusted R^{2} (d)	0.339	0.376	0.252	0.337	0.392	0.406	0.392

Notes: T-ratios below the coefficients' estimates. Significance levels of 1% (*), 5% (**) and 10% (***). (a) G&T stands for a joint Group (country) and Time effect. (b) The F/LM/Hausman tests choose between *Pooled* OLS and FEM/Pooled OLS and REM/FEM and REM; G&T effects are chosen over individual effects if significant; (c) To avoid values close to zero, ratios with *L* were multiplied by 10^3, and ratios with *K* by 10^9, thus expressing in all cases indices of oil abundance *per* factor unit; (d) From the FEM G&T; grey–shaded rows represent the results of the breakdown of oil production between rigs and rig productivity for all oil growth-effects. Estimations obtained with Limdep 8.0 software.

Since the number of observations is not high in our regressions (ranging from 267 to 402), we use auxiliary estimations (denoted with the suffix 'a' after the regression number) to compare results with other regressions using a common sample. This assures that differences in estimates do not result from variations in sample sizes when comparing regressions.

Regarding interpretation, we remind the reader that the estimate for $(\hat{K}-\hat{L})$ represents capital elasticity as resulting from the assumption of constant returns on *Lf* and *Kg*. All estimates convey the growth-effects of the associated variables as reflected on the dependent variable $\hat{w}$, the real wage growth, derived as labor productivity growth inside the model. As for the oil variables, the $O\hat{i}l$ coefficient (which is broken down between $R\hat{P}$ and $Ri\hat{g}s$ in the grey background rows) represents oil elasticity in relation to *Y*, thus assessing the impact as a factor of production (which, if insignificant, does not dismiss the assumption of constant returns on *Lf* and *Kg*). The estimates for $\frac{Oil}{L}$ and $\frac{Oil}{K}$ (which can be interpreted as measures of relative oil abundance) assess the oil growth-effects through labor and capital efficiency, respectively (they are broken down between $\frac{RP}{L}$ and $\frac{Rigs}{L}$, and $\frac{RP}{K}$ and $\frac{Rigs}{K}$ in grey shaded rows to assess the importance of oil concentration, as proxied by rig productivity, on efficiencies).

Starting with the oil coefficients, in regression 1 (before oil production breakdown) we find the oil effect as a factor of production ($O\hat{i}l$ coefficient) to be statistically insignificant at 10% (i.e., we do not reject, at 10%, $\gamma=0$), and the same goes on with the growth-impacts through labor ($\frac{Oil}{L}$) and capital efficiency ($\frac{Oil}{K}$). The oil growth-effects are also all insignificant when we remove the institutional quality indicators (*Fiscal Policy* and *Polity*$_{-1}$) in regression 2 (this result is confirmed in auxiliary regression 2a using a common sample), thus dismissing an oil curse working through institutions in our panel.[29]

In regression 3, we examine the importance of oil concentration by breaking down our oil abundance proxy (oil production) and examining the growth-effects of rigs and rig productivity. The only significant result is a positive impact (with a significance level of 10%) of rig productivity through capital efficiency, associated with $\frac{RP}{K}$ (all the other growth-effects, either as factors of production or through efficiencies, are not statistically different from zero), which means that oil concentration matters to growth.

The positive impact of oil concentration remains in regression 4 (and in auxiliary regression 4a, using the same sample of regression 3), were we remove the oil impact as a factor of production since it is always insignificant (with or without the oil proxy breakdown).

With respect to the institutional quality indicators, $Polity_{-1}$ is insignificant (at 10%) in all regressions, and *Fiscal Policy* shows a significant (at 10%) positive impact in regressions 3 and 4 (although it loses its significance using regression 3 sample, as shown in 4a), and also in auxiliary regression 1a, where we use the sample of regression 3 to compare this estimate. We note that the Freedom House indicator is also insignificant when we can include it in estimations.[30] Therefore, the usual indicators based on 'durable' institutional features of societies are less suited than a (more time-variable) policy approach to institutions (assessed by fiscal policy, in our case) in a single-panel study.

The estimates of the other control variables are also positive, as expected in growth factors, although in most cases they are not significant in all regressions. Investment ($(\hat{I} - \hat{L})$) is always significant at 5%, but trade $(\hat{T} - \hat{L})$ is only significant in regression 2 (where the sample is higher), both benefiting growth through labor efficiency. As for the effects through capital efficiency, infrastructures $(In\hat{f} - \hat{K})$ is significant at 5% (except in regression 2), and R&D $(R\hat{D} - \hat{K})_{-1}$ is significant at 10% with a one-year lag in regressions 1, 2 and 2a. The capital elasticity estimate $(\hat{K} - \hat{L})$ is significant at 1% and close to 30% in all cases.

In Table 3, we decompose the significant effect of rig productivity by using our dummies. According to test statistics, the REM (with country and time effects) is still the adequate model for all regressions in Table 3 – estimation form (10). Since $Polity_{-1}$ is always insignificant in Table 2, we exclude it in Table 3. The effects of rigs through labor and factor efficiencies ($\frac{Rigs}{L}$ and $\frac{Rigs}{K}$) are also removed, as they are insignificant and we want to concentrate on the impact of rig productivity. In regression 1 of Table 3, we can see that the measure of fit (the reference FEM adjusted R^2) is slightly improved compared to regression 4 in Table 2 (with the same sample size) after the above-mentioned exclusions, and that the estimates of the significant coefficients are very similar both in value and significance.

[29] As a robustness test, we conducted estimations with five-year panels and also found no evidence of an oil curse, but these results are not satisfactory (and thus are not shown), as several growth factors become insignificant or show unexpected coefficients, probably due to loss of annual information.

[30] Since we cannot estimate the Freedom indicator and Polity in the same regression, we choose to present results only with Polity, as it can be estimated in all regressions.

The 284 resultant observations correspond to 21 countries. We show the number of estimated years for each of these countries in Table B1 (Appendix B), along with the corresponding dummy categories, which are also shown for the remaining countries of our panel of 46 crude oil producers. An inspection of Table B1 shows diversity of situations to carry our estimation, but data constraints lead to underrepresentation of some area groups.[31] Therefore, the results of dummy decompositions should be taken with caution.

Before we decompose the positive impact of rig productivity ($\frac{RP}{K}$) with our dummies, first we assess, in regression 2, if it is influenced by removing *Fiscal Policy* from the estimation. Apparently, the estimate of $\frac{RP}{K}$ is improved in value and significance in regression 2, but this result is influenced by an increase in the sample size. The appropriate comparison is made in regression 2a, where we use the sample of regression 1.

We find that, in fact, the positive impact of oil concentration (through capital efficiency) loses significance (it is only significant at 11%) excluding fiscal policy from the regression. Therefore, it appears that fiscal responsibility is crucial for oil concentration to foster growth.

The other regressions in Table 3 decompose the impact of $\frac{RP}{K}$ by using the multiplicative dummy variables presented in Section 3. Regression 3 shows that rig productivity benefits growth (through capital efficiency) only in low/middle-income countries (the coefficient of $LIC \times \frac{Oil}{K}$ is positive and significant at 10%, while $HIC \times \frac{Oil}{K}$ is insignificant), as expected. This positive effect originates in (low/middle-income) countries from East Asia & Pacific and Latin America & Caribbean, as we find in regression 4 (the coefficients for *EAP* and *LAC* are significant at 1% and 10%, respectively). In the case of *EAP*, only Malaysia is represented.

Table 3 – Wage equations (1980-2003)

Regressions	1	2	2a	3	4	5	6	7
Sample			Regr.1					
Model; statistics				REM G&T				
F	2.883	2.598	2.712	2.869	3.036	2.915	3.097	2.861
LM	15.29	21.19	14.31	15.44	15.08	15.12	14.94	15.58
Hausman	5.55	7.94	2.94	5.76	9.73	6.52	10.81	5.91
Dep.variable				$\hat{w}$				
Constant	0.422	1.000	-0.568	0.461	0.190	0.289	-0.079	0.459
	(0.357)	(0.094)	(-0.552)	(0.389)	(0.110)	(0.237)	(-0.046)	(0.389)
$(\hat{I} - \hat{L})$	0.064**	0.071*	0.069**	0.063**	0.067**	0.065**	0.069*	0.063**
	(2.353)	(3.154)	(2.546)	(2.314)	(2.493)	(2.399)	(2.587)	(2.311)
$(\hat{T} - \hat{L})$	0.069	-0.009	0.055	0.070	0.075	0.070	0.075	0.070
	(0.991)	(-	(0.791)	(1.000)	(1.076)	(1.001)	(1.081)	(1.000)

[31] Considering our dummies, only Sub-Saharan countries (SSA) are not estimated in our regressions due to data constraints. Middle East countries are also clearly underrepresented in our dummy MNA (only one observation from Iraq) due to data constraints.

		0.166)						
IQ	0.420***			0.431**	0.417***	0.402***	0.401***	0.432**
	(1.944)			(1.983)	(1.866)	(1.843)	(1.785)	(1.989)
$\frac{RP}{L}$	-0.006	-0.017	0.001	-0.002	-0.001	0.034	0.046	-0.001
	(-0.355)	(-1.138)	(0.088)	(-0.090)	(-0.078)	(0.750)	(0.977)	(-0.070)
$\frac{RP}{K}$	0.142***	0.168**	0.123					
	(1.833)	(2.277)	(1.601)					
Income dummies								
$HIC \times \frac{RP}{K}$				0.105	0.138			
				(1.089)	(1.228)			
$LIC \times \frac{RP}{K}$				0.192***				
				(1.771)				
Tech.Clubs dum.								
$A \times \frac{RP}{K}$						-0.228	-0.306	
						(-0.567)	(-0.731)	
$FM \times \frac{RP}{K}$						0.091		
						(0.951)		
Geog. dum. (for LIC;FM)								
$EAP \times \frac{RP}{K}$					32.758*		32.906*	
					(3.097)		(3.116)	
$LAC \times \frac{RP}{K}$					0.193***		0.103	
					(1.731)		(1.012)	
$MNA \times \frac{RP}{K}$					-0.461		-0.416	
					(-0.228)		(-0.205)	
$SAS \times \frac{RP}{K}$					6.271		7.511	
					(0.204)		(0.244)	
$ECA \times \frac{RP}{K}$							11.253	
							(0.399)	
Inequality dum.								
$GL \times \frac{RP}{K}$								0.101
								(1.051)
$GH \times \frac{RP}{K}$								0.197***
								(1.815)
$(\hat{K} - \hat{L})$	0.304*	0.317*	0.295*	0.302*	0.300*	0.303*	0.302*	0.302*
	(5.855)	(6.433)	(5.675)	(5.799)	(5.841)	(5.844)	(5.892)	(5.795)
$(\hat{Inf} - \hat{K})$	0.143*	0.040	0.145*	0.135*	0.127**	0.146*	0.135*	0.134**
	(2.803)	(1.008)	(2.862)	(2.588)	(2.423)	(2.850)	(2.634)	(2.567)
$(\hat{RD} - \hat{K})$	0.022	0.019	0.024***	0.023	0.023	0.021	0.022	0.023
	(1.550)	(1.409)	(1.662)	(1.623)	(1.575)	(1.514)	(1.524)	(1.627)
$(\hat{RD} - \hat{K})_{-1}$	0.014	0.004	0.017	0.017	0.017	0.014	0.015	0.017

	(1.001)	(0.336)	(1.198)	(1.121)	(1.146)	(0.990)	(1.047)	(1.138)
$(\hat{RD}-\hat{K})_{-2}$	-0.014 (-0.864)	-0.016 (-1.078)	-0.011 (-0.710)	-0.013 (-0.829)	-0.014 (-0.891)	-0.013 (-0.832)	-0.015 (-0.913)	-0.013 (-0.821)
Observations	284	327	284	284	284	284	284	284
R^2	0.518	0.466	0.506	0.518	0.546	0.522	0.551	0.518
Adjusted R^2	0.407	0.353	0.395	0.404	0.432	0.409	0.435	0.404

Notes: same notes of Table 2.

This country shows the highest contribution of rig productivity to growth in the estimated panel (52.3%, on average) despite the low levels of this indicator (average of 4.374 in the estimated period, much bellow total sample) and also *per* unit of *K*.[32]

In regression 5, we divide the $\frac{RP}{K}$ effect between technological-knowledge clubs, but neither *A* nor *FM* groups are significant. When we apply the area division to *FM* countries in regression 6, we find that only *EAP* is significant (again, only Malaysia is present), at 1%. The *LAC* group is not significant for *FM* countries (unlike for *LIC*) due to the presence of Trinidad and Tobago, a follower but high-income country. In fact, all estimated countries in *EAP* and *LAC* groups are followers in terms of technological convergence.[33]

Finally, in regression 7 we find that an increase in rig productivity benefits growth only in countries with high inequality (the coefficient of $GH \times \frac{Oil}{K}$ is positive and significant at 10%, while the estimate of $GL \times \frac{Oil}{K}$ is insignificant). We stress that all high-inequality countries in our panel belong to the *LIC* group**,** with the notable exception of the United States, which reduces the significance of $GH \times \frac{Oil}{K}$ and renders results very similar to those in regression 5, where we use the income dummies.[34] As for the estimates of the control variables, no major differences were found with respect to the first regression.

4. Concluding remarks

In this study, we estimate the growth-effects of oil abundance to re-evaluate whether there is oil 'curse' or bonus, as existing empirical studies show conflicting results and the subject has political relevance, chiefly in developing oil producers.

We follow an original approach, by using a panel framework that estimates the effect of oil as a factor of production, and also its impacts through labor and capital efficiency, while controlling for the most relevant growth factors (labor, capital, investment, trade, institutional quality,

[32] This differs from the average behaviour, since we find a mild positive correlation between the series rig productivity (in level and also divided by *K*) and the associated estimated growth contribution in our results.
[33] We note that Algeria, Egypt (*MNA*) and India (*SAS*) are the only marginalized countries in our estimated panel, following the same classification by Castelacci (2008), as shown in Table B1 (Appendix B).
[34] As the decomposition of $GH \times \frac{Oil}{K}$ using area groups produces irrelevant results, they are not presented.

infrastructures, R&D; human capital is considered inside the real wage growth, derived as the dependent variable inside the model), which are significant in our results.

By focusing on a panel of oil producers, we also control for specificities of oil economies that may not be addressed in most studies on the resource curse, as they usually include resource-poor countries as well. However, the usual cross-section curse plot is found inside our panel of crude oil producers considering oil production, which is the chosen proxy to the oil stock included as a factor of production by considering a constant extraction rate.

Our panel estimations dismiss a potential oil curse working through institutions (the most consensual thesis thus far) by, we deem, affecting labor and capital efficiency. The oil growth-effects are all insignificant (even when we exclude the proxies for institutions) considering our oil abundance proxy, which points to the presence of (random) unobserved effects as a probable cause of the cross-section curse result in our sample.[35]

However, after decomposing the oil abundance proxy, our results show a positive growth-effect of oil concentration (in space), as measured by rig productivity, through capital efficiency. This is an expected result, as a higher oil concentration allows oil to be explored with less capital, due to economies of scale. Moreover, this positive growth-impact of oil concentration is only significant in the presence of (past and present, due to instrumentation) fiscal responsibility (as measured by the budget balance as percentage of GDP), our proxy for institutions following a policy approach, which, by allowing more time variability, proves more adequate than usual institutional indicators in our single-panel strategy (crucial to augment the data and capture the variability of oil windfalls in the curse evaluation).

This importance of fiscal responsibility in materializing the positive growth-impact of oil concentration also makes sense. Fiscal responsibility, being correlated with institutional quality in general, decreases oil exploration risks (namely profit repatriation, in the case of foreign companies, and possible civil disturbances, seen in several developing oil producers), and thus reduces financing costs by requiring a smaller interest rate premium. Legal and bureaucratic questions should also be less costly in the presence of better institutions, and workers may be more productive, thus reducing operational costs.

Finally, we decompose the positive impact of rig productivity using dummies that separate countries according to income level and inequality, technological-knowledge clubs and geographical areas. These results show the positive effect is confined to low/middle-income countries (from East Asia & the Pacific and Latin America & the Caribbean, all followers in terms of technological-knowledge convergence), and showing high-income inequality. In our view, this occurs because only in developing countries can the oil sector induce a productivity advantage over the rest of the economy, driving growth and inducing wage inequality (e.g., Sachs and Warner, 2001). Distinct oil exploration conditions may explain why only two of our area groups for low/middle-income countries show significant effects of oil through capital efficiency. However, due to the relatively small sample size, these dummy decomposition results must be read with caution (particularly regarding the area groups, some of which have few countries).

[35] Other specificities of oil economies, which we control for by focusing on a panel of crude producers, may also explain the curse (eventually through institutions, a hypothesis we dismiss here) in studies that also include resource-poor countries.

Overall, our results show that oil abundance is not significant to economic growth, but oil concentration benefits growth in the presence of fiscal responsibility (and good institutions in general), by reducing the amount of capital necessary to oil exploration. The positive impact is only significant in developing countries, where institutions are weaker and there is a broader scope for factor-efficiency and technological improvements arising from the oil industry, which is defined by a highly globalised know-how.

Future research should attempt to overcome data constraints, and also include data regarding natural gas and more countries. Despite data constraints, we believe they do not affect the major conclusions of this study.

Appendix A – Table A1: Data sources

Variable	Name	Measure	Source	Comments
Y	Output	GDP at constant prices	UN (NAD)	
L	Labor	Employment level	ILO, OECD, WB, IMF, UN (CD), UNECE	Compatible data was used to extend the series.
K	Capital Stock		Authors own calculations with *I* and *Y*	Permanent Inventory method[36]
$\hat{w}$	Real wage *per* worker log growth	Labour compensation growth (National Accounts approach) minus GDP deflator and *L* log growth rates	Sources for labour compensation: UN (CD), OECD, WB; Source for product deflator: UN (CD)	Only compatible labour compensation series are used.
I [(a)]	Investment	Gross capital formation (constant prices)	UN (NAD)	
T [(a)]	Trade	Exports + Imports (constant prices)	UN (NAD)	
IQ	Institutional Quality	Budget balance in percentage of GDP	UN (NAD), OECD, WB, IMF	Compatible data was used to extend the series.
		Polity, Polity$_{-1}$, Polity (1979)	Polity IV Project	
		Freedom, Freedom$_{-1}$, Freedom (1979)	FH	
Oil [(a) (b)]	Oil	Crude oil production	OPEC	

[36] Initial capital is calculated as $K_{1970} = \frac{I_{1970}}{r+d}$, following Harberger (1978), with I_{1970} being the first available value for *I*, *r* the average GDP growth in 1970-80 and *d* the depreciation rate (6%, as in Hall and Jones, 1999). For the following years: $K(t) = [1-d)]K(t-1) + I(t)$, following the capital dynamics of the Solow-Swan Model.

	abundance indicators	(thousand barrels/day), # rigs		
RD [(b)]	R&D	patent applications to national patent offices[37]	WIPO	
Inf [(b)]	Infra-structures	number of telephone lines and subscriptions for cellular telephone services	UN (CD), WB	Data is compatible between sources.
GNIpc79	Initial Income	GNI *per capita* in (1979 $)	UN (NAD) (ATLAS method)	
Dummies	country dummies	Income, geog., tech.clubs, inequality groups	WB; Castelacci, 2008 (tech.clubs)	

[(a)] Divided by *L* (K) inside the labor efficiency specification; [(b)] Divided by *K* inside the capital efficiency specification.

Sources:

FH, the Freedom House, Freedom in the World Country Ratings;

ILO, International Labor organization, yearly and periodical data;

IMF, International Monetary Fund, International Financial Statistics;

OECD, Organization for Economic Co-operation and Development, Statistic database;

OPEC, Organization of the Petroleum Exporting Countries, Annual Statistical Bulletin, 2007;

Polity IV Project (by Monty G. Marshall and Keith Jaggers), Polity IV Data Series version 2007;

UN (CD), United Nations, Common database online;

UN (NAD), United Nations, National Accounts database online;

UNECE, United Nations Commission for Europe, statistical database online;

WB, World Bank, World Development Indicators 2007;

WIPO, World Intellectual Property Organization, Intellectual Property Statistics.

[37] Includes international applications under Patent Cooperation Treaties and excludes those to regional offices, which concede protection in the area. The WIPO notes that not all inventions are patented, patent application and inventive activity may not coincide in time and space, and the number of applications may vary across countries due to differences in patent systems. Still, this is the best R&D proxy for a high number of countries and years.

Appendix B – Table B1: Estimation panel for regressions in Table 3 (Section 4)

	Oil producer	*t*=t0	*t=T*	*N*	Dummies				
					Area *LIC*	Area *FM*	Income	Tech.Clubs	Ineq.
1	Algeria	1994	2000	7	*MNA*	*MNA*	*LIC*	*FM*	*GL40*
2	Albania			0	*ECA*	*ECA*	*LIC*	*FM*	*GL40*
3	Angola			0	*MNA*	*MNA*	*LIC*	*FM*	*GH40*
4	Argentina			0	*LAC*	*LAC*	*LIC*	*FM*	*GH40*
5	Australia	1980	2003	24			*HIC*	*A*	*GL40*
6	Bahrain			0		*MNA*	*HIC*	*FM*	n/a
7	Brazil			0	*LAC*	*LAC*	*LIC*	*FM*	*GH40*
8	Brunei			0			*HIC*	*n/a*	n/a
9	Cameroon			0	*SSA*	*SSA*	*LIC*	*FM*	*GH40*
10	Canada	1980	2003	24			*HIC*	*A*	*GL40*
11	Chile	1980	2003	21	*LAC*	*LAC*	*LIC*	*FM*	*GH40*
12	China			0	*EAP*	*EAP*	*LIC*	*FM*	*GH40*
13	Colombia	1980	2002	10	*LAC*	*LAC*	*LIC*	*FM*	*GH40*
14	Congo, Dem. Rep.			0	*SSA*	*SSA*	*LIC*	*FM*	n/a
15	Denmark			0			*HIC*	*A*	*GL40*
16	Ecuador	1989	1994	2	*LAC*	*LAC*	*LIC*	*FM*	*GH40*
17	Egypt, Arab Rep.	1991	2001	5	*MNA*	*MNA*	*LIC*	*FM*	*GL40*
18	France	1980	2003	21			*HIC*	*A*	*GL40*
19	Gabon			0	*SSA*	*SSA*	*LIC*	*FM*	n/a
20	Germany	1980	2003	24			*HIC*	*A*	*GL40*
21	Hungary			0	*ECA*	*ECA*	*LIC*	*FM*	*GL40*
22	India	1995	1998	4	*SAS*	*SAS*	*LIC*	*FM*	*GL40*
23	Indonesia			0	*EAP*	*EAP*	*LIC*	*FM*	*GL40*
24	Iran, Islamic Rep.	2001	2001	1	*MNA*	*MNA*	*LIC*	*FM*	*GH40*
25	Iraq			0	*MNA*		*LIC*	n/a	n/a
26	Italy	1980	1985	6		*ECA*	*HIC*	*FM*	*GL40*
27	Kuwait			0		*MNA*	*HIC*	*FM*	n/a
28	Libya			0	*MNA*		*LIC*	n/a	n/a
29	Malaysia	199	1995	5	*EAP*	*EAP*	*LIC*	*FM*	*GH40*

		1							
30	Mexico	1992	2003	12	*LAC*	*LAC*	*LIC*	*FM*	*GH40*
31	Netherlands	1980	2003	22			*HIC*	*A*	*GL40*
32	New Zealand	1987	2003	14			*HIC*	*A*	*GL40*
33	Nigeria			0	*SSA*	*SSA*	*LIC*	*FM*	*GH40*
34	Norway	1980	2003	24			*HIC*	*A*	*GL40*
35	Oman			0	*MNA*	*MNA*	*LIC*	*FM*	n/a
36	Peru			0	*LAC*	*LAC*	*LIC*	*FM*	*GH40*
37	Qatar			0			*HIC*	n/a	n/a
38	Romania			0	*ECA*	*ECA*	*LIC*	*FM*	*GL40*
39	Saudi Arabia			0		*MNA*	*HIC*	*FM*	n/a
40	Syrian Arab Republic			0	*MNA*	*MNA*	*LIC*	*FM*	n/a
41	Trinidad and Tobago	1980	2002	3		*LAC*	*HIC*	*FM*	*GL40*
42	Tunisia			0	*MNA*	*MNA*	*LIC*	*FM*	*GL40*
43	Turkey			0	*ECA*	*ECA*	*LIC*	*FM*	*GH40*
44	United Arab Emirates			0		*MNA*	*HIC*	*FM*	n/a
45	United Kingdom	1980	2003	24			*HIC*	*A*	*GL40*
46	United States	1980	2003	20			*HIC*	*A*	*GH40*
47	Venezuela, RB	1980	1994	11	*LAC*	*LAC*	*LIC*	*FM*	*GH40*
48	Yemen, Rep.			0	*MNA*	*MNA*	*LIC*	*FM*	*GL40*
	Estimated Panel (#=21)	1980	2003	284					

Authors' own estimations; the former USSR and Yugoslavia are excluded due to lack of data; $t = t_0$ and $t = T$ indicate the initial and final years with information for all variables, respectively; N = number of observations with data for all variables.

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Potential of CO2 taxes as a policy measure towards low-carbon Portuguese electricity sector by 2050

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Abstract

The European Union proposed introduction of taxes on emitted CO2 emissions as an effective policy measure for the reduction of CO2 emissions in its electricity sector. Applying TIMES (The Integrated MARKAL-EFOM System) modeling tool, this paper examines cost effectiveness of different price evolution of CO2 taxes under the Emissions Trading System in Europe by 2050 in order to investigate the possible roles and limits for different mitigation technologies within the Portuguese electricity supply system. The results were analyzed based on the final year CO2 emissions of the electricity system when compared to 1990 levels. The results show that when employing CO2 prices reaching below 50 €/tonne by 2050 there is no reduction in emitted CO2 emission by 2050 when compared to the levels of 1990. For CO2 prices reaching between 50 and 100 €/tonne there is a clear increase in CO2 reductions with the increase in the price, from only 7% with 50 €/tonne to 79% with 100 €/tonne. For prices above 100 €/tonne the increased taxation has only a slight impact on the reduction of CO2 emissions, as even with a 300 €/tonne price the CO2 reductions achieved are only of 87%.

Keywords: Electricity generation; CO_2 emissions; CO_2 taxes; The Integrated MARKAL-EFOM System; Portugal

JEL Classification Codes: C32, C81, E61, H21, O31, Q41

1. Introduction

The amount of CO_2 present in the atmosphere keeps rising caused continued and increasing use of fossil fuels for energy production. Portugal as a member of the European Union (EU) and within the framework of the Kyoto protocol and the United Nations Framework Convention on Climate Change (UNFCCC) must deal with climate change as one of the main factors towards long-term sustainable development (PEA, 2011). Projection of the European Commission (EC) shows that under current policies domestic GHG emissions would be reduced by 60% in 2050 compared to 1990 levels (EC, 2011a). Therefore in 2011, the European Council proposed an initiative to design policy measurements in the energy and transportation sectors to achieve 80–95% GHG emissions reduction by 2050 compared to 1990 domestically (EC, 2011b). The largest mitigation of CO_2 is expected to be performed in the electricity sector, mainly due to technology innovation and energy efficiency in end-use (McKensey, 2009; van Vuuren et al., 2009). In practice, the use of some existing supply technologies will have to be expanded and new advanced technologies will have to be introduced and commercialized to meet GHG reductions in the electricity market. The Emissions Trading System in Europe (EU-ETS) will be a key component to commercialize low carbon technologies at large scale (EC, 2013). However, it is difficult to predict long term evolution of CO_2 prices.

In Portugal, large incentives have been used to implement technologies using renewable energy sources (RES) in the electricity sector due to country's favorable location for their use (Gomes, 2008; Ramos and Ramos, 2009; Scharmer and Greif, 2000). The Portuguese National Renewable Energy Action Plan to the European Commission confirms that nearly 50% of electricity is derived by RES currently and define a goal of 60% share of RES in the electricity generation by 2020 (DGEG, 2010). Further, a larger share of RES would be necessary to reduce CO_2 emissions in the electricity sector to near-zero values. However, the RES sources have fluctuating output which might become a main barrier to guarantee steady electricity demand. To ensure a minimum continuous load operation, fossil fuel power plants with carbon capture and storage (CCS) will complement RES generating electricity (IPCC, 2005). Hence, large-scale demonstration of plants with CCS with environmental safety and economic viability is an essential step towards commercialization of this technology (Bennet, 2011; Global CCS Institute, 2013).

This paper looks at different CO_2 taxes which might be applied to reduce CO_2 emissions in the Portuguese electricity sector. The TIMES model tool was used to perform the representative electricity system over the period of 2005-2050. The paper starts with the presentation of modeling methodology and applied assumptions. Next, different evolutions of CO_2 taxes were modeled and reduction of CO_2 emissions by 2050 in the electricity system was compared. Under the most relevant trends of CO_2 prices, the evolutions of the electricity system from 2005 to 2050 were compared in terms of the electricity production mix.

2. Portuguese Electricity System

Electricity generation in Portugal is divided into two regimes: ordinary and special. Special regime relates to the generation of electricity by RES (except large hydropower plants), subject to different licensing requirements together with benefits regarding tariffs. Currently, EDP (Energias de Portugal) is obliged to purchase all electricity generated and special regime generation activity (excluding wind) is undertaken by EDP Production. Hence, this business activity includes electricity generation through mini-hydro, cogeneration and biomass. Table 1a summarizes main characteristics of the existing fossil fuel power plants and Table 1b presents evolution of generation capacity by RES in the Portuguese electricity system from 2005 to 2011.

Table 1a. Characteristics of Portuguese centralized fossil fuel power plants.

Power plant location	Combustion technology	Installed capacity (MW)	Start operation	Efficiency (%, LHV)
Sines	PC	1,180	1985	39
Pego	PC	628	1993	43
Ribatejo	NGCC	1,176	2004	55
Medas	NGCC	990	2000	55
Lares	NGCC	870	2009	55
Pego II 1	NGCC	417	2010	55
Pego II 2	NGCC	417	2011	55
Sines*	NGCC	830	2013	55
Lavos*	NGCC	830	2017	55
Carregado	Fuel-oil	710	1968	38
Setúbal	Fuel-oil	946	1979	40
Barreiro	Fuel-oil	56	1978	35

*Licensed power plant

Table 1b. Generation capacity by renewable sources in the Portuguese electricity system in MW.

	2005	2006	2007	2008	2009	2010	2011
Large hydro	4,578	4,578	4,578	4,578	4,578	4,578	4,980
Small hydro	333	365	374	379	395	410	412
Wind	891	1,515	2,048	2,624	3,357	3,702	4,081
Solar	0	0	13	50	95	122	155
Biomass	1,166	1,295	1,365	1,463	1,610	1,696	1,868

3. Modeling Methodology

3.1 TIMES model

The Integrated Markal-Efom System (TIMES) is an energy/economic/environmental tool developed for ETSAP - Energy Technology Systems Analysis Program (ETSAP, 2007). It is used to estimate energy dynamics in local, national or multi-regional energy systems over a long-term, multi-period time horizon (Vaillancourt et al., 2008, Loulou, 2008). TIMES is a bottom-up partial equilibrium optimization model and it is built through a detailed description of technologies and commodities that characterize the energy system. Then, it computes the minimum cost solution that is capable of providing the modeled energy demands by making decisions on equipment investment and operation, primary energy supply and energy trades. It is a partial equilibrium model as the quantities and the prices in each time period are such that the suppliers produce exactly the quantities demanded by the consumers, which means that the total surplus is maximized.

In this study, the TIMES simulation tool is designed to represent the Portuguese electricity system and its evolution going out to 2050 with annual steps in between. The purpose of the model is to ensure that enough electricity is generated to meet the annual volume of demand. Moreover, the model employs a very detailed time resolution through dynamics within the electricity system to meet the peak electrical demand and cover unforeseen outages. The electricity consumption includes simplified load duration curves for typical days of the year. Hourly fractions have been calculated and interpreted within the TIMES for three typical days of a week (weekday WD, Saturday S and Sunday SD) in each season (Spring SP, Summer SU, Fall FA and Winter WI) giving a total of 288 time slices per year. The typical peak shaping of the curve occurs mostly during week days in winter reaching maximum at 8 p.m. Therefore the electricity generation system is obligated match this peak in demand (slice WI_WD_20) at any time.

For the electricity generation by fossil fuel plants and cogeneration plants it has been considered a medium annual availability of 90% for each time slice and for some less efficient existing power plants a minimum value of 30% was applied to guarantee continuous operation. Hydro power generation is highly affected by annual variation in precipitation. To overcome this problem in the model a median average availability for each time slice was used depending on the variability of water resources year-round. It should be noted that most of the large hydropower plants in the model have a storage capacity in dams. To accomplish electricity generation by solar technologies typical irradiation solar curves of Portugal were used for each typical day and combined with the total installed capacity and efficiency for the available technologies. Wind generation is very unpredictable due to its random behavior. In order to determinate the availability factor for wind power generation a histogram of distribution showing percentage of full power generation in every hour in the year was prepared to present in each time slice. The required parameters for demand and supply side were based on historical statistics provided by the National Transmission System (REN, 2012).

3.2 Assumptions

The demand curve is estimated on joint evolution of GDP and power intensity (ECF, 2010) under the projections of the Portuguese Government until 2020 (MFPG, 2013; Cabral, 2012). Further, the average annual growth rates are assumed to increase by 1.3% and 1.5% in the period 2020-2030 and 2030-2050, respectively. Domestic energy production is limited to renewable sources. Table 2 presents the evolution of the imported fossil fuel prices. Across the whole presented period it is considered that all fossil fuels are imported without limitations. Electricity consumption and electricity prices dynamically link the final electricity demand and transformation sector.

Table 2. Evolution of fossil fuel prices

Fossil fuel	Units	2011	2015	2020	2025	2030	2035	2040	2045	2050
Crude oil	\$2011/bbl	176.8	107.6	118.4	128.3	135.7	141.1	145	154.9	165.5
Natural gas	\$2011/Mbtu	14.0	9.6	11.2	12.1	12.9	13.4	13.7	13.8	13.9
Coal	\$2011/ton	123.4	110	115	119.2	122.5	125	129.8	134.7	139.8

The development of the electricity supply system over time is based on phasing out current power plants and providing the infrastructure with new investments. New technologies available from 2010 are ultra supercritical coal power plants, Integrated Gasification Combined Cycle plants (IGCC), Natural Gas Combine Cycle power plants (NGCC), onshore wind, offshore wind, solar photovoltaic (PV), concentrated solar power/parabolic trough collector (CSP/PTC), small and large hydro and wave. From 2015 onwards it is assumed that the concentrated solar power/solar tower technology will be commercially available and Pulverized Coal plants with

CCS (PC with CCS), IGCC with CCS and NGCC with CCS from 2020. The generation of electricity through nuclear technology is not an available solution for Portugal (Reference). For simplification, Portugal is modeled as an isolated system and therefore import and export of electricity is not taken into consideration in this study.

Techno-economic parameters which describe the supply side technologies are interpreted by typology (commodity in/out), the contribution of the power plant towards meeting the peak requirement, installed capacity, efficiency, fossil fuel consumption, investment along with fixed and variable operating and maintenance costs and respect technical lifetimes. Data used for the input information were obtained from various literature sources (ECF, 2010; IEA, 2010; IPCC, 2005; IRENA 2012, WEC 2012). Technology development is taken into account for further assumption and therefore technology investment cost will proportionally decrease and efficiency of fossil fuel power plants will expectably increase with time. A homogenous discount rate of 5% was applied for all economic values and kept constant over the entire modeling horizon. The model includes an existing installed capacity by 2012, new investments which are licensed or under construction and mid-term period investments expected by the Portuguese government. (Amorim, 2013). Further investments are cost-effective decisions of the model. However, potential of maximum installed capacity is limited for abounded RES to assure the technical quality and realistic grid interconnection (Seixas, 2012). Transmission losses of electricity is considered to be 10%.

3.3 Scenarios

This study examines different evolution of CO_2 taxes by 2050. In all scenarios the tax price starts at 20 €/tonne in 2010 and linearly reaches values from 30 to 300 €/tonne of CO_2 in 2050. Therefore presenting results of 100 €/tonne, as an example, means scenario when evolution of CO_2 tax over time reaches 100 €/tonne of CO_2 by 2050.

4. Results

4.1. Impact of CO_2 taxes on CO_2 emissions reduction

The results were analyzed based on the final year CO_2 emissions of the electricity system when compared to 1990 levels. The taxation of CO_2 emissions results in an increased production cost of fossil fuel based electricity, which can result in a reduction of total CO_2 emissions. However, for CO_2 prices below 50 €/tonne there is no reduction by 2050 when compared to the levels of 1990, as shown in Figure 1 a). For CO_2 prices between 50 and 100 €/tonne there is a clear increase in CO_2 reductions with the increase in the price, from only 7% with 50 €/tonne to 79% with 100 €/tonne. For prices above 100 €/tonne the increased taxation has only a slight impact on the reduction of CO_2 emissions, as even with a 300 €/tonne price the CO_2 reductions achieved are only of 87%.

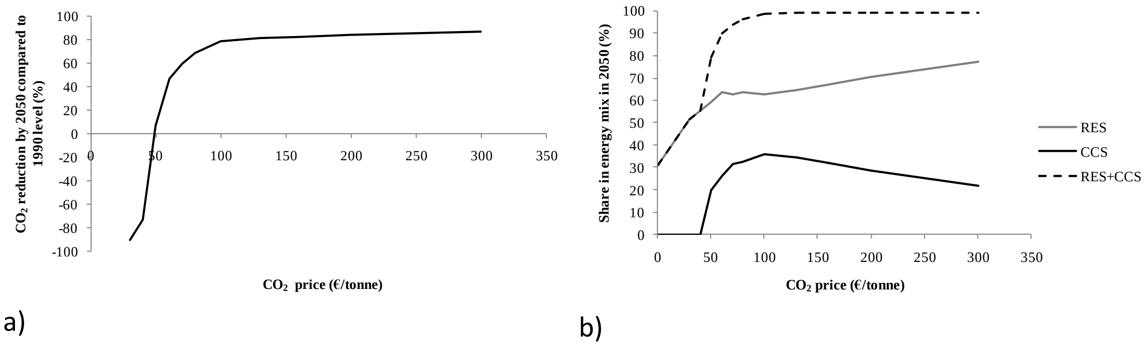


Figure 1 – a) CO_2 emissions reduction (%) by 2050 when compared to 1990 levels for different CO_2 prices; b) Share of RES and CCS technologies in the production of electricity for different CO_2 prices.

The reduction of total CO_2 emissions when compared to 1990 can be based on both the introduction of additional RES for electricity production and the investment in CCS technologies, as shown in Figure 1 b). While for CO_2 taxes reaching below 50 €/tonne the total CO_2 emissions increase when compared to 1990, the results show that even in low CO_2 taxes there is investment in additional RES generation capacity, which helps avoid even higher increases in CO_2 emissions.

From 50 €/tonne to 100 €/tonne the decrease is mainly justified by the investment in CCS technologies, which are responsible for between 20% and 36% of all electricity produced. While there is also an increased investment in RES in CO_2 taxes in this range, this increase is much smaller than the one observed for CCS technologies, as the share of electricity produced from RES goes up from 59% with 50 €/tonne to around 63% with 100 €/tonne.

For CO_2 taxes of 100 €/tonne or higher, conventional fossil fuel power plants vanish over time and more than 99% of all electricity is generated through RES or CCS technologies. The increase of CO_2 prices leads to a decrease in the cost-effectiveness of CCS technologies when compared to RES technologies, with the decrease in the share of electricity produced from CCS being compensated by the increase in RES.
When compared to the international goals of 60% and 95% reductions in the electricity sector, whereas the first goal could be achieved with a CO_2 tax of 70 €/tonne by 2050, the second would only be achieved with unrealistically high taxes. In auctioning scheme of EU-ETS, price 70 €/tonne of CO2 could be achieved as a response to the expected worldwide increase in coal and natural gas usage.

4.2. Carbon storage capacity needs for different CO_2 prices

The investment in CCS technologies will require the design of auxiliary systems for the transportation and storage of CO_2. The maximum amount of CO_2 captured per year in the simulations performed was of around 17 Mtonnes of CO_2, which occurs for a CO_2 price of 100 €/tonne, as shown in Figure 2. However, the total amount of CO_2 captured in the time period under analysis is achieved for taxes between 130 and 200 €/tonne, reaching values of around 355 Mtonnes of CO_2. This is because, even though they have slightly lower maximums of yearly

CO_2 capture, the higher tax increase through time enables the earlier investment in CCS technologies.

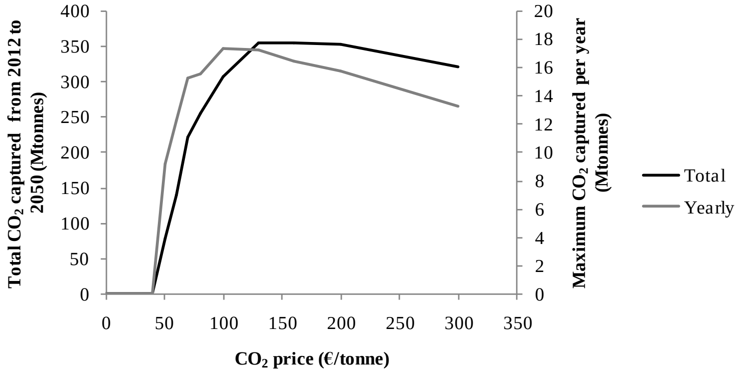
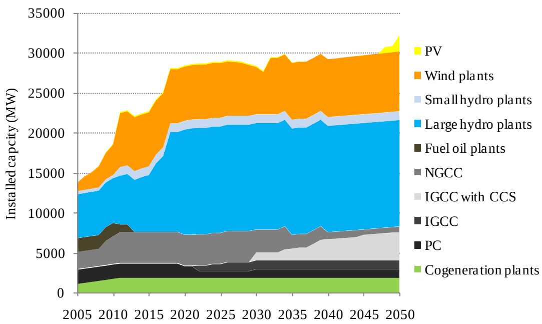


Figure 2 – Total CO_2 captured in the time period 2012-2050 and maximum CO_2 captured per year for different CO_2 prices.

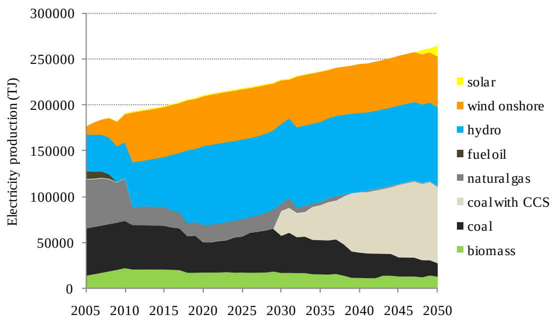
4.3. Assessment of evolution of the Portuguese electricity system under different CO_2 taxes

4.3.1. Portuguese electricity system evolution under 70€/tonne of CO_2

To achieve a reduction of 60% in CO_2 emissions when compared to 1990 levels in the Portuguese electricity sector, a CO_2 price of around 70 €/tonne will be required, see Figure 1. Figure 3 b) presents the development of electricity generation by source under this scenario satisfying the required electricity demand. Electricity production by biomass maintains practically constant. The wind and hydro will increase considerably and after 2010 are generating almost two times more electricity than in the base year. On the contrary, fuel oil power plants come to the end of their lifetime and none will be built after the last ones retire as seen in Figure 3 a).



a)



b)

Figure 3 – a) Installed capacity by 2050; b) Electricity generation by source.

With increasing CO_2 taxes over the period more capacity on NGCC power plants will be installed due to a lower flue gas CO_2 compared to coal power plants of approximately the same size. Higher efficiency of IGCC plants create a moderate investment over the PC plants from 2020 and in 2030 IGCC with CCS will become part of a portfolio for CO_2 mitigation technology within the electricity supply system. By the end of the studied period the solar PV technology becomes competitive resulting in the slight growth of electricity generation through RES. Less mature technologies such as waves, concentrated solar or offshore wind are still too expensive to play role in the Portuguese electricity supply system.

4.3.2. Comparison of electricity generation from 2005 to 2050 under different evolutions of CO_2 taxes

Figure 4. summarizes electricity production under four different evolutions of CO_2 taxes by presenting share of electricity generation in 2020, 2035 and 2050. In 2020 electricity generation through RES reach more than 60% share of electricity production which is in agreement with the National Renewable Energy Action Plan. However, its evolution further depends on technology maturity and applied CO_2 taxes. In 2050, only applying CO_2 taxes higher than 100 €/tonne lead to higher share of RES in portfolio. Under scenario reaching 50 €/tonne of CO_2 by 2050, IGCC with CCS will start generate electricity after 2035, whereas, with higher CO_2 taxes in 2035 IGCC with CCS will generate significant share of electricity. Costs of carbon emissions required to cover capture costs is a linear function of the electricity price and under 100 €/tonne, IGCC with CCS will reach the highest share in the electricity generation. Higher CO_2 taxes impose higher CO_2 reduction (as possible see in Figure 1a) and more investment of RES technologies contributing to higher share of RES, mainly solar, in electricity production. This could demonstrate CCS as a transitional technology until less mature RES technologies will become competitive in the energy market.

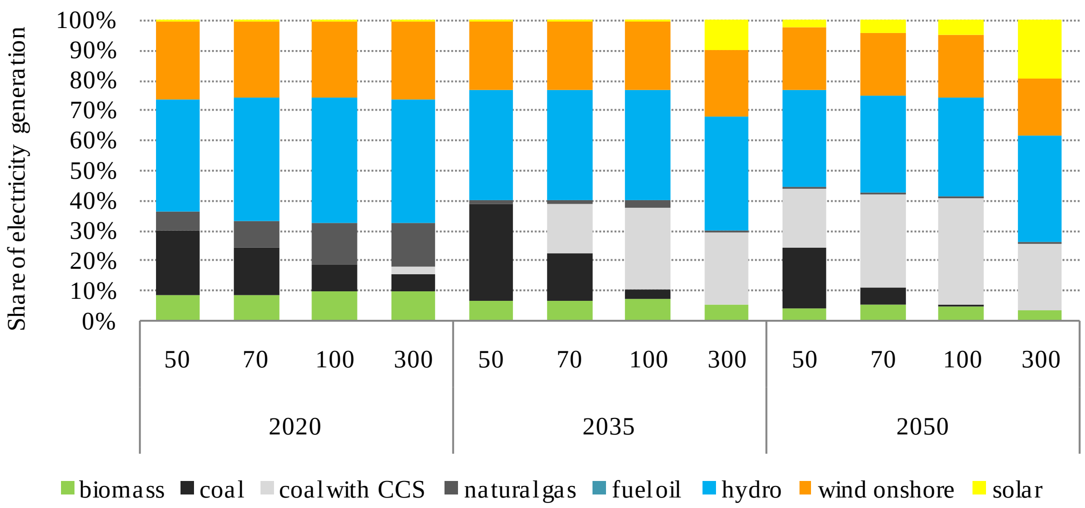


Figure 4 – Share of electricity generation in 2020, 2035 and 2050 under four different evolutions of CO_2 taxes reaching 50, 70, 100 and 300 €/tonne of CO_2 by 2050.

5. Discussion

While the introduction of CO_2 taxes can be an effective measure for the reduction of CO_2 emissions in the electricity sector, their impact seems to be limited due to the limited potential for cost-effective RES such as wind onshore and hydro, and the significant costs of other RES with high potential and complementary resource availability such as solar, wave and wind-offshore technologies. To achieve a reduction of 60% in CO_2 emissions when compared to 1990 levels in the Portuguese electricity sector, a CO_2 price reaching of around 70 €/tonne would be required. Nonetheless, the increase of the CO_2 price to 100 €/tonne would have even more significant results, enabling a reduction of around 79%. The introduction of CCS technologies occurs only for CO_2 prices around 50 €/tonne or above, reaching a maximum penetration at 100 €/tonne and decreasing for higher prices due to a decreased competitiveness when compared to RES. To achieve a reduction of 95% it is not be possible to rely only on the use of CO_2 taxes, with other policy measures, such as the direct taxation of fossil fuels or ambitious goals for RES penetrations, and the development of further technological efforts to improve efficiency and decrease investment costs of RES being required. The use of energy storage technologies for long-term storage could provide some support in increasing the cost-effectiveness of RES technologies by enabling a better match between electricity supply and demand.

6. Conclusions

When applying CO_2 prices reaching between 50 and 100 €/tonne of CO_2 by 2050 in the Portuguese electricity system there is a clear increase in CO_2 reductions from only 7% with 50 €/tonne to 79% with 100 €/tonne comparing to 1990 level. This increase is mainly justified by the investment in CCS technologies, which are responsible for between 20% and 36% of all electricity produced in 2050. When compared to the EU goal of achieving a 60% reduction of CO_2 emissions, this could be achieved in the Portuguese electricity sector with a gradual increase of the CO_2 tax to around 70€/tonne by 2050. In this scenario, CCS technologies would enter the electricity system around 2030. For prices reaching above 100 €/tonne of CO_2 by 2050, the increased taxation has only a slight impact on the reduction of CO_2 emissions. Therefore, to achieve a stronger decarbonization scenario, such as the 95% goal that is being discussed in the EU, other policy measures would have to be developed to complement the use of CO_2 taxes.

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Methodology to develop integrated scenarios for electricity demand, mix electricity supply, price and GDP (Gross Domestic Product)

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Abstract

In this work, we developed a model to forecast world electricity production. We analyzed historical data for electricity production, population and GDP per Capita for the period 1900-2008 and found general trends and characteristic behaviors for electricity production. We obtained equations for "model countries" for electricity production and GDP/Capita. The behaviors of these model countries are followed by other countries at a regional scale. These equations were used to forecast electricity production per capita up to 2100 under a low and a high scenario for the evolution of GDP per Capita. For electricity production two main scenarios were also set: "Current Energy Mix Scenario" and "Electricity as Main Energy Source Scenario", with two additional sub scenarios for different energetic intensities. Trends found included an electricity energetic intensity target of 0,20-0,25 kWh per unit of GDP as economies mature, except in countries traditionally relying heavily on renewable electricity (hydroelectricity), for whom this target ranged between 0,50 to 0,80 kWh per unit GDP (US$2012). Forecasts up to 2100 yielded an electricity production 3.5 to 5 times higher the current production. Forecasts fitted well with IEA/ EIA[1] forecasts.

Keywords: forecast, electricity production, model-country, historical data, logistic function, polynomial regression

JEL Classification Code: Q47- Energy Forecasting

[1] IEA – International Energy Agency/OECD – Organization for Economic Cooperation and Development
; EIA – Energy Information Agency, Department of Energy, United States of America

Modelling the Hungarian energy system
– the first step towards sustainable energy planning

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Abstract

Due to the socio-economic and environmental consequences of using fossil fuels, a change is needed in energy planning towards energy systems with a high penetration of renewable sources. In Hungary, there is no real alternative to the fossil-based energy system yet, therefore, an alternative energy scenario is needed. As a first step, in this paper, an energy model of the Hungarian energy system of 2009 is created, as the basis model for a future scenario. After a brief review of the recent Hungarian energy system, it is modelled with the EnergyPLAN software. Lack of reliable data and missing functions from EnergyPLAN model are factors which can cause errors in the model. After verifying the model called HUN_2009_IEA_2.6, an analysis is carried out to see how a high penetration of renewable energy production could have been reached in 2009 within the existing infrastructure, optimised by EnergyPLAN from environmental aspects. Therefore, alternative models 2.6b and 2.6c were designed. Renewable penetration doubles in model 2.6b, however, fossil and total primary energy sources' consumption, therefore carbon-dioxide emission increases. Model 2.6c is optimal from several points of view: while renewable energy production increases by 30%, total primary energy use does not change; furthermore, fossil fuel consumption slightly decreases.

1. Introduction

The World's energy management arrived to an important turning point – the age of cheap, seemingly endless seemed fossil fuel sources are approaching their end (Tsoskounoglou et al., 2008; Jakobsson et al., 2012; Haftendorn et al. 2012), while the global demand is rising. In Hungary, where fossil fuels play a dominant role in energy consumption, and where they are on average in 80% imported, these trends are of critical importance to the country's economy.

However, the shortage of fossil fuels and its economical and societal consequences are not the only reasons for the urgent need for switching to renewable energy sources. The mining and burning of fossil fuels has enormous effects on the global ecological system like decreasing biodiversity, disappeared habitats and damaged natural services. In the case of energy sector effects on the global carbon cycle can be highlighted, causing change in global climate (IPCC, 2007), to which the whole biosphere has adapted. In the case of the Carpathian basin, including Hungary, heat waves, droughts, extreme floods, early and late frosts and degradation of biodiversity can be highlighted as the expected (and already experienced) hazardous consequences (Faragó et al. [eds.], 2010). To ensure mitigation and adaptation in Hungary as well, fossil fuels should be phased out from the energy system while the share of renewable-based local energy sources has to be increased. Furthermore, energy conservation and higher energy efficiencies are key factors for creating a sustainable energy system.

1.1. Towards sustainable energy systems

The first step on the way to technological change are research and planning. In the last decade, numerous 100 or nearly 100% renewable-based – or from another perspective, low or zero carbon – energy strategies were designed by several research groups and centres. The increasing trend of sustainable energy planning is indicated by the fact that at least 68 computer tools, designed for renewable integration modelling, were available in 2009 (Connolly et al., 2010). In Europe, several 100% renewable energy visions or strategies were outlined, both for Western- and Eastern-European countries (INFORSE, 2012), as well as for the entire European Union (Zervos et al., 2010).

Two countries should be highlighted as they have been leading research on this field. The United Kingdom, where one of the first alternative energy strategies was outlined (Todd and Alty [Eds.], 1977) and since then further developed (Helweg-Larsen et al., 2007), covering a wide range of connected aspects, such as embodied energy minimalisation or land usage optimisation (Kemp and Wexler [Eds.], 2010). The other country is Denmark, where sustainable energy planning has a remarkable tradition, as numerous alternative energy strategies were conducted since the first oil crisis, in the last decadeespecially focusing on large-scale renewable energy integration (The Danish Society of Engineers, 2006; Olesen, 2010; Lund. [Ed.], 2011; Mathiesen et al., 2011). Nowadays Denmark is a world leader in renewable technologies and has a 100% RES energy strategy (to be achieved by 2050), accepted on governmental level (Danish Ministry of Climate, Energy and Building, 2011), with the renewable electricity production share already reaching 40% in 2011 (Danish Energy Agency, 2012).

1.2. Alternative energy planning in Hungary

In Hungary, the current situation in energy management would need rapid changes considering the import-dependency, fuel mix and the infrastructure of the energy system. Despite of the favourable renewable potentials and the urging need of sustainable solutions for domestic energy production, the recent and actual energy strategies did not plan to break away from the present practice. Furthermore, there is a lack of alternative energy strategies, therefore no other possible choices can be seen by the society, and that state is reinforced by the government and its actual discourse about the necessity of a new nuclear power plant.

The first alternative document called *Hungarian Sustainable Energy Strategy* was contracted by the Hungarian non-governmental organisation Energy Club (Ámon, 2006). This work was drafted in one month only, mainly containing are view of the recent Hungarian energy situation and renewable energy potentials, without detailed calculations. Another energy strategy was made and a few years later further developed by Greenpeace International, Greenpeace Hungary and EREC Europe (Teske et al., 2007, 2011). In the latter, two energy scenarios – an 'alternative' and a more ambitious 'progressive' one – were devised, indicating the possibility of a 75% renewable-based energy system in Hungary by 2050. In spite of the more properly grounded calculations and studies connected, there was no substantive discussion about the outlined alternative scenarios afterwards, neither in the scientific community nor in the wider public. On the contrary, the government intended not only to expand the lifetime of the currently working nuclear power plant (and perhaps a lignite-based power plant as well), but they also proposed to build a new nuclear power plant, which was upgraded to a priority investment (Government, 2012). Their main reasons are the old capacities which have to be substituted with new capacities, of which altogether around 6000 MW of new centralised power plants (based on lignite, imported coal and natural gas) have to be built in the next decade according to the actual plans (MAVIR, 2007).

The first 100% renewable energy system vision in Hungary was created by a team of professors and students at Eötvös Loránd University, Faculty of Science, Department of Environmental and Landscape Geography, in cooperation with experts from other universities and INFORSE-Europe (Munkácsy [Ed.], 2011; INFORSE-Europe, 2011). The research team (including the author of this paper) worked out an alternative energy scenario called *Vision 2040 Hungary* with the energy planning tool INFORSE. Based on their calculations, they state, that from the year 2005, it could have been possible to reach a 100% renewable energy system in Hungary by 2040, and a more ecologically sustainable energy system by 2050 (Munkácsy [Ed.], 2011). However, while this Vision was outlined with balancing all the supplies and demands in economy by every five years to 2050, the hour-by-hour advanced energy analysis, taking the fluctuation of the weather – therefore detailed renewable production – could not be carry out. In this case the issue of integration of renewable energy sources was not analysed, although it is one of the main challenges of the present inflexible energy system of Hungary.

2. Scope of the article

There is a need of a 100% renewable energy scenario in Hungary, which could lead to a sustainable energy system and if properly detailed and analysed could be a real alternative to the official scenario. As a first step, the aim of this paper is to create and analyse an operational model of the present Hungarian energy system, which will be the basis of a future 100% renewable scenario.

Since this model will simulate the current energy system in Hungary, the present energy system's main properties will be introduced, highlighting the main issues of energy management and policy and issues which have to be solved in the long term. The paper presents the basic model of the Hungarian energy system covering a review of the main data sources, introducing the EnergyPLAN energy modelling tool and the main conclusions of its first Hungarian application and the verification of the model. After the review of the methodology, a brief analysis will be presented, where the energy model will be evaluated in comparison with alternative models to provide insights on how the Hungarian energy system of 2009 could be optimised by EnergyPLAN from environmental aspects, to have a high renewable energy penetration within the same infrastructural conditions.

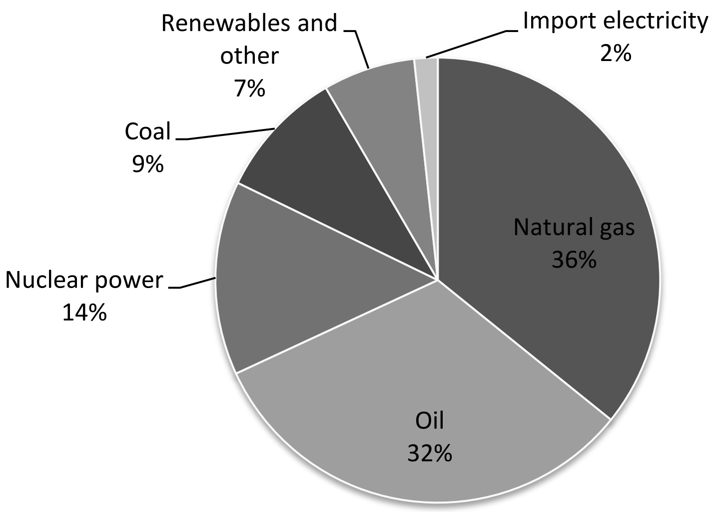
3. Main characteristics of the Hungarian energy system

The total energy consumption of Hungary has been stagnating around 1100 PJ since the 1990's. This value was 1 055.6 PJ in 2009 and 1085.0 PJ (KSH, 2011a) in 2010 (which is the last figure available), from which final energy consumption meant 698.73 PJ (KSH, 2011b). However, the structure of sources changed in an unfavourable way: the use of domestic sources decreased, while the import of energy sources increased, to more than 63% (where nuclear energy production is counted towards domestic energy production, although the fuel rods are imported) (Eurostat 2013). The diversification of import sources has been very slow since the political change, therefore the two-third of the energy source imports are coming from only one country, namely Russia. Unfortunately, there is no governmental effort to change this situation, as the Hungarian Energy Strategy 2030 (Ministry of National Development, 2012) states: "The major part of Hungary's energy supply is imported, and it will remain so for a long time". The situation, is most untenable regarding natural gas, where more than 70% of the total domestic demand is supplied from Russia through pipeline Fraternity via Ukraine and the pipeline HAG via Austria (MOL, 2006). At this point, there is no intention to change this from the government side according to the Energy Strategy: "Russia will remain the most important source of import on the long term (…)" (Ministry of National Development, 2012).

Hungary's energy system is based on fossil fuels in more than 90% (Energy Centre, 2011a), despite the fact, that the country is poor in fossil sources. Regarding coal stocks, the major part of them has already run out or the exploitation highly is uneconomic. An important exception is low calorific lignite, from which 8-9 million tons per year (65 PJ per year) are extracted

(Eurostat, 2011) and the stocks are estimated to 4.45 billion tons, making it the most significant strategic fossil fuel reserve of Hungary (Ministry of National Development, 2012). Regarding crude oil and natural gas stocks, they are almost negligible, supplying only a fragment of the domestic demand (National Office of Mining and Geology, 2012; KSH, 2012). Although the last uranium mine closed in 1997 the main electricity producer of the country is the nuclear plant of Paks, with 2000 MW capacity, producing 43% of the electricity needs alone in 2009 (IEA, 2012).

In the mix of primary energy supply of the country the carbohydrates are dominating (*Figure 1*). Natural gas is the most popular energy source, with an important role in electricity and heat production as well, while oil is mostly supplying the transportation's demand only.



1. Figure: Structure of primary energy sources in Hungary, 2009 (Energy Centre, 2011)

Hungary has diverse and favourable givens regarding renewable sources, although their judgement – therefore their utilisation – is still on a poor level, due to lack of political will and a constantly changing, inadequate regulation system. This explains why Hungary committed towards the European Union to reach only 13.0% renewable energy penetration (compared to the European average of 20%) from the gross final energy consumption by 2020, while this value was already 8.7% in 2010 (Eurostat, 2012).

Since Hungary has favourable agronomic potentials, 79% of the primary renewable energy utilisation comes from biomass (KSH, 2011b), which mainly means solid biomass (co-)burning in condensing power plants with very low efficiency (in average 27% according to Büki and Lovas, 2010). The second most important renewable energy source is geothermal, due to the thin lithosphere in the Carpathian basin, where the geothermal gradient is 1.5-times higher than the global average (Gáspár, 2009). The energy production from solar, hydro and waste is not significant, while wind energy production had a dynamic increase in the last decade (considering Hungary's wind characteristics). The first turbine was installed in 2000, and in 2011, already 329 MW of wind capacity was producing near 2000 TJ (KSH 2011b).

Unfortunately, this growth will slow down, or the wind power production will even decrease due to disadvantageous regulation changes over the past few years.

Regarding electricity production the main sources changed significantly in the last two decades:

- lignite is the most important type of coal used in electricity production;
- due to its increasing prices, oil consumption minimalised;
- the role of natural gas increases constantly;
- after the millenium change, renewable electricity production began to grow, but its penetration is still low (less, than 10 % according to KSH, 2012).

In the last years, domestic electricity production was nearly equal to the final electricity consmption of 35-40 TWh/year(without losses of 6-7 TWh/year) (KSH, 2011a). Hungary is an electricity transit country, exporting 9-10 TWh and importing 13-15 TWh of electricity annually (KSH, 2011a).

The installed capacity of the Hungarian power plants was 9 317 MW in 2010 (Szabó et al., 2011). Less than 20 power plants with more than 50 MW capacity each are producing 83% of the electricity. They are mainly centralised, obsolete condensing power plants with low efficiency. One of the main problems of the energy system is its inflexibility: 64% of the power plants compared to the capacities available cannot be regulated (Szabó et al., 2011). This situation is slightly better with new natural gas-based power plants, but new nuclear plants, planned by the government, would make the large-scale integration of renewable energy sources hard, if not impossible for a long time.

4. Methodology of creating an energy model for Hungary

In order to create future 100% renewable scenarios, first a model of the recent, existing energy system is needed. The methodology of building and verifying this model, data sources and the applied computer software will be detailed in the following chapters.

The model represents the current situation of the energy system of the year 2009, basically applying the statistics and balances as main sources of the International Energy Agency (IEA, 2012). Therefore, the latest version of this model is called HUN_2009_IEA_2.6 developed in EnergyPLAN model. This version has still opportunities to be further improved, therefore it cannot be indicated as a final one, but it reached a level where also some analyses can be undertaken (see verification in *chapter 5.4.*).

4.1. EnergyPLAN

EnergyPLAN is a computer model, an energy system analysis tool, developed since 1999 at Aalborg University, Denmark. It is a deterministic input-output model, which main inputs are (yearly aggregated) demands, renewable and fossil energy sources and capacities, costs and numerous options of regulation strategies. The outputs are energy balances, annual productions, fuel consumption, electricity import or export and total costs (Lund, 2011).

There are numerous energy system tools available (e.g. LEAP, EnergyPRO, HOMER etc.) (Connolly et al., 2010), from which EnergyPLAN (version 9.0) was chosen since it meets the following requirements (Lund, 2009):

- creates an energy system model on a national level;
- for a detailed analysis, hour by hour simulation is available;
- includes all consumption sectors;
- focuses on integration of fluctuating renewable energy sources, which is a relevant aspect regarding the future 100% renewable scenario;
- different regulation options are available.

Although this software is the most suitable for energy system simulation and optimisation with a high penetration of renewable energy sources, the HUN_2009_IEA_2.6 model (with less than 10% renewable share) was also created using EnergyPLAN. The reason for this was to ensure the possibility of proper comparison analyses between the basis and the future scenarios made by the same software.

4.2. Data and sources

Since there were not enough detailed energy statistics available for 2010 or 2011 from Hungarian or international sources the year 2009 was chosen as basis year for the analyses. The main source for energy balances, renewable energy production, electricity and heat production statistics was the database of the International Energy Agency (IEA, 2012). Since energy system model building in EnergyPLAN needs far more data than available in this database, it was completed with data mainly from the Hungarian Energy Office (MEH) and the Hungarian Transmission System Operator (MAVIR) (Szabó et al., 2010; Bock et al., 2010), from the District Heating Services of Budapest (FŐTÁV) (Orbán, 2011), from a power plant and energy network planner company (ETV-Erőterv) (Stróbl, 2011), from Eurostat (Eurostat, 2011), from the Hungarian Central Statistical Office (KSH, 2010), from the Energy Centre(which does not exist autonomously since 2011) (Elek, 2009), and from calculations and assessments based on the previous and other sources. *Table 1* indicates the main figures which were not available through these sources and were therefore based on own calculations (and/or assessments) and used in EnergyPLAN to create the HUN_2009_IEA_2.6 model.

1. Table: Main input data of the HUN_2009_IEA_2.6 model, based on own calculations.

		TWh/yr	Calculation based on	MWe	Calculation based on	Efficiency El.	Efficiency Th.	Calculation based on
Electricity demand		35.91	IEA, 2012	-	-	-	-	-
Fixed electricity import		5.52	IEA, 2012	-	-	-	-	-
Transmission grid capacity		-	-	*1 532	Bock et al., 2010; MAVIR, 2012	-	-	-
District heating demand	**Except CHPs**	1.00	Orbán, 2011; IEA, 2012	-	Stróbl, 2011	-	0.81	IEA, 2012
	Small CHPs	4.46	Orbán, 2011; IEA, 2012	1 135	Stróbl, 2011	0.32	0.47	IEA, 2012
	Large CHPs + cond. PP	7.06	Orbán, 2011; IEA, 2012	5 881	Stróbl, 2011; Szabó et al., 2010	0.30	0.14	Stróbl, 2011; Szabó et al., 2010

** The Hungarian transmission grid capacity is higher, but it is also used for transit (commercial) purposes. 1 532 MW was the maximum of transmission capacity used for electricity export in 2009.*

The hourly detailed distribution files were partly used from the ones built in the software, partly generated from Hungarian statistics and partly made by own calculations or assumptions. The hourly distribution of electricity demand, the electricity import and export was generated from the statistics of the Hungarian Transmission System Operator (MAVIR, 2012). Since there were no available data about the annual trends of Hungarian district heating demand, a Danish distribution was chosen from the EnergyPLAN's dataset, most realistic and similar to the Hungarian trends. As for renewable energy production, mainly meteorological measurements from Debrecen (Eastern-Hungary), such as wind speed at 10 metres and global radiation, were converted to distribution files. The Hungarian water level statistics (VITUKI 2012) were unable to demonstrate the real trends of the hydro production, therefore a Croatian hydro distribution file, which finally lead to a satisfactory result, was used instead. A new distribution file was created for the nuclear power production in the following way. The four reactors are shut down each after each in the summer period for 30-40 days; therefore a distribution with 75% load in 140 days and 100% load in all other days was generated. All other distribution files assumed constant energy production and/or consumption regarding the industrial, agricultural and public sectors.

4.3. Hungarian application of EnergyPLAN model – difficulties and risks of errors

Three main factors have to be discussed which may have altering effect on the results, therefore they have to be considered when evaluating them.

In *chapter 4.2.*, the main sources were already presented, without highlighting the problems of the Hungarian energy statistics and lack of information. Unavailable energy statistics due to institutional changes, refused data delivery by the Energy Office (referring to business confidentiality), and contradictions between official sources made the data collection for the model difficult. For example, only partial information is available about the district heating production of the power plants, while the figures about district heating demands are aggregated only, with numerous contradictions. Furthermore, capacity, heat production and efficiencies of heat plants and small power plants were not available. Therefore estimations had to be involved in this field as well.

Although the EnergyPLAN model was developed for international applications, and thus is considered to be compatible to simulate most (national) energy systems, there were still some options missing to be able to properly model the Hungarian energy system. As for geothermal energy, only electricity production is available to indicate in the model, while Hungary has only heat production, but in a significant quantity: 220 TJ heat was produced in 2009 from geothermal sources (IEA, 2012), which could be not integrated into the model. The situation is the same with the heat production of nuclear power plants: 509 TJ heat production (IEA, 2012) of the most important electricity producing nuclear power plant cannot be indicated. While the sum of these two heat productions gives only around 1.5% to the district heating demands in 2009, the role of the geothermal heat production will become more significant in the future.

As it was mentioned before, Hungary has a notable electricity import and export as an electricity transit country. However, only the annual (fixed) import or only the export and its hourly distribution can be indicated in the model, depending on the user’s choice. Whereas in reality both take place at the same time with different hourly distributions. For a bridging solution, import and export volumes were extracted and the difference was indicated as the import value; and the same method was applied to the hourly distribution file.

4.4. Verification of the HUN_2009_IEA_2.6 model

Since EnergyPLAN is basically used for modelling future energy systems with high penetration of renewable sources, and because this model will be the basis of a future scenario, it is important to see how well this model was able to simulate the operation of the Hungarian energy system of 2009.

The validation was done through two comparisons: two kinds of indicators were compared from the statistics of 2009 and from the HUN_2009_IEA_2.6 model. In the first one, energy input data (fuel balance: total primary energy supply) and in the second one, output data (CO_2-emission, renewable electricity and energy production and share) were chosen as indicators.

2. Table:First comparison for verification: total primary energy supply in statistics (2009) and in model 2.6.

	KSH, 2011b	Energy Centre, 2011a	IEA, 2012		HUN_2009_IEA_2.6	
	TWh/yr	%	TWh/yr	%	TWh/yr	%
Coal and coke	n.a.	9.40	29.76	10.20	25.12	8.97
Oil	n.a.	32.30	81.03	27.77	63.46	22.67
Natural gas	n.a.	35.80	106.40	36.46	115.39	41.22
Renewables and other	21.31	6.70	22.21	7.61	23.74	8.48
Nuclear power	n.a.	14.10	46.89	16.07	46.70	16.68
Import electricity	n.a.	1.70	5.51	1.89	5.52	1.97
Total primary energy supply	293.22	100.00	291.80	100.00	279.93	100.00

Table 2 presents the first comparison, where the energy sources are indicated from three sources from 2009, next to the figures from the model 2.6 generated by EnergyPLAN. Although the exact numbers of primary energy supply by sources were fed into the model for the main sectors, it has an opportunity to change and optimise them between limitations. These limitations were turned off in case of oil and natural gas, to have more similar numbers to the facts of 2009.

Based on this comparison, it can be stated that the calculations of model 2.6 reflect the statistics sufficiently. The total primary energy supply is around 4% less than the slightly more than 290 TJ from the KSH (2011b) and the IEA (2012) database. The explanation can be that the program also optimises the energy system. The main differences can be seen regarding the fossil fuel consumptions, where the variance can almost reach 25% in the case of oil. At that point, one has to mention the differences between the Hungarian (Energy Centre, 2011a) and the IEA (2012) statistics (shares in *Table 2*), which appeared in most versions of the model as well, meaning lower oil and natural gas, and larger coal and renewable-based energy productions. The sum of the absolute values of the differences compared to the total primary energy supply of Hungarian statistics (KSH, 2011b) is 32.93 TWh/year. This means a variance of

11%, which can be considered an acceptable percentage of non-conformity at this level of the model.

In *Table 3*, results of the second comparison can be seen, where output data of model 2.6 are compared to the statistics of the year 2009. The chosen indicators are CO_2emissions, which are cumulating the environmental impacts of the energy system, in a well measurable way; the other are renewable energy-based energy and electricity productions, which are amongst the most significant characteristics of the present and future energy systems as well.

3. Table: Second comparison for verification: output data in statistics (2009) and in model ***2.6.***

		KSH, 2011b, 2011c	Energy Centre, 2011a, 2011b	IEA, 2012	HUN_IEA 2009_2.6
Carbon-dioxide emission (Mt)		58.90	n.a.	n.a.	49.11
Renewable energy sources'	**electricity production (TWh/year)**	*2.91	2.99	*3.01	3.45
	share in electricity production (%)	8.10	8.40	*8.39	9.60
	energy production (TWh/year)	21.31	n.a.	*23.10	*23.93
	share in energy production (%)	*5.98	6.70	*6.13	8.70

**Own calculation based on the sources indicated*

According to *Table 3* it can be stated that the differences seen in input data did not cumulate in a significant amount, because the renewable energy related measures show acceptable differences from the statistics. Regarding CO_2 emissions, the variance is higher, which can be a result of altering calculation methods. The higher values of IEA (2012) renewable based statistics were much lower in this case, appearing just in the energy production of renewables. Although the geothermal energy production is not presented in model 2.6, the renewable electricity and energy production is slightly higher than the Hungarian (KSH, 2011b, 2011c; Energy Centre, 2011a, 2011b) and even than the IEA (2012) statistics.

Summarizing the above differences, their causes – therefore, the possible errors of model 2.6 might be attributed to the following:

- false input data (because of lack of data or errors in own calculation), especially regarding district heating demands and grouping power plants;
- cumulation of inaccuracy of data;
- optimising effect of the EnergyPLAN model (lower energy source consumption, more renewable energy production).

However, the variance between the model and the statistics are low enough to make further analyses on the model, with critical judgement of the results.

5. Analysis of the model

In spite of the fact that substantive consequences about the possibilities of a sustainable energy system can be concluded preferably from analyses of future energy systems, a brief analysis was carried out on the 2.6 model. The aim of the analysis is to answer the following question: how much renewable energy production and what share would the Hungarian energy system have achieved with the existing technologies and infrastructure in 2009, if it worked in an environmentally optimised way according to the EnergyPLAN model?

For the analysis two alternative models – HUN_2009_IEA_2.6b and HUN_2009_IEA_2.6c were created. *Table 4* presents the main changes in the last two versions compared to the original one.

4. Table: Differences between model 2.6, 2.6b and 2.6c.

	Model 2.6	Model 2.6b	Model 2.6c
Distribution of fuel types	oil, natural gas: variable; coal, biomass: fixed	all variable	all variable
Fixed electricity import (TWh/year)	5.51	0.00	5.51
CEEP regulation strategy	option 7: reducing power plant production in combination with wind, PV and hydro	no regulation	no regulation

In model 2.6b, the model has more freedom to define the distribution of fuel types of severe producers (district heating plants, combined power plants, boilers, condensing power plants). While the relative share of coal and biomass fuels were fixed in the case of model 2.6, the alternative models has no limitations given by the user when distributing fuel types (oil, natural gas, coal and biomass) between the groups of producers. Compared to the model 2.6, where 5.51 TWh/year fixed electricity import was defined, model 2.6b has no fixed import or export. The third change is the choice of critical excess electricity production (CEEP) regulation strategies. Since the Hungarian energy system did not have almost any flexible technologies, just the opportunity of reducing power production or exporting the excess electricity, the applied regulation strategy was number 7. This means reduction of power plant production in combination with renewable producers (except of geothermal) in case of CEEP. In model 2.6b and 2.6c no regulation method was selected, therefore the modelshave to avoid CEEP.

5. Table: Comparison of characteristics of model 2.6 and alternative models 2.6band 2.6c.

	HUN_2009_IEA_2.6		HUN_2009_IEA_2.6b		HUN_2009_IEA_2.6c	
	TWh/yr	**%**	**TWh/yr**	**%**	**TWh/yr**	**%**
Coal	25.12	8.97	44.29	15.12	39.81	14.47
Oil	63.46	22.67	62.56	21.36	60.43	21.97
Natural gas	115.39	41.22	103.73	35.43	97.17	35.32
Renewables and other	23.74	8.48	35.48	12.11	30.98	11.26
Nuclear power	46.70	16.68	46.70	15.95	46.70	16.98
Import electricity	5.52	1.97	0.00	0.00	5.52	2.01
Total primary energy supply	279.93	100.00	292.76	100.00	280.61	100.00
Renewable electricity production	3.45	7.30	6.92	14.80	5.54	11.80

As it can be seen on *Table 5*, in model 2.6b, after the changes in regulation of the energy system, the renewable energy production increased by almost 50%, while renewable electricity production doubled from 3.45 to 6.92 TWh/year. Due to the inflexible energy system and the higher electricity production needed, the total primary energy supply grows by 4.6%. The distribution of fuel types changed notably, especially coal utilization increased by 76%, while natural gas consumption dropped by 10%. As the consequence of these changes, the second model's total CO_2 emission is 3.9 Million tons per year more than the original model, reaching 53.01 Million tons per year. To sum up the advantages of this model: the renewable energy production reaches a high penetration (but the total fuel consumption rose as well). However, the renewable energy utilisation increased more (by 11.74 TWh/year) than the fossil fuels' (plus 6.61 TWh/year), while 5.52 TWh/year electricity production was avoided.

Regarding model 2.6c, the trends are almost the same, but the fossil fuel consumption is less than in model 2.6b regarding every type of them. Therefore, this is an important advantage of the model. With keeping the electricity import on the same level, the total primary energy supply practically does not change, while fossil fuel consumption decreases by 6.56 TWh/year and renewable production increases by 7.24 TWh/year. The CO_2 emission is also just a slightly more due to the higher coal penetration compared to the original model, but it is still less than 50 Million tons per year.

6. Conclusion

In this paper an energy model of the Hungarian energy system of 2009 was designed and analysed with the EnergyPLAN software. This kind of application of EnergyPLAN – where an exact year is chosen for modelling – can be said to be unusual since this energy modelling tool focuses on designing, analysing and optimising future energy systems with a high penetration of renewable sources. Therefore, next to the model itself, this experiment was a test case for the newly created model, the recent Hungarian energy system and the software in this altered task as well.

As for the software, a few development opportunities can be assigned. The possibility of setting heat production (in fact, combined heat and power generation) in case of nuclear and geothermal production, and more options for indicating electricity import and export in the same time, would help to create more precise models. These deficiencies had no significant effects on this model, but they can be more crucial for example in case of a country with enormous nuclear and/or geothermal capacities (e.g. U.S.A. or France). Another case where these functions can be useful is an economic optimisation of an energy system, where electricity import and export have different prices and consequences regarding fuel consumption and environmental effects.

Regarding the creation of the model, the main difficulty was the lack of reliable data about the details of the Hungarian energy system. The need of estimations made the probability of errors higher, while they also mean an opportunity to further develop the model. Even so, according to the comparisons of international and Hungarian statistics, the model seemed to be able to analyse and get results fairly accurate.

The result of the analysis strengthened the phrase that not everything, that is renewable, is also sustainable. A radical increase in renewable energy production, without technological change in infrastructure could lead to more serious environmental consequences in an inflexible energy system like the Hungarian one. While 35.48 TWh/year renewable energy production could be reached in the Hungarian energy system according to the model 2.6b, the consumption of most fossil fuels and therefore also CO_2 emission rise. Model 2.6c seems an optimal model from an environmental and probably economical point of view with less fossil fuel consumption and moderately more renewable energy production, although keeping the electricity import as well. For a detailed analysis from a broader perspective an economic optimisation should be carried out on the model as well.

However, an important message for Hungary of this experiment is that in 2009, with a different energy management and regulation, but within the same infrastructural conditions and total primary energy use, 11% of energy production could have been based on domestic, renewable sources, while it amounted to only 7% in reality. Meanwhile, renewable electricity production could have been increased by 80% more compared to the statistics of 2009, which would be definitely more than today, when increase of renewable energy capacities and production stagnated for years due to the recent policy and regulation.

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DAY 10 - 14:30		
Room 613 -Energy Technology 2		
Photovoltaic power predict using neural network	Samir H.OUDJANA[1]	[1]URAER
Support of Electric Energy Requirement at Educational Institutions with Photovoltaic Systems Generating Electricty from Solar Radiation	Ali Vardar[1]; Atalay Çetin[2]	[1]Uludag University; [2]Aksaray University
Addition of fish waste to maize silage fermentation as a sample of synergy effect in biogas production	Andrzej Lewicki[1]; Krzysztof Pilarski[1]; Jacek Dach[1]; Damian Janczak[1]; Wojciech Czekała[1]; Kamil Witaszek[1]; Pablo César Rodríguez Carmona[1]; Krystyna Malińska[2]; Roman Marecik[3]; Paweł Cyplik[3]	[1]Poznan University of Life Sciences; Institute of Biosystems Engineering; [2]Czestochowa University of Technology; [3]Poznan University of Life Sciences; Department of Biotechnology and Food Microbiology
The application of low temperature anaerobic digestion for BTX removal	Bozena Mrowiec[1]; Mariusz Kuglarz[1]; Lucyna Przywara[1]	[1]University of Bielsko-Biala

Photovoltaic power predict using neural network

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Abstract

Photovoltaic power generation predict is an important task in renewable energy power system planning and operating. This paper explores the application of neural networks (NN) to study the design of photovoltaic power generation forecasting systems for one week ahead using weather databases include the global irradiance, and temperature of Adrar city (west south of Algeria) using a data acquisition system. Simulations were run and the results are discussed showing that neural networks Technique is capable to decrease the photovoltaic power generation forecasting error.

Keywords: Photovoltaic Power Forecasting, Regression, Neural Networks

1. Introduction

The world population is growing at a rapid pace, and with This the global energy consumed and demanded also grows. Speculation about the depletion of fossil fuel reserves is a cause of concern for most governments and economies, and together with climate change and energy security issues, drives a massive campaign for clean and renewable energy options that would supplement the current energy production technologies. The issue of reducing C02 emission amount makes the whole world concentrate on installing renewable energy resource. Therefore, the interest in the solar and wind energy is consistently increasing while in these days. However, to equip energy resource holds lots of problems yet so that we cannot rely on such renewable energy generation amount for the national power system. One of the most serious problems is that energy resource is afected by weather condition a lot. Thus, the power produced by energy resource is provided irregularly and depletes the national power system stability and reliability [1,2].

The forecasts are key to the reliable and cost effective large scale integration of photovoltaic (PV) systems into electricity grids. In addition, prediction of PV power generation is also required for the planning and resizing of large scale PV plants, balancing control, power system stabilization, green power transactions, power interruption warnings in autonomous power systems and so on [3].

The Short-term photovoltaic power generation forecasting methods are experience forecast, such as electricity elasticity coefficient, integrated power consumption, output and growth rate of consumption, extrapolation forecast and district load density index method. Such methods need to generation the value, yield and growth rate, and other data [4].

The statistical analysis methods used in the power generation forecasting are regression analysis and time series, such as linear regression model, multiple linear regressions model, nonlinear regression analysis, autoregressive (AR) model, moving average (MA) models, autoregressive moving average (ARMA) model and nonstationary time-series. The statistical analysis methods need some relationship of values and the changes among identify consumption, load, time, total output value of industry in electricity gross domestic product, and then use mathematical models to forecast. The entire process is projected to ongoing mathematical model calibration and adjustment process, which will be taken longer time to complete [5-11].

The intelligent methods based power generation forecasting are expert system, grey generation, fuzzy logic, artificial neural networks, which used in the economic environment changes, and other random factors interfere with the power system under load accurately forecast. which widely used to analyze numerous uncertainties and the power load forecast correlation. But how accurate will describe the criteria adopted for the artificial uncertainties are relatively difficult. This paper provides a neural network models based on the temperature and irradiance data [12-15].

The objective is to develop a forecasting model which will be able to consistently forecast the energy generated by photovoltaic modules using explanatory variables available at most weather stations. The aim of this study is to enable future photovoltaic projects in Adrar city to be deployed at a much faster rate and at lower costs.

2. Regression Method

Regression is a statistical technique for building a link between a explanatory variables and dependent variable. The aim is to predict the dependent variable when you know the explanatory variable or establish if there is an effect of one variable on another.

2.1. Simple Linear Regression

The basic model for a deterministic set of ***n*** observations is given by equation (1):

$$Y_i = b_0 + b_1 X_i + e_i \qquad i = 1, 2, \ldots n \qquad (1)$$

Y_i: dependent variable,

X_i: explanatory variable,

b_0: standard estimator,

b_1: explanatory variable estimator.

Estimators b_0 and b_1 are calculated by the least squares method.

If the power P_{i+1} (dependent variable) depends only on the corresponding temperature T_{i+1} (independent variable), the prediction is generated as follows:

$$P_{i+1} = b_0 + b_1 T_{i+1} + e_{i+1} \qquad (2)$$

The strength of association between two variables is estimated by the correlation coefficient ***(r)***. This coefficient ranges from -1 to +1. If it is between 0.8 and 1 (absolute value), the strength of association between two variables is important. Between 0.5 and 0.8 is moderate, and between 0.2 and 0.5 it is weak:

$$r = \frac{\sum_{i=1}^{n} x_i y_i - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{\sqrt{\left[\sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2\right]\left[\sum_{i=1}^{n} y_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} y_i\right)^2\right]}} \qquad (3)$$

2.2. Multiple Linear Regression

Multiple regression is a generalization of the simple linear regression. The difference is that there are more variables to explain the dependent variable. Thus for ***k*** variables, the model become:

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_k x_k \qquad (4)$$

wherein **Y** *is a vector of values of* **y** *while* **X** *is a matrix of independent variables* **x** *described as follows:*

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, \; X = \begin{bmatrix} 1 & x_{11} & x_{12} \cdots x_{1k} \\ 1 & x_{21} & x_{22} \cdots x_{2k} \\ \vdots & \vdots & \vdots \; \vdots \\ 1 & x_{n1} & x_{n2} \cdots x_{nk} \end{bmatrix} \qquad (5)$$

The estimators are calculated by the ***B*** matrix:

$$B = \begin{bmatrix} b_0 & b_1 & b_2 \cdots b_k \end{bmatrix}^T = (X^T X)^{-1} X^T Y \qquad (6)$$

3. Neural Networks

From the beginning of nineties, new techniques appear to study the electrical load forecasting such as artificial neural networks. These recent techniques quickly became widely used in short-term PV generation forecasting. The mathematical model of an artificial neuron (Fig.1) consists essentially of an integrator that performs a weighted sum of its inputs. The result ***n*** of this sum is then transformed by a transfer function ***f*** which produces the output of a neuron. The ***R*** input neurons correspond to the vector $\boldsymbol{P} = [\boldsymbol{p_1}, \boldsymbol{p_2}, \ldots, \boldsymbol{p_R}]^T$, whereas $\boldsymbol{W} = [\boldsymbol{w_{11}}, \boldsymbol{w_{12}}, \ldots, \boldsymbol{w_{1R}}]^T$ represents the vector of the weights of the neuron. The output ***n*** of the integrator is given by the following equation:

$$n = \sum_{j=1}^{R} w_{1,j} p_j - b \qquad (7)$$

To verify the performance of the forecasting model, we can calculate the mean absolute percente error:

$$MAPE = \frac{100}{n} \sum_{t=1}^{n} \frac{\left| P_t - \hat{P}_t \right|}{P_t} \qquad (8)$$

P_t: Desired Power

$\hat{P}_t$: Forecast Power

n : Number of sample

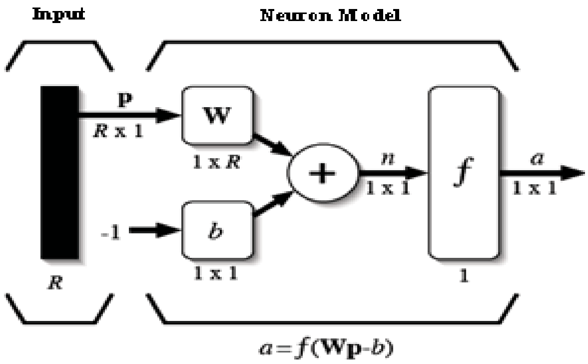

Figure 1. Model of an artificial neuron

4. Forecasting Models

Three models have been tested and valídate using differnet factors to virify they performances.

4.1 Model 1

This forecasting model requires only the temperature as an explanatory variable or as a database using simple regression and the neural network methods to predict the PV power generation for seven days ahead.

4.2 Model 2

The irradiance (solar radiation) factor at the previous time are used as database to predict the power generation for one week ahead, using the simple regression method and the neural network technique. Table 1 shows the correlation between the power and the corresponding temperature.

4.3 Model 3

The database of this model depends on two independent variables: the temperature and that of irradiance parametre correspondig to the same day of power forecasting value.

The strength of association between the generated power of photovoltaic module and the temperature is low (Table 1). Against by the strength of association between the current power and irradiance factor is very strong. The correlation coefficient ***r*** = 0.98 explains the intensity correlation, and the positive sign of this value expresses the proportional relationship of power with the corresponding value of irradiation, which means that when the irradiation increases the power generated by the PV module increases. Fig. 4 and 5 illustrate the correlation between the generated power of photovoltaic module and temperature, and between power and the irradiance factor corresponding respectively. Fig. 2 and Fig. 3 illustrate the temperature and irradiance of Adrar city in 2010.

TABLE 1. EXPLANATORY VARIABLES CORRELATION

Explanatory Variables	**Correlation Facteur (*r*)**
Temperature	0.37
Irradiance	0.98

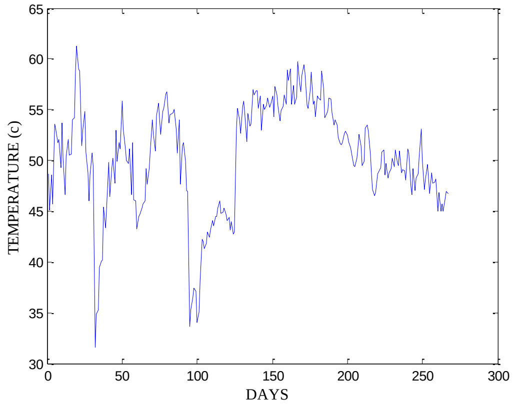

Figure 2. Temperature Curve

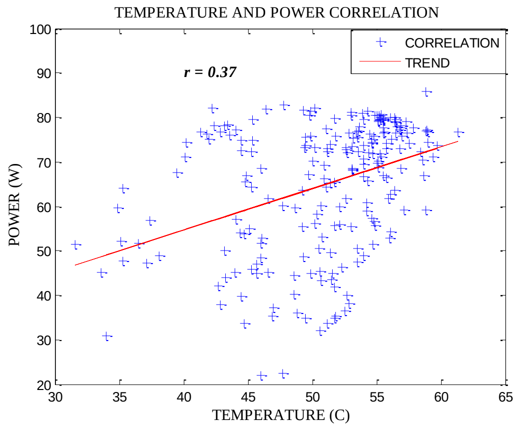

Figure. 4 Temperature vs. Power correlation

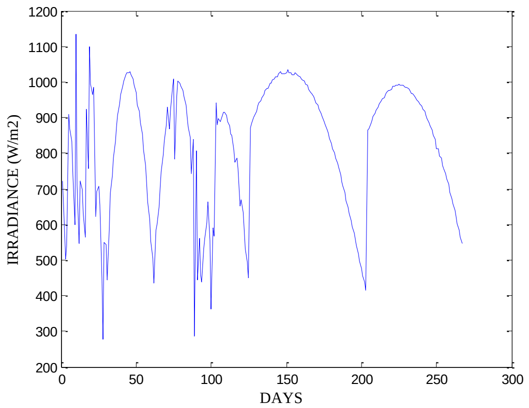

Figure 3. Irradiance Curve

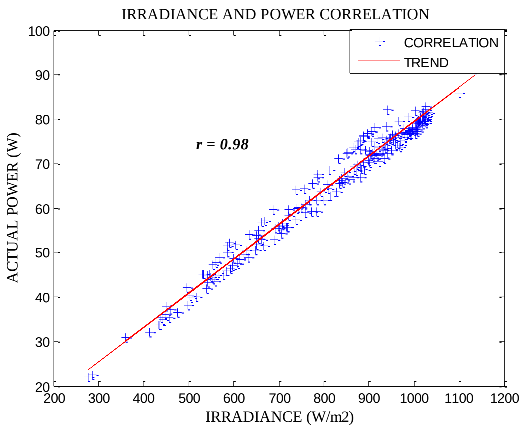

Figure 5. Irradiance vs. Power Correlation

5. Simulations

To validate the three forecasting models presented, in terms of the mean relative error, we must test multiple databases. For this, we used three database of 2008: 70%, 80% and 90% of data used to train the neural network by MATLAB code that we can predict the power generated in one week ahead, Table II representing three databases. The three models will be tested using the method of simple regression and neural networks. The performance of each model is verified by the mean absolute percent error MAPE.

The prediction error of Model 1 (Table 3) is large because only one independent variable or explanatory (temperature) was used. Its correlation with the PV module power is low, it is necessary to introduce other variables to improve performance. However, it is preferable to use neural networks in this case because it does not require several explanatory variables. Thus, Fig. 6 shows the power forecasting of this model. The difference between the desired power and that achieved using the regression is great because it can not predict the power associated with changes in temperature. On the other side, the method of neural network prediction narrowed the power gap to 1.48% that has a correlation with temperature by this intelligent technique.

Since the factor of radiation having a strong correlation with the power of the PV module, the forecast error will obviously decrease compared to model 1, and this is the case shown in Table 4, knowing that the average errors of the three tested is less than 4% using the method of simple linear regression, and the best accuracy is 1.093% using the neural network. Fig. 7 illustrates the application of Model 2 which shows the approach of the forecasting curve to that desired.

By hybridizing the model 1 and model 2, we obtain model 3, that is to say that the explanatory variables used to forecast power of photovoltaic module are temperature and irradiance. The accuracy of prediction using this model is even better (Table 5) because the power produced by photovoltaic panel depends on the meteorological factors and the correlation between these variables and power is even stronger. Fig. 8 shows the curve prediction by multiple regression and neural networks and shows that the power curve are realized and that provided nearly superimposed, such that the accuracy of prediction reached 0.217% (Table 5) by the NN. This means that the prediction using the parameters of temperature and irradiation is more accurate than using the variable temperature or irradiation. Table 6 summarizes the difference between the regression and the neural networks.

TABLE 2. DATA SETS

Set	Test (day)	Validation (day)
01	187	188-194
02	214	215-221
03	240	241-247

TABLE 3. VALIDATION OF MODEL 1 PERFORMANCE BY MAPE (%)

Set	Simple Regression	Neural Networks
01	39.148	2.717
02	21.969	1.484
03	11.754	2.082
Mean (%)	**24.290**	**2,094**

TABLE 4. VALIDATION OF MODEL 2 PERFORMANCE BY MAPE (%)

Set	Simple Regression	Neural Networks
01	4.876	6.070
02	3.250	1.093
03	1,744	3.702
Mean (%)	**3,290**	**3,621**

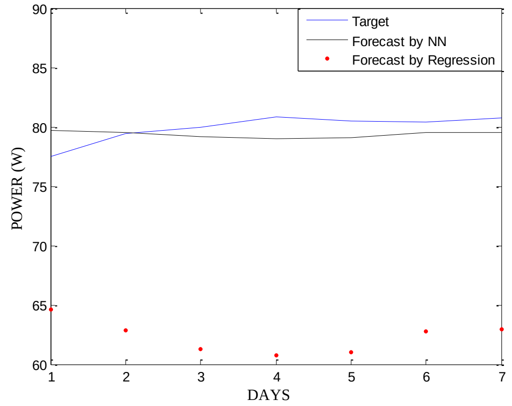

Figure 6. PV Power Forecasting Using Model 1

TABLE 5. VALIDATION OF MODEL 3 PERFORMANCE BY MAPE (%)

Set	Multiple Regression	Neural Networks
01	0.708	0.676
02	0.767	0.758
03	0.218	0.217
Mean (%)	**0.564**	**0.550**

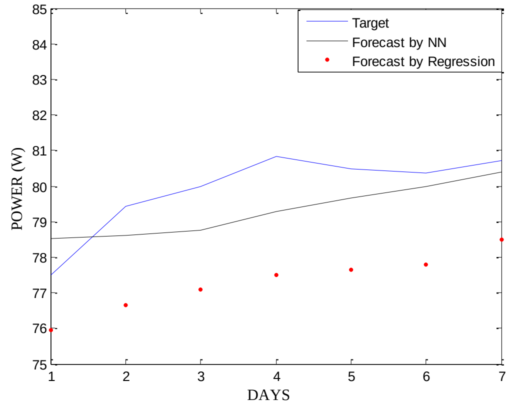

Figure 7. PV Power Forecasting Using Model 2

TABLE 6. NEURAL NETWORKS vs. REGRESSION COMPARISON

Regression	Neural Networks
requires a mathematical model	does not require a mathematical model
Several explanatory variables	Few explanatory variables
Small data base	large database
Short execution time	Long execution time

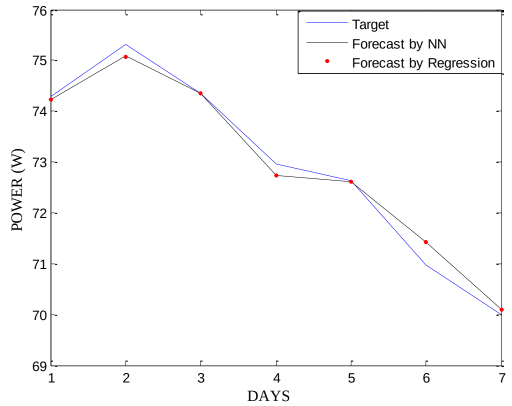

Figure 8. PV Power Forecasting Using Model 3

6. Conclusion

Short-term photovoltaic power generation forecasting is important to the operation of power system to make decisions by the dispatching center that cares to ensure electrical network security management while having a reliable and cost effective production system that meets specific environmental constraints.

The work initiated in this paper aimed to achieve a program that can predict the power generated by a PV generator to one week ahead at the site of Adrar (south of Algeria) and analyze the relationship between meteorological factors and the power supplied by applying the neural network technique. The regression is a standard statistical method based on a mathematical model. Against by the technique of neural networks does not require a mathematical model, but is based on artificial intelligence.

Before choosing a forecasting model of the power supplied by a photovoltaic module, we must first determine the correlation between independent variables and the desired power. For Model 1, the strength of association between temperature and power is low, so the forecast error is large. But the correlation between the predicted power and the irradiation is strong; consequently the forecast error becomes acceptable using model 2. Model 3 gave us a better accuracy, based mainly on two factors: temperature and irradiance, so that they can be used to short-term electric power of a photovoltaic plant. We conclude that the choice of forecast model output based on the study of the relationship of the explanatory variables with the desired power. Furthermore, this correlation is stronger, the model is better.

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Support of Electric Energy Requirement at Educational Institutions with Photovoltaic Systems Generating Electricty from Solar Radiation

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Abstract

It is possible to make use of solar energy which is a renewable energy source nearly all around the world, though in different proportions. Solar energy has become widespread in different sectors since it has no transportation cost. In this study, an educational institution (Mediha Hayri Çelik Science High-School) which provides part of their energy requirement from solar energy, an alternative and renewable source of energy was studied. A photovoltaic system which has 23 kW power was installed in order to support energy requirement of this institution and yielding and economy of the system was discussed through findings. In the study in which performance of the solar energy system (photovoltaic system) was determined, it was observed that the investment made for system is reimbursed within 9 years. According to the findings of the study; it is understood that national electric network can be supported by designing photovoltaic system generating electricity from solar radiation in similar public institutions and also important economic acquisitions will be enabled.

Keywords: Solar Energy, Photovoltaic, System Performance, Economy

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1. Introduction

The main energy source of the world is sun. Nearly all of the primary energy sources that used today are based on sun. The whole energy required for both physical and biological activities on earth are derived from sun actually. The sun enlightens our world, causes winds and creates climactic conditions suitable for human life. Coal, petroleum and natural gas which are known as fossil fuel are different states of solar energy. Although there are energy sources which are not based on sun, most of the energy sources in the world depend on sun in a way.

Solar energy is a clean and renewable energy resource which has a great potential. In this respect various technologies have been developed in order to make use of sun rays which has great potential for energy generation. It is possible to divide these technologies as ***thermal solar technologies and solar cells*** (Boyle, 2004). In some of these technologies, solar energy is used as luminous or thermal energy by the way in others solar energy is transformed into electric energy directly or indirectly. Heat is obtained primarily from solar energy in thermal solar technologies which is one of the methods of solar energy generation. This heat can either be directly used or utilized in electric generation. In solar cells (photovoltaic cells) semiconductive materials transform sun-light directly into electricity. Solar cells work depending on photovoltaic principle. In other words, there is electric voltage on the edges when they are illuminated. The source of electric energy given by the cell is in fact the solar energy on its surface. The most important feature of solar cells is the ***yield*** value which indicates the rate of transformation of solar radiation on cell surface into electric energy. Today these yield values differ according to the material, but it varies between 5% and 20% (Karamanav, 2007).

In order to increase power output, numerous solar cells are installed on a surface by connecting in parallel or in series. This structure is called solar cell module or photovoltaic module. Depending on the power demand, modules can be connected with each other in series or in parallel ans system from a few W to MW can be installed. Yielding condition of materials used in solar cell is an important variable. Like transistors and rectifier diodes used in solar products today; solar cells are made of semi-conductive materials. Among various semi-conductive materials; the most suitable ones to make solar cell are crystalline silicone, gallium arsenide and cadmium tellurate.

1.1. Solar Energy Potential

Turkey has advantageous than many other countries in the sense of solar energy potential due to its geographical location. Technical potential of solar energy in Turkey is calculated as 76 million TEP (Alaçakır, 2010). Additionally in a study carried out for Germany, it was determined that only southern regions received 1200 kWh/m^2-year sun light (Janzing, 2008). This value is even lower than the value of 1400 kWh/m^2-year which is the lowest sun-light amount obtained in northern regions of Turkey (Anonymous, 2009). Despite of all, Turkey has 420.000 TEP installed heat capacity with sun collectors. In addition to that hand installed capacity of electricity is 1 MW. From these values and with a rough caluculation, we can say that Turkey only uses 4,2% of its technical potential of solar energy (Vardar, 2012).

Considering the values of earth solar radiation map in Figure 1(NASA, 2008), areas between the zone including Turkey and Portugal and above the southern hemisphere and countries within this zone are quite advantageous compared to the countries in the north of northern hemisphere in the sense of solar energy radiation and sunshine duration. In fact, Turkey has quite suitable sunshine period with averagely 7 hours a day and has solar energy potential. Likewise some countries in Africa which have better condition than Turkey, some sountries in the Middle-East and South America are also lucky in this sense.

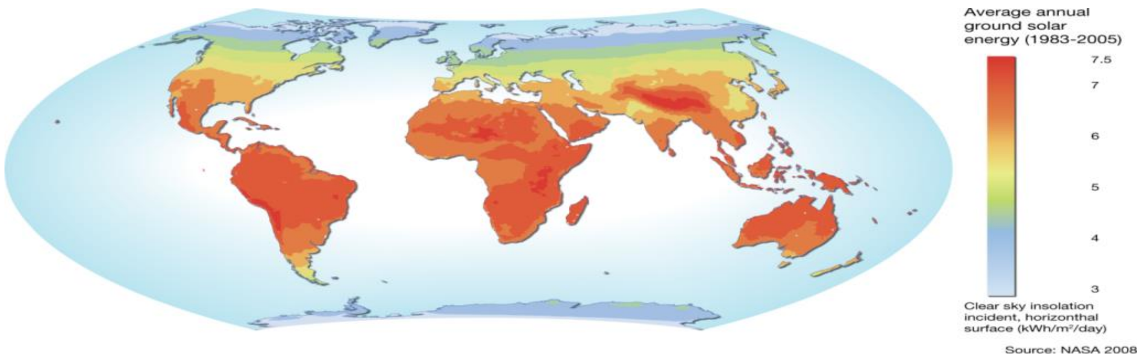

Figure 1. Earth solar radiation map.

On the other hand, the regions in Turkey which are advantageous in the sense of solar radiation is given in Figure 2 (Anonymous, 2009). According to data of Atlas of Potential Solar Energy (GEPA), even the most disadvantageous places in Turkey in the sense of solar radiation are in better condition than most of European countries with the values of 1200 kWh/m^2-year (NASA, 2008; Anonymous, 2009). In this sense, it is possible to say that it can be produce an energy from solar nearly in all regions and in different ways. Accordingly the most advantageous regions are Southeastern Anatolia, Mediterranean, Central Anatolia and Aegean regions.

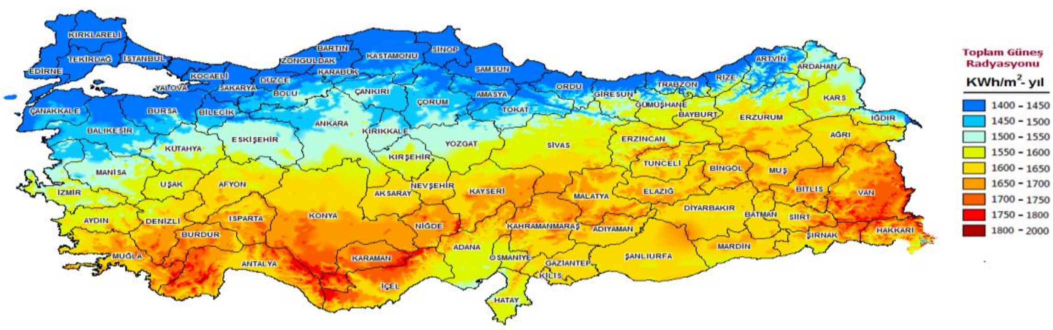

Figure 2.Atlas of Potential Solar Energy in Turkey.

Specific superior aspects of renewable solar energy which has quite high potential for Turkey and is extremely utilizable as such. First of all; solar energy that is a type of renewable energy source has no transportation cost and can be supplied from everywhere. Although the yield varies according to places which receive more or less sunlight, solar energy can be used at mountain peaks, in valleys or plains. In this context solar energy is away from every kind of crisis that may occur in energy supply. For instance, a change in national electric network would not influence this type of energy. Another superiority of solar energy is that it does not require any complex technology. Nearly all the countries can make use of this energy with the help of local industry institutions.

Despite all these superiorities, there are some problems about solar energy. For example, the power of solar energy is limited and discontinuous. It may not be available in desired amount when necessary. Investment expense of mechanism used in generating solar energy is high in the sense of current technological conditions. The amount of energy obtained from sun is not optional and cannot be controlled. In order to decrease incompatibility between the amount of energy obtained from sun and amount of energy required in the sense of time and rate, solar energy should be stored. The amount of heat energy to be stored and the method of storage to be applied depend on the level of incompatibility between current amount of heat (resource) and required amount (demand). However, despite some minor disadvantages solar energy provides quite important opportunities.

1.2. Economy

General information about properties and costs of solar energy technologies are given in Table 1 (Anonymous, 2010).

Table 1.Solar Energy Technologies and Properties.

Type of Technology	System Yield (%)		Maximum outlet temp. (°C)	Cost of initial investment ($)	Energy cost	
	Electicity	heat			Electricity ($/kWh)	Heat ($/kWh)
Planar collector	-	50-70	80	250-1000	-	0.0013-0.004
Parabolic trough	14	46	380	2800 kWe	0.15	0.0053
Parabolic dish	24	79	700	5000 kWe	0.28	-
Central Receiver	15	46	600-700	3000 kWe	0.16	0.004
Mono-crystalline silicon	12	-	-	6000 kWe	0.29	-
Poly-crystalline silicon	10	-	-	6000 kWe	0.29	-
Single thin film	4	-	-	5000 kWe	0.25	-
Multiple thin film	7	-	-	5000 kWe	0.24	-

Considering in the sense of investment cost and system yields, it can be said that parabolic trough and central receiver systems are more advantageous in the sense of energy cost, in other way planar and central receiver systems are more advantageous in the sense of heat generation. On the other hand, solar cells have higher cost under current conditions compared to other solar energy technologies. Yet their technology is improving rapidly and getting cheaper concordantly.

1.3. General information about the project

This project was conducted in ***Mediha Hayri Çelik Science High-School*** and was supported by ***BEBKA*** (Bursa Eskişehir Bilecik Development Agency). The general purpose of the project is to prevent environmental pollution in Bursa-Eskişehir-Bilecik region, improve and enhance of current control and treatment plants, increase energy yielding and enable transition to renewable energy and support sustainable development. Concordantly specific purpose of the project is to support electric energy requirement of institution with solar energy which is one of the renewable energy sources.

Within the frame of project, first of all the most sutiable photovoltaic solar energy was chosen and purchased considering the location of school and energy consumption characteristics. Afterwards photovoltaic solar energy system was placed and installed on the roof of school according to scientific principles and started operation. Within testing of system performance, the amount of energy generated by photovoltaic energy system and used at school was determined and recorded. Moreover, the amount of energy obtained from national electric network was recorded and monitored at this stage. Finally, a report was prepared about system performance and project was completed after it is introduced.

2. Material

The most important element of the project is photovoltaic solar energy system installed on the roof of the school. A schematic image of mentioned photovoltaic solar energy system is given Figure 3.

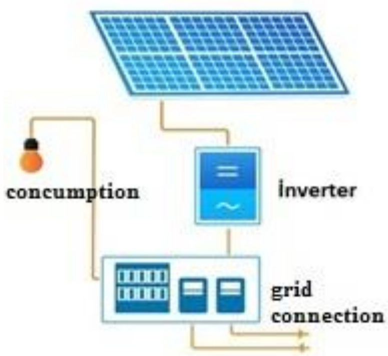

Figure 3. Photovoltaic solar energy system

Photovoltaic solar energy system is composed of solar panels which has 15+8 kW power value. The energy generated in these panels are DC (direct current) electricity and conveyed to an on-grid inverter. DC/AC (direct current/alternative current) transformation takes place in the inverter and AC (alternative current) electric is conveyed to a consumption point through electricity meter. If the energy demand rate is more than the amount of energy generated by photovoltaic solar energy system, the required lacking amount is compensated from national electric network. On the contrary situation, ie.the energy demand rate is less than the amount of energy generated by photovoltaic solar energy system, the extra energy that generated from photovoltaic solar energy system is conveyed to national electric network.

There are 96 photovoltaic panels in total; 63 of them are 15 kW photovoltaic solar energy system and 33 of them are 8 kW photovoltaic solar energy system. Each photovoltaic panel is 1640x992x45 mm, 19.5 kg and has 240 Wp power (Turkwatt, 2012). Besides that catalogue yield value of solar cell is 15% and the material is "polycrystalline". Connection and placement schemes of photovoltaic panels on the roof of institution are given in Figure 4-5. There are 2 inverters within system; 1 for 15 kW and 1 for 8 kW (Figure 6). Both of them are on-grid inverters. DC voltage generated from PV panels is 380/220V 50 Hz 3 phase 1 neutral, total sinus together with inverters whose control system is available (Turkwatt, 2012). Photovoltaic solar energy system is connected to current network line (in parallel) (ONGRID system) and system operates synchronously with network (Figure 6).

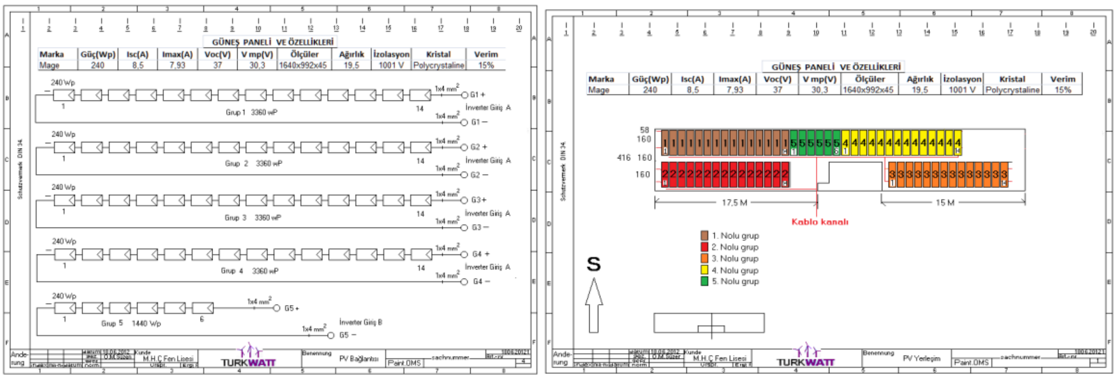

Figure 4. Connection and placement scheme of solar panels belonging to 15 kW

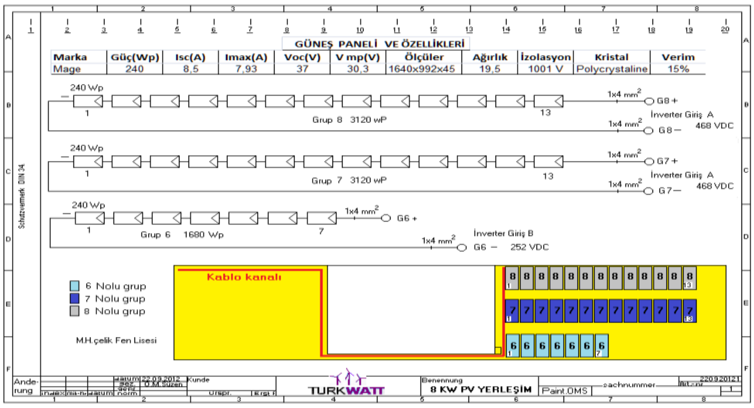

Figure 5. Connection and placement scheme of solar panels belonging to 8 kW

Figure 6. Inverters of 15 kW and 8 kW Photovoltaic solar systems

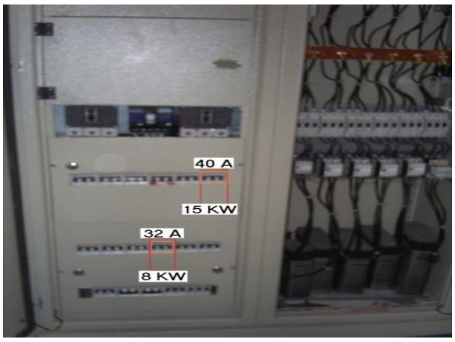

Figure 7. Network connection of electric generated by photovoltaic solar panels

General image of photovoltaic solar energy system installed within the scope of study is given in Figure 8.

Figure 8. General image of photovoltaic solar energy system

3. Method

Performance tests of Photovoltaic Energy System were conducted in Mediha Hayri Çelik Science High-School in Bursa-İnegöl. Tests were carried out in two stages. First of all, the physical condition of system was investigated and connections were controlled. Then,it were recorded total amount of electric consumed by the institution for a specific period of time; amount of electric consumed by the institution during daytime and amount of electric generated by photovoltaic energy system. Eventually in these processes, countermeasure of electric drawn from network and countermeasure on inverters were used. The method used in determination of system performance is given below (Vardar, 2011):

$$KO_t = GE \cdot ET_t \tag{1}$$

$$KO_g = \frac{GE}{ET_g} \tag{2}$$

$$SE_t = SD_2 - SD_1 \tag{3}$$

$$SE_g = SD_{g2} - SD_{g1} \tag{4}$$

$$GE = \dot{I}D_2 - \dot{I}D_1 \tag{5}$$

$$F = GE \cdot EF \quad (6)$$

$$AS = M \cdot YK \quad (6)$$

KO_t : Compensation rate of energy consumption of institution from photovoltaic solar energy
KO_g : Compensation rate of energy consumption of institution during daytime from photovoltaic solar energy
GE : The amount of electric generated from photovoltaic system

ET_t : Total electric consumption of the institution
ET_g : The amount of electric consumed during daytime
$ŞE_t$: The amount of monthly electric drawn from national network
SD_2 : The value of countermeasure at the end of month
SD_1 : The value of countermeasure at the beginning of month
$ŞE_g$: The amount of monthly electric drawn during daytime from national network
SD_{g2} : The value of countermeasure showing daytime hours at the end of month
SD_{g1} : The value of countermeasure showing daytime hours at the beginning of month
$İD_2$: The value of countermeasure at the end of month
$İD_1$: The value of countermeasure at the beginning of month
F : The amount of monthly monetary decrease in electric bill
EF : Unit price of network electric
AS : Period of redemption
M : Total system cost
YK : Annual earning of photovoltaic system

4. Results and Discussion

Data which were obtained as a result of tests were transformed into performance indicators with the help of equations mentioned in the method. Performance indicators that can also be stated as research results are given in Table 2.

Table2. Performance indicators

Performance indicator	**Measurement unit**	**Current value**	**Target value**	**Realized value**
Total installation cost of photovoltaic system	€	-	-	34.315
Compensation rate of energy consumption of institution from photovoltaic solar energy	%	-	19	21
Compensation rate of energy consumption of institution during daytime from photovoltaic solar energy	%	-	36	40
Average amount of monthly electric drawn from national network	kWh/mouth	10500	8500	8295
Average amount of electric drawn from national network during daytime	kWh/mouth	5500	3500	3300
Average decrease in electric bill	€/mouth	-	257	327
The amount of electric generated from photovoltaic system	kWh/mouth	-	2000	2340

When research results given as *realized value* in Table 2 and data of *target value* given in project suggestions are observed; it is clearly seen that the aim is achieved. Considering performance indicators one by one; while *compensation rate of energy consumption of institution from photovoltaic solar energy* was aimed as 19%, it was actually 21%. *Compensation rate of energy consumption of institution during daytime from photovoltaic solar energy* was aimed as 36% and it was 40% finally. It was aimed to decrease *average amount of monthly electric drawn from national network* , from 10500 kWh/ month to 8500 kWh/month though this value was decreased to 8295 kWh/month. It was also aimed to decrease *average amount of electric drawn from national network during daytime* from 5500 kWh/ month to 3500 kWh/month and this value was decreased to 3300 kWh/month at last. *The amount of electric generated from photovoltaic system* was aimed as 200 kWh/month and it was 2340 kWh/month in actual. *Average decrease in electric bill* was aimed as 257 €/month and it was 327 €/month actually. Within the frame of these results, it was calculated that the investment made for this photovoltaic energy generation system is reimbursed within 9,3 years.

5. Conclusions

It is not common neither in education sector nor in any other sector to support energy requirement from alternative energy sources other than national electric network. The rate of utilization from renewable energy as alternative energy is especially low. With this project; Mediha Hayri Çelik Science High-School could diversify electric consumption portfolio with photovoltaic solar energy systems which is among renewable energy sources by decreasing their dependence on national electric network. This "*Support of Electric Energy Requirement at Educational Institutions with Photovoltaic Systems Generating Electricty from Solar Radiation"* project which was designed carefully and put into practice successfully is an exemplary project for many institutions in the future. The effect of project when implemented primarily by private and state educational institutional and by all the other institutions will be an important acquisition. Concordantly that solar energy system could pay back to itself at such a short time as 9 year shows it's feasibility and necessity.

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Addition of fish waste to maize silage fermentation as a sample of synergy effect in biogas production

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Abstract

Fish waste can create a serious problem for environment. However, this waste can also be valuable co-substrate for biogas production. The aim of this study was to analyze an influence of fish waste addition on biogas production efficiency of maize silage – the most typical substrate for biogas production in Central Europe. The cumulative methane production for all examined mixtures with fish waste was higher than for the sample with maize silage only. The best synergy effect of fish waste and maize silage fermentation was observed with the proportion of 50:50% and the obtained biomethane production was 13.1% higher than theoretical CH_4 yield.

Keywords: Biogas, waste management, fish waste, synergy effect.

1. Introduction

Biogas is produced in different environments, e.g., in landfills, sewage sludge and biowaste digesters during anaerobic degradation of organic material [Rasi et al., 2007]. The main component of biogas – methane - is a valuable renewable energy source. Unfortunately, it is also a harmful greenhouse gas if emitted into the atmosphere [Sneath et al. 2006]. Methane, upgraded from biogas, can be used for many different purposes- heat and electricity production or as biofuel for vehicles, to reduce environmental emissions and the use of fossil fuels. Biogas can be CO_2-neutral biofuel and if used as vehicle fuel, emits lower amounts of nitrogen oxide, hydrocarbon and carbon monoxide emissions than petrol or diesel engines [Wellinger and Linberg 2000]. Upgrading of biogas for use as vehicle fuel is feasible in large-scale sewage and biowaste digesters and pioneering work has recently also been done on farm-scale biogas concepts in this field [Lampinen 2004].

Typically, biogas contains also ammonia, hydrogen sulphide and other sulphur compounds such as aromatic and siloxanes and halogenated compounds [Rasi et al. 2007]. Although the amounts of trace compounds are low compared to methane, emitted in natural conditions (i.e. from landfills) they can have a great impact on environment for example stratospheric ozone depletion, the greenhouse effect and/or reduce the quality of local air [Rasi et al., 2007]. Many volatile organic compounds (VOCs) present in biogas can be harmful to the environment or to humans. Aromatics, heterocyclic compounds, ketones, aliphatics, terpenes, alcohols and halogenated aliphatics are found, especially in landfill gas [Eklund et al. 1998; Shin et al. 2002; Jaffrin et al. 2003]. Anaerobic digestion has a strong potential for treating biodegradable solid waste. Production of biogas could replace, at least some part of fossil fuels and reduce environmental impacts including global warming and acid rain. Another thing is that the product of this process – digested pulp can be used in agriculture after the stabilization or composting step. This technology is established in Europe, with 200-full-scale plants treating almost 6 million tons of organic waste per year [De Baere and Mattheeuws 2010]. The methane potential is a key parameter for assessing design, economic and managing issues for the implementation of the anaerobic digestion process. This parameter depends on the composition of solid waste [Zhou et al. 2012]. A wide variety of substances, presented in high concentrations in waste can cause inhibition or even failure of the fermentation process. A good option for improving the yield of biogas is co-digestion [Zhou et al., 2012]. That is the use of a co-substrate that in most cases increases biogas production due to positive synergism established in the digestion medium and to the supply of missing nutrients [Mata-Alvarez et al., 2000].

During fish processing from the food products the important amount of fish waste is generated [Eiroa et al. 2012]. Usually they are uneatable parts of fish bodies. Types and properties of fish waste contingent on the place of their production. It depends also on fish species, the final form of fish product and the method of processing it. Fish waste can be a heavy burden for the natural environment. But, on the other hand, they are good substrates for high-energy, protein-containing fodder (fish flour, fish oil).

For the right evaluation of fish waste production scale it was necessary to analyze this market. It was done by National Marine Fisheries Research Institute in Gdynia – Poland during the project “Ecological, complex fish waste management for fodder production”. According to this data, about 50-60 thousand tons of fish waste are produced yearly in Poland [Kołodziej 2007]. Most of it can be successfully transformed into valuable fodder. Unfortunately some of it is contaminated by detergents making it unfit to fodder production.

The aim of this study was to analyze the influence of fish waste addition on biomethane production efficiency from maize silage – the most typical substrate for biogas production in Central Europe.

2. Materials and methods

The study was conducted in Laboratory of Eco-technologies – the biggest biogas laboratory in Poland, Laboratory working within the Institute of Biosystems Engineering (Poznan University of Life Sciences). The research based on modified German standard DIN 38 414, while chemical and physical analytical methods based on Polish Standard System. The analytical procedures concerning biowaste were also developed within several scientific projects financed within EU 6th Framework Program and Polish Ministry of Sciences within the years 2006-12 [Stachowiak et al., 2008; Wolna-Maruwka and Dach, 2012].

2.1. Solid waste and inoculum

Solid fish waste was obtained from the canning industry from Wielkopolska region – middle Poland. The waste came from tuna, sardine, mackerel and needle fish. Because of some specific contamination (i.e. surfactants or oils), processing plant could not use it for fodder production. Maize silage came from Przybroda – an experimental farm of Poznan University of Life Sciences – where it was stored in a typical silo with the walls made of concrete within 10 months. Inoculum (digested pulp) was taken from an agricultural Polish biogas plant working on caw slurry and maize silage.

2.2. Methane production set-up

The experiment of biogas production was conducted through anaerobic digestion in the set of multichamber biofermentor (Fig. 1). This biofermentor is commonly used for testing biogas efficiency for large amount of biomass samples.

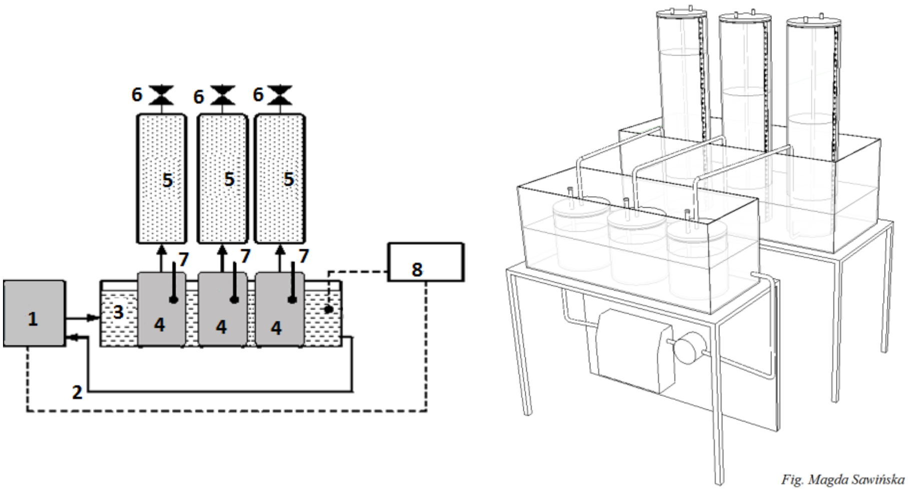

Fig. 1. Scheme of biofermentor for biogas production research (3-chamber section)

1. Water heater with temperature regulator, 2. Insulated conductors of calefaction liquid, 3. Water coat with temp. 39°C, 4. Biofermentor with charge capacity 2 dm^3, 5. Biogas reservoir, 6. Cutting off valves, 7. Sampling tubes, 8. Recording central station

Aerobic digestion experiments were carried out in stirred tank reactors constructed of glass in the Laboratory of Eco-technologies. General rules for biofermentor work were based on the fermentation of organic substrate samples which were put in the chambers with 2 dm^3 capacity. Without oxygen presence and additive of fermentation inoculum the conditions present within the fermentation chamber allowed to create an ideal condition for methane fermentation of the samples. Glass chambers with samples were placed in water with regulated temperature (around 39°C) – the real conditions of biogas plant. Biogas produced in each separate chamber was transferred to cylindrical store – equalizing reservoirs, filled in with liquid. The samples were tested in 3 replications.

2.3. Solid samples

Prepared samples needed to be analyzed in respect to the correct physical and chemical parameters. The most important one was pH (optimum between 6.8 and 7.5) and ammonium nitrogen concentration (lower than 2.5 g/dm^3 of prepared mixture). The pH was measured using laboratory multi-meter CP-411 (Elmetron). Additionally, dry matter and organic dry matter were determined. It was necessary to calculate biogas production efficiency in typically used units – m^3/Mg of dry matter.

During the experiment the following standard methodology established by Polish Norms (PN) has been used: for dry matter PN-75 C-04616/01, pH - PN-90 C-04540/01, conductivity PN-EN 27888:1999 and organic dry matter PN-Z-15011-3. Ammonia was determined according to Standard Methods [APHA et al., 1998].

2.4. Gas samples

The volume of the produced biogas has been measured every 24 hours. Gas composition has been checked out from at least each 1 dm^3 of the produced biogas (at the beginning of the experiment it was once a day, and after the culmination point, when the production slowed down, each three days). The concentration measurements of methane, carbon dioxide, hydrogen sulphide, ammonia and oxygen in the produced biogas have been carried out with the use of the absorption sensors working in an infrared and electrochemical sensor line. The type Mg-72 and MG-73 heads for gas concentration measurement have been used (ALTER S.A.) [Wolna-Maruwka, Dach, 2009].

The ranges of detected gaseous compounds were: 0-100% CH_4, 0-100% CO_2, 0-25% O_2, 0-2000 ppm H_2S and 0-2000 ppm NH_3, respectively. Therefore, each sample for biogas production was monitored for the gas compounds daily. The volume of biogas production and the methane content of biogas were calculated in the Excel sheet. According to the graph, it was possible to determine if the sample is working properly during the experiment. Gas-monitoring system has been calibrated each week using calibration gases provided by Messer Company, using the following concentration of gas calibration: 65% of CH_4, 35% of CO_2 (in same mixture). 500 ppm of H_2S and 100 ppm of NH_3. For O_2 sensor calibration, the typical synthetic air was used.

2.5. Mixture preparations

Preparation of fermentation mixtures established varied proportions between analyzed substrates (Table 1).

Table 1. Fermentation mixtures proportion

	Substrates		
	Fish waste [g]	Maize silage [g]	Inoculum [g]
100% Fish waste	100	0	1100
70% Fish waste 30% Maize silage	70	30	1100
50% Fish waste 50% Maize silage	50	50	1100
30% Fish waste 70% Maize silage	30	70	1100
100% Maize silage	0	100	1100

Cumulative weight of substrates added to each reactor based on availability of easily-digestible fractions (when the concentration of it is to high may causes acidification process) and started pH of prepared mixtures.

2.6. Cumulative production calculation VDI 4630

For the batches with the mixture of the substrate or of the reference substrate, the proportion of gas production from the seeding sludge in the test is calculated by means of the following equation:

$$V_{IS(korr.)} = \frac{\Sigma V_{IS}\, m_{IS}}{m_M} \quad (1)$$

Where:

$V_{IS(korr.)}$ gas volume which was released from the seeding sludge, in m l_N

ΣV_{IS} total of the gas volumes in the test with seeding sludge for the test duration under consideration, in ml_N

m_{IS} mass of the seeding sludge used for the mixture, in g

m_M mass of the seeding sludge used in the control test, in g

The net gas normal volume of the substrate or of the reference substrate in the test is obtained for the same test times as the difference between the normal volumes of the dry gas in the test less the normal volume of the dry gas from the seeding sludge. The specific fermentation gas production Vs from the substrate or reference substrate as a function of the test duration is calculated step by step from reading to reading in accordance with the equation:

$$V_S = \frac{\Sigma V_n\, 10^4}{m\, w_T\, w_V} \quad (2)$$

V_S the specific fermentation gas production relative to the ignition loss mass during the test period, in l_N/kgGV;

ΣV_n net gas volume of the substrate or of the reference substrate for the test duration under consideration, in $ml_{N;}$

m mass of the weighed-in substrate or of the reference substrate, in g;

w_T dry residue of the sample or of the reference sludge, in %;

w_V loss on ignition (GV) of dry mass of the sample or of the reference sludge [%].

The net methane normal volume of the substrate or of the reference substrate in the test is obtained for the same test times as the difference between the normal volumes of the methane in the test less than the normal volume of the methane from the seeding sludge. The methane normal volume is calculated by multiplying the normal volume of the dry gas by the methane content of the dry gas. If only the carbon dioxide content of the dry gas is available rather than the methane content, the methane content is calculated under the assumption that the dry gas is composed only of methane and carbon dioxide.

3. Results and discussion

3.1. Substrate analysis

At the beginning of the research, chemical and physical parameters of substrates have been analyzed. Organic dry matter content was similar for both substrates and it was high, over 95% (Table 2); therefore, the fish waste is a good candidate for anaerobic digestion because they contain high levels of potentially biodegradable materials (proteins and fats). Low pH, and the presence of easy digestible sugars in substrates have an influence on amount of substrate added to the fermentors.

Table 2. Physical and chemical parameters of substrates

Substrate	Dry matter [%]	Organic dry matter [% D.M]	pH	Conductivity [mS]	Ammonium nitrogen [g N_{NH3} / kg DM]
Fish waste	47.13	95.21	5.2	1.267	2.344
Maize silage	32.18	95.72	4.08	1.298	1.413
Inoculum	3.06	73.17	8.17	22.2	1.947

3.2. Digestion of maize silage

Fermentation of the sample containing maize silage only is presented on the fig. 2. The process started dynamically from the very beginning and the amount of methane raised up constantly to reach the final cumulative concentration over 55%.

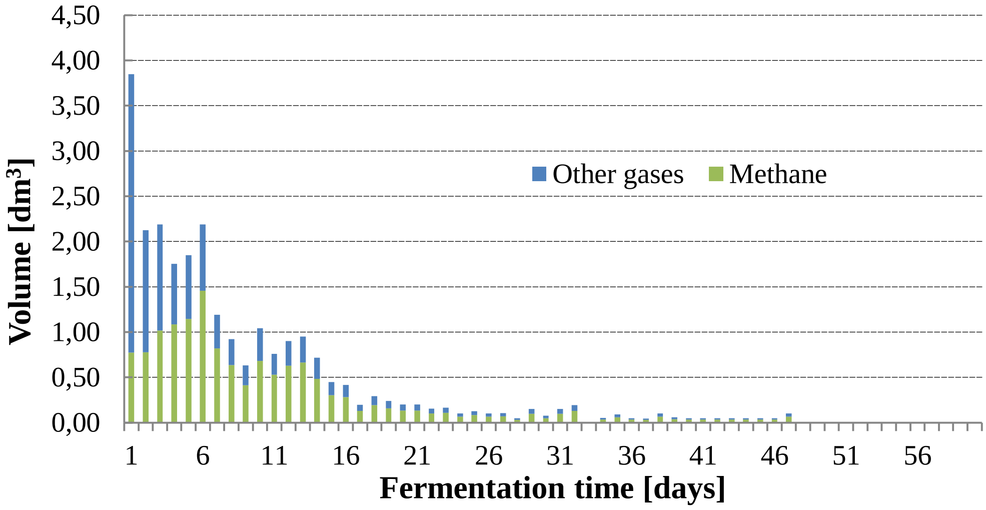

Fig. 2. Daily biogas production from maize silage

Which is adequate to all calculations for this substrate as well as the final result of the cumulative methane production - 390 m^3 for tone of dry matter [IE et al.. 2007].

3.3. Digestion of solid fish waste

Fermentation of sample containing fish waste is only presented in the Fig. 3. Although the process was stable. it was not very intensive in the beginning. In time biogas production accelerated and reached the culmination moment between 19th and 28th day. Concentration of methane high – over 68%. what fits perfectly to theoretical calculations – the amount of methane from protein is 70-75% and from fats 68-73%. The results of cumulative biogas production in this assays was over 1040 m^3 for tone of dry matter which also fit into the theoretical calculations [IE et al.. 2007].

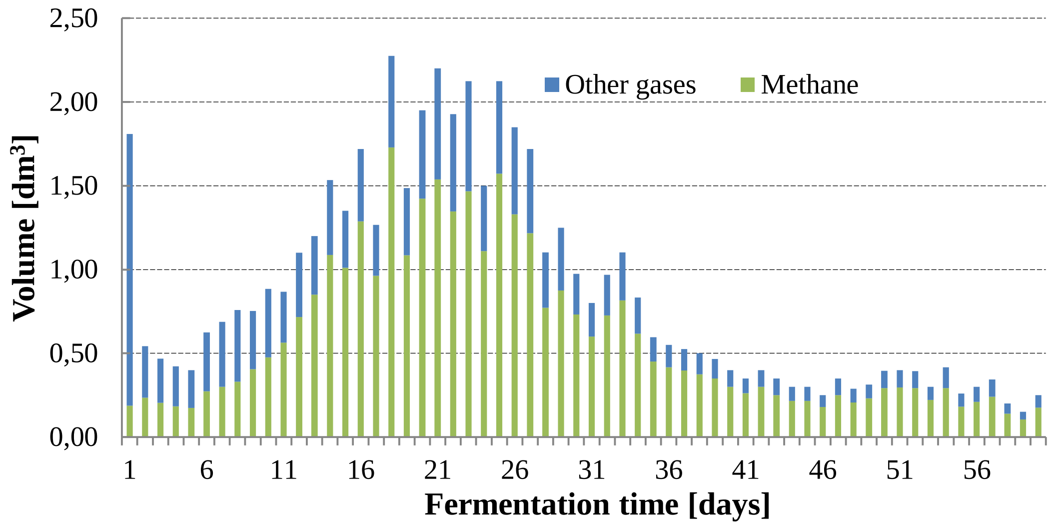

Fig. 3. Daily biogas production from solid fish waste

3.4. Digestions of mixtures

Results of cumulative methane production in the assays with different content of fish waste and maize silage are presented in Fig. 4. Cumulative methane production for all mixtures with fish waste was higher than for the sample with maize silage only. Furthermore. it respectively increased with fish waste concentration.

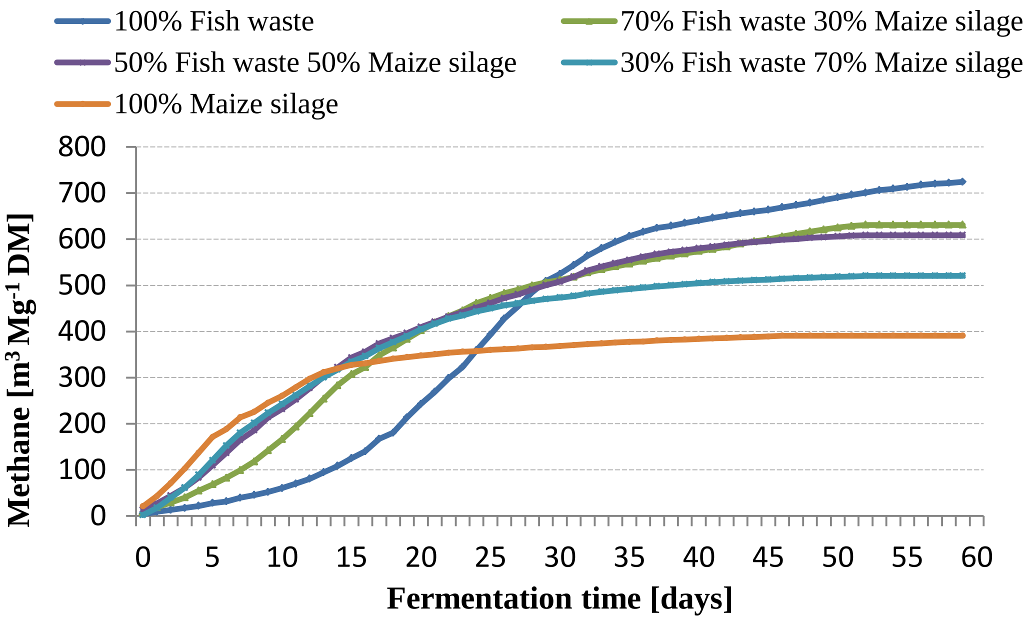

Fig 4. Cumulative methane production

It is worth highlighting that the fact that the two substrates (maize silage and fish waste) working together produced the results greater than the sum of their individual effects – it is. so called “synergy effect”. For a better visualization of this effect another graph has been done. The theoretical calculation based on assumption that substrate produce biogas with constant efficiency and amount of it depends on weight of added substrate. When we compare the theoretically calculated efficiency (blue bars) with experimentally obtained data (red bars) the clear synergy effect can be found (Fig. 5.).

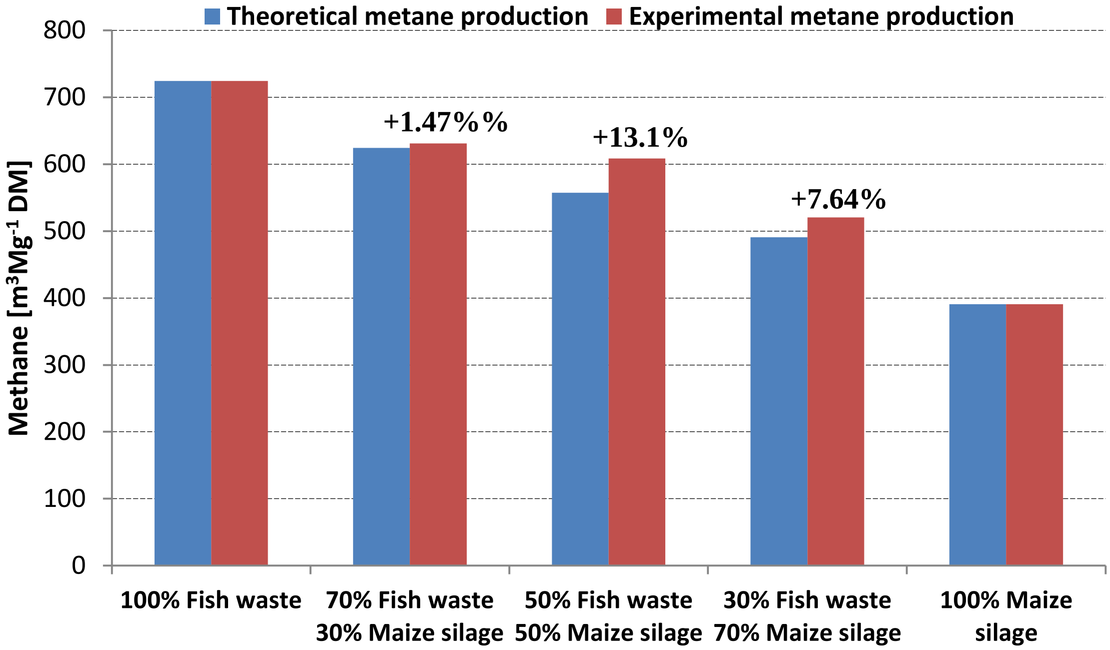

Fig. 5. Comparison between theoretical and experimental methane production – synergy effect

As it is shown in Fig 5. addition of 30% of fish waste gives better result (7.64%) than it would result from theoretical calculations. When the total quantity of fish waste rises up to 50% even a higher synergy effect reaching 13.1% in plus can be observed.

3.5. Economic estimation and socio-environmental impact

Additional result which can be found in Fig. 4 is clearly higher biomethane production from fish waste comparing to the maize silage. In Poland, like in Germany, the maize silage is the substrate most commonly used for biogas plant feeding. However, the prices of maize silage in Poland varying between 28 and 36 euro/Mg seem to be very expensive which makes negative profitability of production. In fact, the upper limit calculated by specialist from PULS Poznan was 29 euro per Mg of maize silage. Comparing to this situation, the fish waste can be obtained for free (or even with some money paid by the fish waste producer). In addition, the fish waste biomethane productivity is clearly higher than in case of maize silage which is related with very high content of fat in fish waste [Yahyaee et al., 2013]. This clearly shows the profitability of fish waste usage as the substrate for biogas plant.
Additionally, the synergy effect found during described research can increase the biomethane production only by optimizing the substrates proportion - without any financial investments or technical modifications of the biogas installation. Growth of biogas production from fish waste (or similar leftover substrates) let to decrease the usage of maize silage and in consequence reduce the monoculture commonly found in Western Poland and Eastern Germany.

It has to be underlined that energetic usage of fish waste as the substrate in biogas plant lets to decrease the negative impact to the neighborhood. This impact is mainly related with awful odors released from fish waste as well as potential sanitary risks because this waste should be moved immediately from production to the biogas plant within hermetic installation. In consequence the welfare of people living around should grow up significantly comparing to actual state.

4. Conclusions

Synergy effect is very desirable phenomenon in each biogas plant. It has a positive influence on the economic balance of each biogas business. The research has proved that addition of fish waste to maize silage fermentation gave the significant synergy effect in each studied case and let to obtain the growth of biomethane production reaching 13.1% comparing to theoretical calculation. From an economical point of view, it is extremely important to find a co-substrate for fermentation (the best solution is using wastes because it is cheap) and reach a synergy effect as high as it is possible.

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The application of low temperature anaerobic digestion for BTX removal

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Abstract

Anaerobic treatment has favourable effects like removal of higher organic loading, low sludge production, high pathogen removal, biogas production and low energy consumption. Psychrophilic anaerobic treatment can be an attractive option to conventional anaerobic digestion for municipal sewage and industrial wastewaters, are discharged at moderate to low temperature. The aim of this study was to evaluate the feasibility of anaerobic biological treatment of BTX containing wastewater under ambient conditions 15 – 17^{o}C. The concentrations of BTX (the sum of aromatic hydrocarbons) in effluent decreased on average by 56 % - for treatment with HRT 72 h and 68 % for - HRT 144 h. The investigations have shown a moderate effect of organic matter removal. The average values of COD decrease on the level of 40 % were obtained.

Keywords: anaerobic processes, anaerobic wastewater treatment, anaerobic biodegradation of BTX, psychrophilic anaerobes

1. Introduction

Aerobic treatment systems, such as the conventional activated sludge (CAS) process, are widely adopted for treating low strength wastewater (< 1000 mg COD/L) like municipal wastewater. CAS process is energy intensive due to the high aeration requirement and it also produces large quantity of sludge (about 0.4 g dry weight/g COD removed) that has to be treated and disposed of. As a result, the operation and maintenance costs of a CAS system are considerably high. Anaerobic process for domestic wastewater treatment is an alternative, potentially more cost-effective, particularly in the sub-tropical and tropical regions where the climate is warm consistently throughout the year.

Many wastewater are discharged at low ambient temperatures. Heating them for mesophilic or thermophilic treatment is energy intensive and costly, wherefore psychrophilic wastewater treatment is desirable. However, low temperature needs to be taken into account in design and operation of treatment systems, as it changes many properties in the treatment process. Solubility of gases increases with decreasing temperature, leaving more methane into effluent than at higher temperatures. Moreover, higher solubility of carbon dioxide may lower the pH. Liquid viscosity is also increased at low temperatures, wherefore mixing requires more energy, and particles settle more slowly due to decreased liquid-solid separation (Luostarienen, 2005; Lettinga et al., 2001). At such temperatures, chemical oxygen demand (COD) removal is limited and long hydraulic retention time is needed for one step system to provide sufficient hydrolysis of particulate organics (Gasparikova, 2005). Low temperature causes deleterious effect on anaerobic digestion due to relatively longer generation time of anaerobic bacteria populations and lower biochemical activity, resulting in the decrease of biogas yield and digester failure (Singh et. al., 1999).

Recently, it has been proposed that bacterial strains that grow optimally at low temperatures (< 20^{o}C) can be used to augment biodegradation at temperatures as 5 - 10^{o}C. Studies reported in the literature were mainly concentrated on the identification and characterisation of naturally occurring cold-active microorganisms and their enzymes. A few reports highlight the degradation and detoxification of pollutants at very low temperatures (Ramana and Sing, 2000; Lettinga et al. 2001; Luostarienen, 2005). Psychrophilic bacteria are defined as those that grow optimally at < 15^{o}C with an upper growth temperature of 20^{o}C. However, bacteria that grow optimally between 15-25^{o}C are known as psychrotrophs. These psychrophilic bacteria can also grow sub-optimally between 0-15^{o}C. Cold-active bacteria (anaerobic microorganisms), such as acetogens and methanogens play an important role in the anaerobic degradation and CH_4 formation in variety of ecosystems, ranging from deep granite rock aquifers, forest soils to deep lake sediments and Tundra soil. In some instances, polluted sites are located at ambient temperature that coincides with the optimum growth temperatures of cold-active bacteria. A limited numbers of investigations have highlighted the importance of cold-active bacteria in the bioremediation of soil, water and marine conditions (Ramana and Sing, 2000).

The start-up and treatment of municipal wastewater in cold regions was investigated in two UASB reactors operated at temperatures of 32, 20, 15, 11, and 6°C with several HRTs ranging from 48h to 3d (Singh and Viraraghavan, 1999). Biomass aggregation (granulation) was achieved in approximately 281 d at 20°C. Luostarienen (2005) used the UASB-septic tanks for treatment of synthetic black water, dairy parlour wastewater, and mixture of black water and kitchen waste at low temperatures of 10 – 20°C with HRTs from 1.2 to 4.8 d. In the pilot studies 65 % of COD was removed. Orozco (1997) investigated a full scale anaerobic baffled reactor (AnBR) for the treatment of municipal sewage of an average BOD of 314 mgO_2/L and a hydraulic retention time of 10.3 hours, (organic loading rate 0.85 $kg/m^3 \cdot d$).The removal efficiency amounted to 70%; but it has to be stressed that the process was run at very low temperature between 13 and 15°C. Treatment of domestic wastewater in a UASB and two anaerobic hybrid (AnH) reactors was conducted by Elmitwalli et al. (1999) at a temperature of 13°C. For pre-settled wastewater treatment, the AnH reactors removed 64% of total COD, which was higher than the removal in the UASB reactors. Connaughton et al. (2006) expanded granular bed anaerobic filter (EGSB-AF) for the treatment of medium-strength synthetic wastewater and efficient wastewater treatment at low HRT value (4.88 h).

Low temperature or psychrophilic (< 20°C) anaerobic digestion (PAD) has recently been proven feasible for the treatment of a range of industrial wastewater representing a technological breakthrough for environmental management. Therefore, psychrophilic anaerobic treatment is an attractive option to conventional anaerobic digestion for wastewaters that are discharged at moderate to low temperature.

The increased application of anaerobic digestion to a broader range of wastewaters, including more recalcitrant streams such as those from pharmaceutical production, would provide significant environmental and economic benefits to those sectors. Pharmaceutical wastewater can contain a variety of solvents at varying concentrations. Enright et al. (2005) stated that PAD of pharmaceutical – like solvent - containing wastewater is a feasible treatment option. The introduction of different solvents to the influent wastewater at different time-points, to mimic conditions prevalent in the pharmaceutical industry, was compatible with efficient reactor operation; the COD removal efficiencies of 60 – 70 % were achieved.

At municipal wastewater treatment plants, among various substances, the monoaromatic hydrocarbons (BTX) are found very often. BTX can be discharged with industrial wastewater, from small factories as well as public utilities and domestic sewage, (Escalas et al., 2003). Our own research results and the literature data present a quite common occurrence of aromatics hydrocarbons in municipal wastewater. The BTX concentrations are varying in the range of 0 to 933 µg/L. Toluene is the compound most often measured in raw wastewater. The aim of this study was to evaluate the feasibility of anaerobic biological treatment of BTX containing wastewater under ambient conditions 15 – 17°C.

Materials and methods

Biomass

A mesophilic, anaerobic sludge was obtained from a full-scale municipal wastewater treatment plant (WWTP), Bielsko-Biala Poland. The sludge was adapted with municipal sewage to psychrophilic conditions (15-17°C) during three months.

Laboratory anaerobic reactors

Two glass bottles (1) and (2) of a volume 2.5 L were used. Reactors were closed by a fermentation tubes. The volume of treated wastewater was 2.1 L. The average suspended solids (SS) concentration in each of reactors was about 0.8 g/L. A loading rates of 200 and 100 gCOD/m^{3}·d were applied to reactors (1) and (2) with a hydraulic retention time (HRT) of 72 and 144 h, respectively. The operational temperature was maintained at 16°C. The influent was supplemented with BTX – sum concentration in the range from 2.06 to 5.73 mg/L. The concentrations of individual compounds were in the range of 515-1267, 521-1433, 517-1601 and 504-1424 µg/L for benzene, toluene, p-xylene and o-xylene respectively.

Analytical methods

All chemical analyses were performed for samples before and after of anaerobic digestion. Chemical and physical parameters were determined according to the procedures given in the Standard Methods for Examination of Water and Wastewater (Eaton et al., 1995). For colorimetric determinations, a spectrophotometer HACH DR 5000 was applied. pH and conductivity measurements were carried out with a WTW inoLab Level2 meter, equipped with a SenTix K1 electrode for pH. Suspended solids (SS) concentration was determined according to the Wastewater Engineering Treatment and Reuse (4th edition) (Tchobanoglous et al., 2002). The BTX concentrations were determined in wastewater using the gas chromatography HP 6890 equipped with a "purge and trap system" and thermal desorption. The GC had a capillary column HP-5 Crosslinked 5% ME Siloxane (length 30 m, internal diameter 0.32 mm, film thickness 0.25 µm) and a FID detector.

The presented here results are based on 10 experiments. Arithmetic average and standard deviation were calculated. Standard deviation was determined according to the estimator of highest credibility in STATISTICA 6.0.

Results and discussion

Addition of aromatic hydrocarbons (BTX) to treated wastewater in anaerobic digestion were conducted after psychrophilic conditions. The main parameters for digestion control were: pH, temperature, ORP (oxidation-reduction potential), volatile fatty acids, alkalinity. All parameters were typical for psychrophilic wastewater digestion. The total concentration of the BTX used in the psychrophilic digestion amounted to from about 2.06 to 5.73 mg/L. For individual compounds the concentrations were varied from about 0.5 to almost 1.6 mg/L. The average COD of raw wastewater was at the level of 600 mgO_2/L. The psychrophilic digestion were carried out with two different HRTs, i.e. 72 and 144 h for 1 and 2 reactors, respectively. Therefore, the loading rates of 200 and 100 gCOD/m^{3}·d were applied. The anaerobic treatment processes have been conducted over a period of 2 months and the results of first part are presented below.

After the psychrophilic digestion, the concentrations of BTX (the sum of aromatic hydrocarbons) in effluent decreased on average by 56% for treatment with HRT 72 h and 68% for HRT 144 h. Initially, the BTX removal proceeded with less efficiency. After the 10 days of adaptation, the efficiency of treatment varied in narrow range, and for HRT 72 h it was from 46 to 64%. For higher HRT (144 h) the adaptation of psychrophilic microorganisms was faster, and after 7 days the efficiency of BTX removal increased and varied in range of 60 to 75%. The COD in the anaerobic treatment was decreased in low range. Probably, it was the result of aromatic hydrocarbons presence. The investigations have shown a moderate effects of organic matter removal. The average COD decrease on the level of 40% was observed for anaerobic process with HRT 72 h. For the HRT 144 h, the better results of treatment were expected. But in the case the effects of COD removal were inferior, although better BTX removal was achieved. The average value of COD decrease was 35%. The highest BTX concentration, on the level of 5.73 mg/L, clearly caused a decrease in efficiency of COD removal. Especially, it was stated for digestion with HRT 144 h, when the COD removal decreased to values below 20%. The concentration of sum BTX practically has no impact on individual compounds removal.

The decrease of BTX concentration and COD removal after the psychropchilic digestion for the processes with HRT 72 h and 144 h are shown in Fig. 1 and 3, respectively.

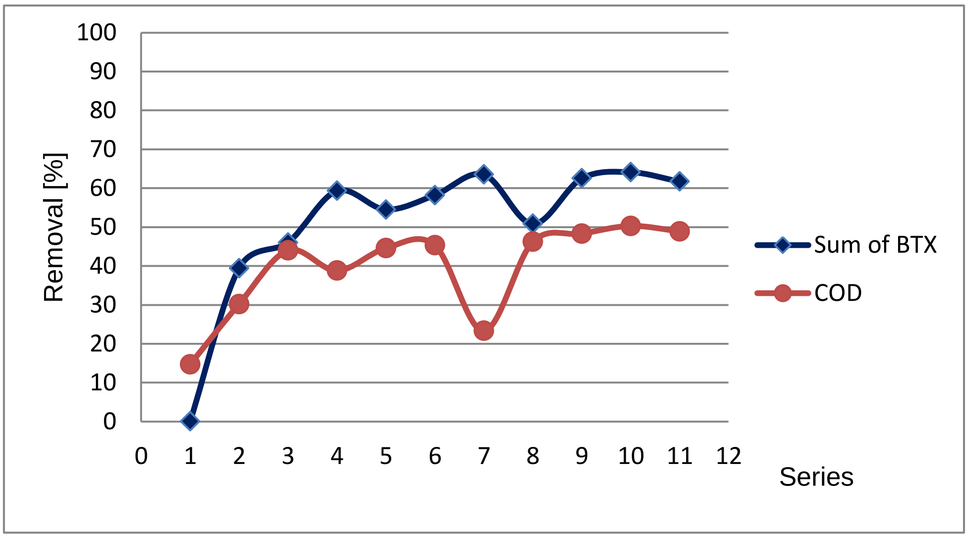

Fig 1. Removal of BTX (sum concentration) and COD after psychrophilic digestion with HRT 72 h

In the conditions applied, the removal of benzene, toluene, p- and o-xylene were achieved in a differentiated ranges. However, the greater removal of individual BTX were achieved in case of wastewater digestion in the reactor with a longer retention time (HRT 144 h). The average removal of BTX in psychrophilic digestion in the reactor with HRT 72 h was 63.4% for benzene, 64.2% for toluene, 50.7% for the p-xylene and 45.1% for o-xylene. Higher values have been obtained for the wastewater anaerobically treated in the reactor with HRT144 h, which amounted to 78.4% for benzene, toluene 77.4%, 61.7% for p-xylene and 56.9% for o-xylene. The decrease of individual BTX concentration after the psychropchilic digestion are shown in

Fig. 2 and 4 for HRT 72 h and 144 h respectively. The ranges and average values of benzene and toluene removal in the psychrophilic digestion with HRT 72 h and 144 h respectively are presented in Fig. 5. The similar results for p-xylene and o-xylene are shown in Fig. 6.

Higher degrees of removal were obtained for benzene and toluene and lower for xylenes. Such the relationship could result with a much lower concentration of solid particles (about 0.8 g/L SS) in the anaerobic wastewater treatment and the dominant process for BTX removal was biodegradation in comparison to sorption.

Sorption is important for the removal of BTX from wastewater during treatment process. The earlier own results of BTX removal in anoxic conditions of wastewater treatment have shown that the p-xylene was the highest sorbed on sludge particles (Mrowiec et al., 2012). Under the conditions, the highest removal efficience of BTX from wastewater was for p-xylene and the compound has had the highest degree of sorption on solids (sludge). Sorption process is directly related to the chemical structure of a hydrocarbon and depends on the individual BTX concentration in a mixture, however, does not represent a linear relationship (Zytner, 1994; Jean et al., 2002). Also, the process can be important for efficiency of biological wastewater treatment processes, both for the removal of aromatic hydrocarbons and other contaminants present in wastewater. For the anaerobic digestion, the sorption on sludge particles was not determined, due to the low concentration of biomass and implementation of treatment in a characteristic conditions for the wastewater digestion. Therefore, lower concentration of anaerobic suspended solids probably limited the xylenes removal from wastewater by sorption. The results of the BTX removal in the psychrophilic digestion are also different from the data presented in the literature. According to literature, the compound which is removed in the least range is benzene. The compound is considered as slow biodegradable in the absence of dissolved oxygen, whereas its aliphatic derivatives (toluene and xylenes) are regarded as relatively easily biodegradable under anaerobic conditions (Grbic-Galić and Vogel, 1987; Edwards et al., 1992).

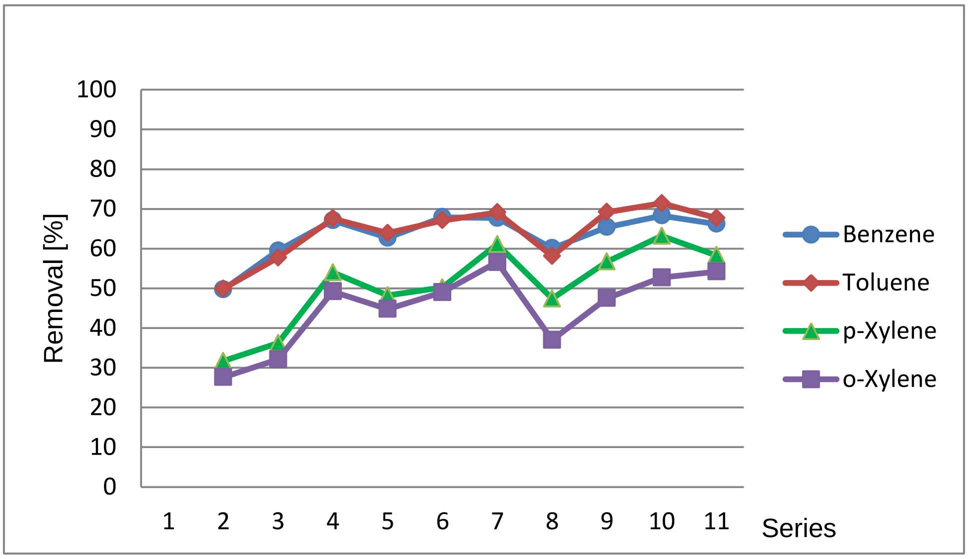

Fig 2. Removal of Benzene, Toluene and Xylenes after psychrophilic digestion with HRT 72 h

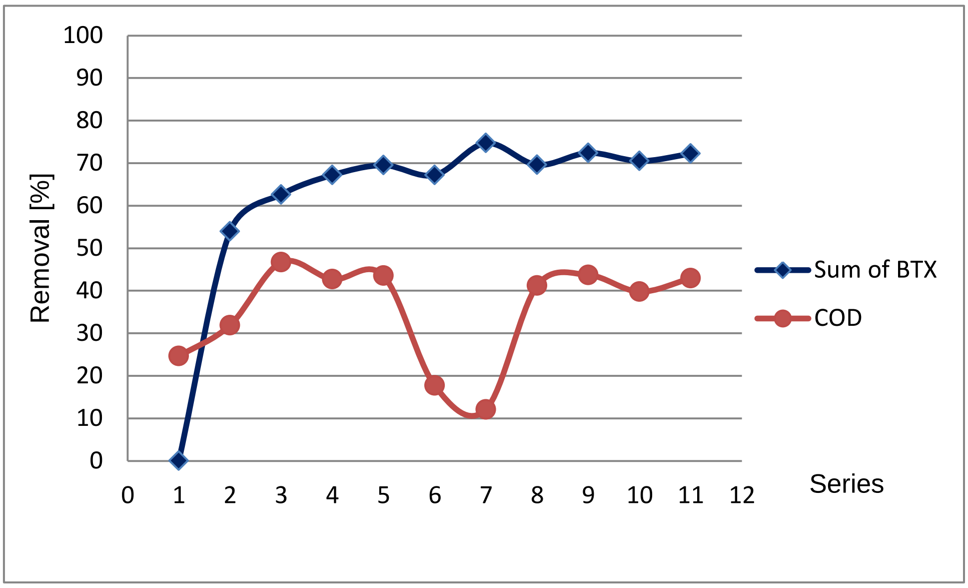

Fig 3. Removal of BTX (sum concentration) and COD after psychrophilic digestion with HRT 144 h

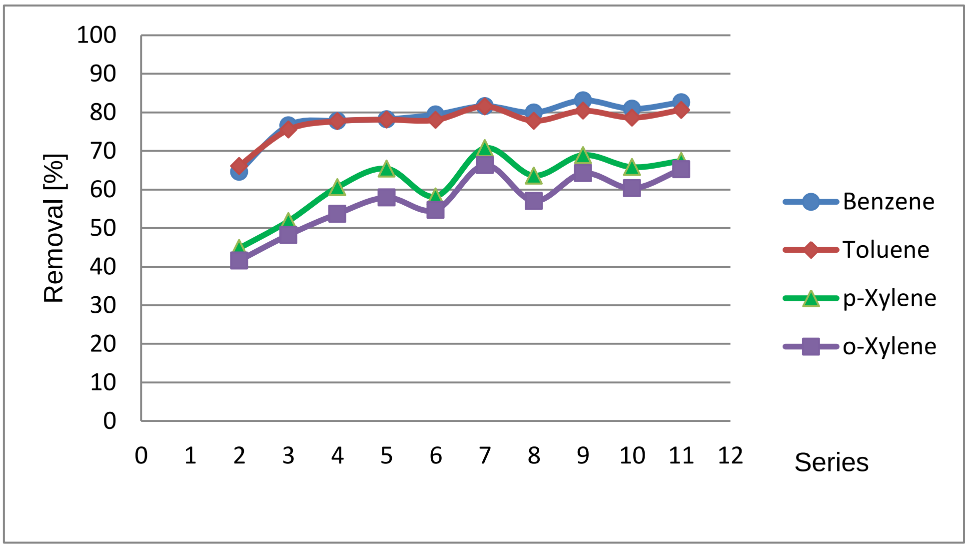

Fig 4. Removal of Benzene, Toluene and Xylenes after psychrophilic digestion with HRT 144 h

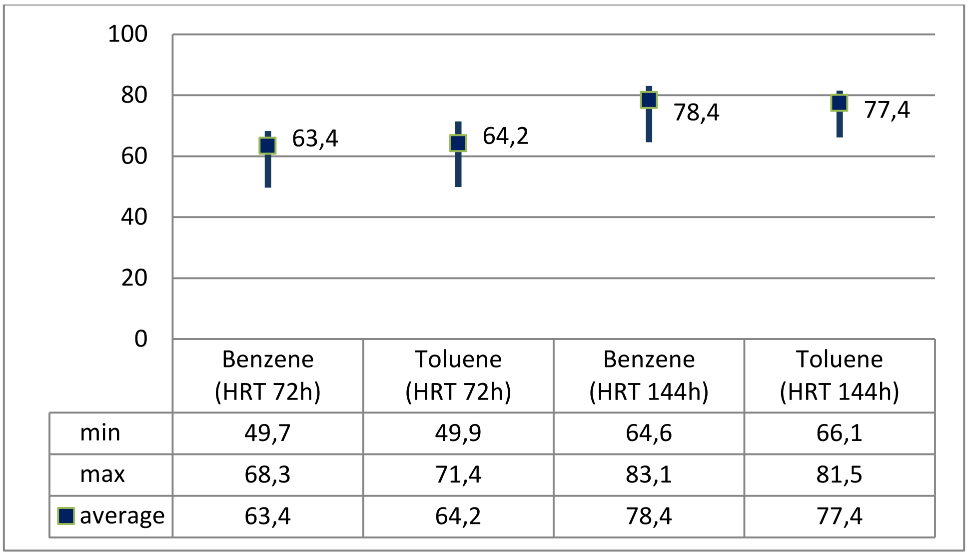

Fig. 5. The ranges and average values of benzene and toluene removal in the psychrophilic digestion with HRT 72 h and 144 h respectively

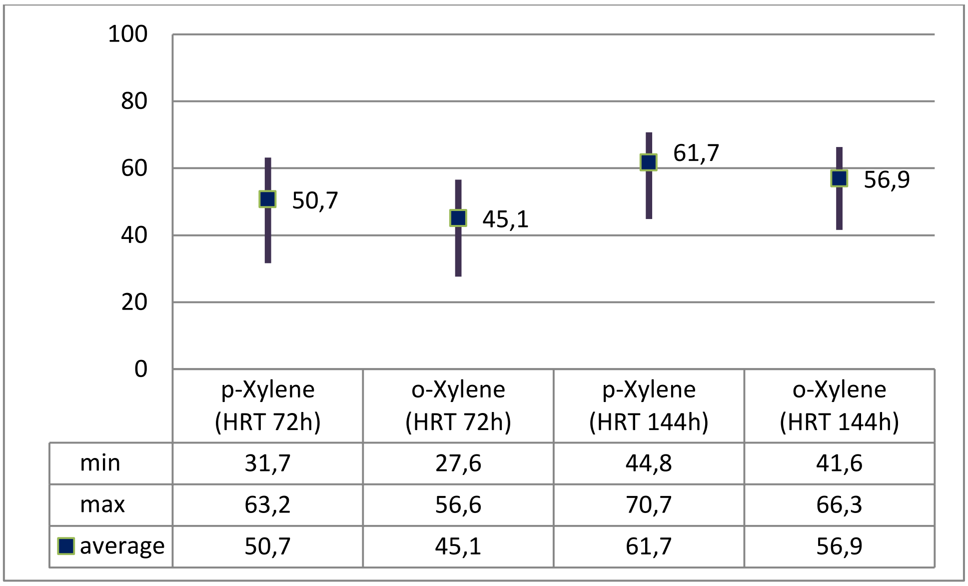

Fig. 6. The ranges and average values of p-xylene and o-xylene removal in the psychrophilic digestion with HRT 72 h and 144 h respectively

However, as demonstrated by Rene et al. (2007) and Jo et al. (2008), increased concentration of individual hydrocarbons in the treated wastewater stimulated the efficiency of BTX removal. In assessing individual substances on the efficiency of BTX removal has affected their individual toxic properties, the mechanism of decomposition and the concentrations of other hydrocarbons. Similarly to studies conducted in terms of anaerobic wastewater containing toluene by Enright et al. (2007). For the retention time of 24 h, the authors obtained the removal of toluene in the 55-99%. The results were comparable to those obtained in studies of this work. For toluene, as mentioned, the removal fluctuated between 49.9 to 71.4 and 66.1 to 81.5 % in the digestion with HRT 72 h and 144 h, respectively. The average removal values on the levels 64.2 % (HRT 72 h) and 77.4 % (HRT 144 h) obtained for toluene in the processes could be the results the presence of other hydrocarbons in the influent, especially benzene, which inhibited the efficiency of removal of other substances present in the mixture (Nunes-Halldorson et al., 2004; Rene et al., in 2007 and Jo et al., 2008).

2. Conclusions

The laboratory tests of psychropchilic digestion have showed enhanced BTX removal abilities under anaerobic wastewater treatment. Analysis of the removal of BTX in anaerobic conditions with low activated sludge concentration is an issue so far unprecedented in scientific reports, but important for the realization of biological wastewater treatment and limitations of BTX stripping to atmosphere. Biodegradation under anaerobic psychrophilic conditions can make a significant contribution to using the wastewater treatment processes as well as increase the overall efficiency of the BTX removal from wastewater. The results of this study indicated the feasibility of anaerobic conditions for the treatment of BTX contaminated wastewater.

Acknowledgements

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DAY 10 - 14:30		
Room 639 -Energy Efficiency 2		
Improve Energy Efficiency and Sustainability in a Retractable Plastic Factory	João Galvão[1]; Licínio Moreira[2]; João Ramos[1]; Sérgio Leitão[3]	[1]Leiria Polytechnic Institute & INESCCoimbra, Portugal; [2]Leiria Polytechnic Institute, Portugal; [3]UTAD - University of Trás-os-Montes and Alto Douro, Vila Real, Portugal
Refurbishment of barracks housing - Energetic, economic and ecological	Kathleen Schwabe[1]; Falk Schaudienst[1]; Manuela Walsdorf-Maul[1]	[1]TU Berlin
A preliminary assessment of energy performance in refurbished schools	Manuel Carlos Gameiro[1]; Carlos Henggeler Antunes[2]; Hermano Bernardo[2]; Humberto Jorge[2]; Luís Cruz[3]; Eduardo Barata[3]; Luísa Dias Pereira[1]; Mariana Coimbra[4]; Gonçalo Luis[4]; Luis Borges[4]; Luís Neves[5]; José Costa[1]	[1]University of Coimbra and ADAI – LAETA; [2]University of Coimbra and INESC Coimbra; [3]GEMF, University of Coimbra; [4]TDGI – Tecnologia e Gestão de Imóveis, S.A.; [5]Polytechnic Institute of Leiria and INESC Coimbra
Measuring energy efficiency in exports	Joao Liborio[1]	[1]European Commission

Improve Energy Efficiency and Sustainability in a Retractable Plastic Factory

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Abstract

This work aims to improve the energy efficiency in an industrial facility. The main objective of this research is to develop an energy model for a small plastic factory that may lead to further energy savings with environmental advantages (lower emissions of greenhouse gases). This may grant access to eco-sustainable certifications/awards as a factor of competitiveness, as well as economic benefits. The methodology followed to design the new energy model was developed from an energy audit to characterize the existing consumptions and use of energy. This first approach led to the division of the areas to improve lighting, compressed air systems and self electrical energy production.

Keywords: Energy Efficiency, Rational Use of Energy, Environmental Impact, Energy Audit in Industry, Electrical Production. Sustainability

JEL: Q41, Q42; Topic: Energy efficiency

1. Introduction

Energy efficiency can be defined as a set of actions that lead to the optimization of energy consumption needs, while maintaining the level of customer satisfaction. This involves a more rational use of energy and the adoption of best practices in various sectors: transport, industry, commerce, buildings (services and residential), and other municipalities [ECE, 2012]. Moreover, energy efficiency can involve the use of cleaner energy sources for the environment compared with other that many countries use intensively nowadays!

The main objective of this research is to raise standards of energy efficiency of a case study and to develop a methodology to apply the principles of the policy that regulates this issue which is transverse to different sectors: housing and industrial buildings and the activities within [Wilkinson et al., 2007], [Kenney, 1984], [Galvão et al. 2011]. It is also intended to be a model for other similar industries which conforms to the European legislation and to improve the environmentally sustainable energy practices. A significant part of this work (which has been proposed to the company management) is the production of electrical energy to supply the lighting part by means of a photovoltaic system, due to the amounts involved are relatively low, in relation to the total energy consumption involved in this industrial activity [Law 34, 2011], [Law 58, 1982]. On the other hand, the availability of radiation of the case study geography place has capacity of solar radiation, which makes viable, in medium term the investment on this system.

1.1 Energy Policies and Strategy

Another objective of this research is to facilitate the assimilation of the national programme which implements these requirements for greater energy efficiency (the 20/20/20 Plan) by the various economic and industrial players. This 20/20/20 Plan predicts a cut of 20% in GHG emissions for the EU by the year 2020, a share of 20% of energy from renewable sources and a 20% increase in energy efficiency [Wilde & Coley, 2012], [Wada, 2012].

To accomplish these goals, Portugal developed / created the programme ENE 2020 (National Strategy for Energy) which serves as a guide in implementing the European policy. To lead to the execution of these actions, the main headlines are the following:

- Being an agenda for competitiveness, growth and energy and financial independence; Investing in renewable energy, promoting energy efficiency, ensuring security of power supply;
- Sustainable Energy Strategy for the purpose of achieving some of the following goals:
    - Reduce foreign energy dependence to 74% in 2020, producing, on this date, from endogenous resources, equivalent to 31% of final energy;
    - Implement commitments taken by Portugal in the context of European policies to tackle climate change, allowing a final energy consumption decline of 20% in 2020;
    - Promote sustainable development by creating conditions for achieving the emissions reduction targets set by Portugal in the European context;

- Reduce the energy import balance by 25% by increasing endogenous sources use [ENE, 2010].

With this number of shares present and the emerging importance of this area is of high potential.

2. Developed Research Methodology

The energy audit plays a key role in defining and establishing the plan of action, which gives a deep knowledge of the facility analyzed, in order to detect, quantify, and try to correct the existing energy losses [Martinez, 2006]. The audit procedures depend on the scope thereof, as well as on the size and type of the audited facilities. In general, one can consider the following steps: Planning; Fieldwork; Data processing; Preparation of a Report.

Briefly, auditing a facility has the following objectives: to quantify the consumption and costs by type of energy; to examine how energy is used in the facility; to relate energy consumption to production, to establish the specific energy consumption as a relevant indicator; to determine the energy consumption by sector, process or equipment; to examine in detail how energy is used; to identify situations of waste of energy; to propose corrective measures and analyze the technical and economical viability of the proposed measures; to propose, if not existing, an organized energy management system.

2.1 Case Study

The TECTIL - Retractable Plastics factory produces and sells retractable and non retractable plastic films, leaf, open and closed sleeves and bags of several measures, mainly under direct order of the customer. This company has clients in many different industries and countries. It has customers in the beverage industry, soft drinks, coating, electrical equipment and retailers. It is located in an industrial area and occupies a covered space of 2800 m^2. The facilities consist of the production areas, storage facilities and administration offices. In the production several machines are used (several extruders, one co-extruder, cutting machines and the compressed air system). The production process is a continuous cycle, that is, the company starts operating on Monday morning and halts the production on Friday afternoon or Saturday, depending on the production needs.

2.2 Electrical Installation

The company owns a LV (low voltage) costumer substation that is fed by an aerial 30 kV feeder. The substation has a transformer of 630 kVA - 30/0.4 kV, which will supply the LV main switchboard located inside the production area. From this switchboard, the energy is distributed to other partial switchboards spread by the facilities. In the main switchboard differential and over current protection of each electrical circuit is guaranteed. These switchboards are one for each machine in production area, compressors and pumps and administrative area. In addition, the main switchboard includes the illumination of the industrial building and general use outlets (single and three phases).

Partial switchboards for each machine, (the six extruders, one co-extruder and three cutting machines), in addition to the electrical feeders and respective protection, contain all types of instrumentation and automation associated with each machine. The electrical switchboard installed in the administrative area allows control of lighting and outlets for general use, areas of administration, boardroom, accounting and other facilities.

The electrical switchboard feeds two compressors, a dryer (for compressed air), two air pumps for raw material suction and distribution to production machines, and single phase and three phase outlets for general use.

2.3 Energy Audit for Energy Consumption Characterization

The characterization and understanding of the energy in a variable energy consumer installation is based on energy audit. This consists of several aspects that will allow us to identify critical parts of this facility and that should be improved in order to achieve a higher level of performance. In this context, the energy facilities and activities associated with them were characterized according to the standard Energy Management Systems [EMS, 2011], [Galvão et al., 2012].

All energy consumption was analyzed and discriminated by energy source. Electricity is the sole form of used energy. Besides energy use, the extrusion machines present in the production area, the building structure and materials (walls, roof, warehouse and office) were also analyzed. The energy audit of all sectors and all forms of energy, and its pursuance requires knowledge of the electrical, mechanical and environmental areas of the building. Thus, energy audits provide specific information and identify the actual energy savings, consisting primarily of a critical examination of how energy is used based on the available records of energy consumption and costs.

An energy analysis was carried out, leading to the characterization of energy consumption in recent years. This consisted in the use of existing energy bills from the utility and the use of several energy analysers, as shown in Figure 1. Data recording campaigns were carried out during one week in December 2011 (cold period) and another week in May 2012 (almost warm period).

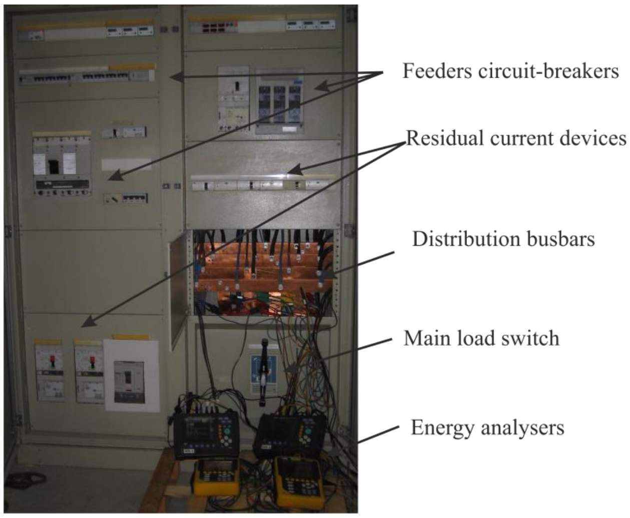

Figure 1 - Installation of the energy analysers on the main distribution switchboard.

Some important indicators are the relation between the production and the amount of energy used and its costs. These indicators were calculated and their variation is expressed in the graphs in Figure 2 a) and b).

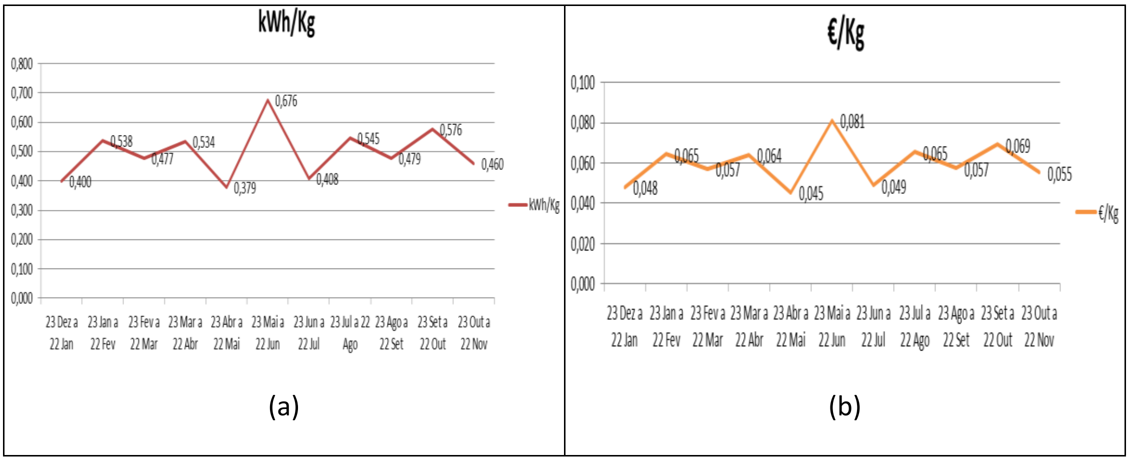

Figure 2 - a) Electricity use per kilogram produced in 2011; b) Cost of electricity per kilogram produced.

Figure 3 illustrates the electrical energy consumption of the process during two not consecutive weeks (representative sample of consumption).

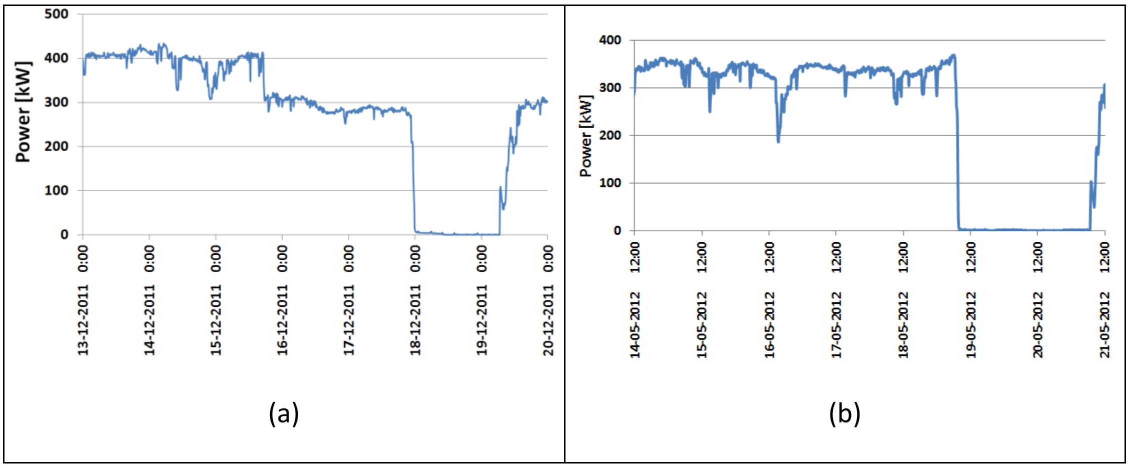

Figure 3 - Power demand of the facility: a) Cold season period; b) Warm season period.

The samples collected in the period of cold season (Figure 3.a) and the samples gathered in warm-season period (Figure 3.b) are intended to illustrate the correlation between the consumption during these two periods. One may conclude that these consumptions are dependent on the type of customer orders and the countries of origin and not specifically on the climate of the locality where they are being manufactured.

The data collected (by energy analyzers and energy bill analysis) was thoroughly analysed, leading to a remarkable information volume. Figure 4) shows the consumptions disaggregated by tariffs (peak; half-peak; normal off-peak and super off-peak hours). Figure 4 b) shows the disaggregation of the consumption of the industrial unit by usage. As shown, the largest individual consumer is the co-extruder, responsible for about 37% of electricity consumption. The remaining loads include the extruders, cutting machine and the power drained from general use electrical sockets in the production area.

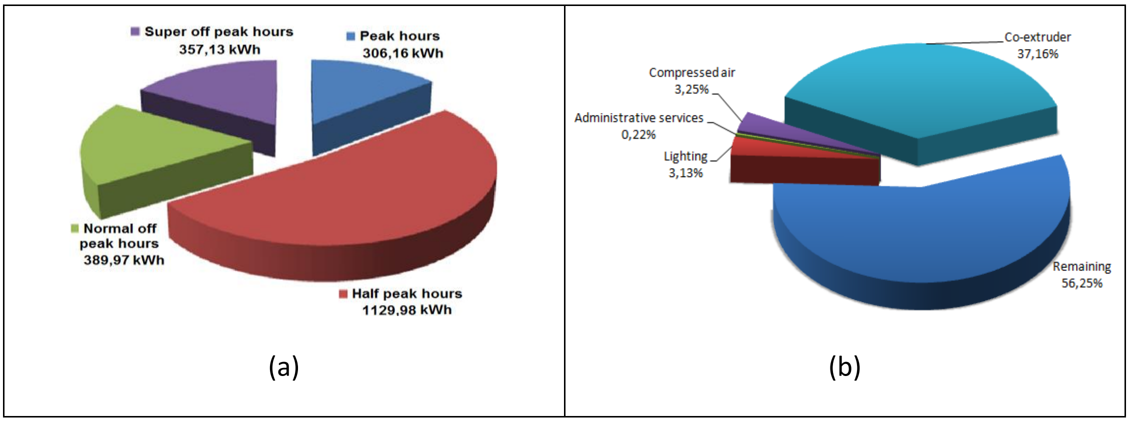

Figure 4 - Electric energy consumption disaggregation: a) By tariff and b) By use.

3. Actions to Improve Efficiency

Some measures were proposed in order to increase efficiency and reduce energy bills, particularly in terms of power factor correction (reactive power compensation), motion and presence detectors in the corridors and offices and energy consumption monitoring at a distance (web, phone) for a more effective control of consumption. Advantages, limitations, design and financial return for each proposed measure were studied. But the main focus of the analysis was centred on the lighting and compressors, because the potential savings were the highest. The feasibility of a 20 kW photovoltaic power plant was also analysed since the company provides optimal coverage for solar use.

At this stage of the research process for the improvement of the energy system, the proposed actions are easy to implement and the costs are consistent with the investment plan of the company's management, in a short / medium term.

3.1 Compressed air system

Compressed air systems are used in a majority of processes; therefore, it is important that they have an optimized efficiency. A cost cutback on these systems leads to an overall energy efficiency increase and to a boost in market competitiveness.

The compressed air production system on this facility comprises two rotating screw compressors with service pressure of 7.5 bar (22 and 11 kW), one air dryer (1.28 kW, 14 bar and 400 l/min) and a tank (1 m^3, 7.84 bar). Most of the time, one running compressor, absorbing approximately 12.5 kW, is enough to supply the compressed air demand. If the demand increases, the second compressor starts running, reaching an overall electricity demand of around 28 to 32 kW. The interruption of the system occurs during the weekend, when factory production stops. This working cycle is illustrated in Figure 5.

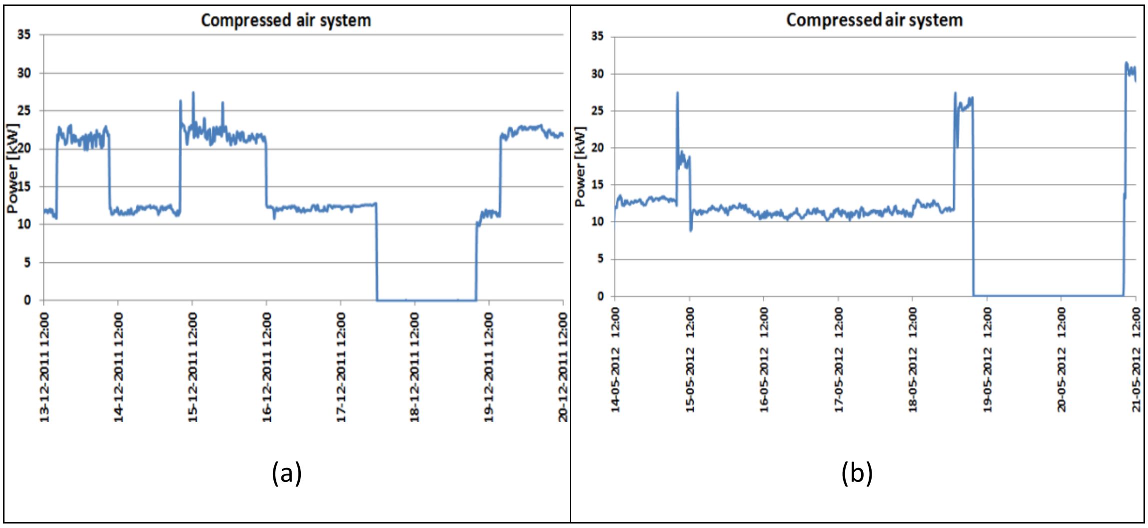

Figure 5 - Electricity demand of compressed air system during two different periods: a) Cold season; b) Warm season (six-month apart).

The differences in the electricity demand are related to the quantity of materials processed. The facility has several extruders and not all are working continuously. The production in December was higher, resulting in longer operating of the second air compressor.

As the compressed air system is a large consumer of electricity, some actions, presented in Table 1, were recommended to decrease energy consumption without compromising the process [Santos, 2012]. For this particular installation, the most viable measure is the leak detection and elimination and the use of variable speed drives (VSD) for the compressors.

Table 1 - Recommended actions for air compressed system.

Action	**Aplicability**	**Annual savings**	**Contribution potential**
Increased motor efficiency	25 %	2 %	0,5 %
Use of variable speed drives	25 %	15 %	3,8 %
Compressor substitution	30 %	7 %	2,1 %
Optimize control system	20 %	12 %	2,4 %
Heat recovery	20 %	20 %	4,0 %
Upgraded performance in intake cooling, drying and filtering	10 %	5 %	0,5 %
Tubing and other components design	50 %	9 %	4,5 %
Decrease in losses caused by pressure drop	50 %	3 %	1,5 %
End use devices optimization	5 %	40 %	2,0 %
Maintenance - leak reduction	80 %	20 %	16 %
Maintenance - filter substitution	40 %	2 %	0,8 %
TOTAL			**32,9 %**

3.2 Production area lighting

The production area has around 2800 m^2 and the primary lighting is provided by 250 W high intensity discharge lamps (high pressure mercury). The lamps are manually controlled. The lights are on during the production period (day and night, except for most of the weekend). Figure 6 depicts the power consumption of the lighting for the production area. The average power is around 8 kW for the full week and 9.8 kW for working hours.

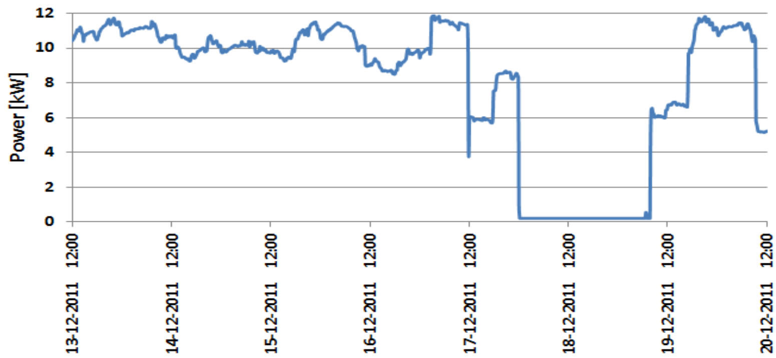

Figure 6 - Power consumption by the production area lighting.

Using a digital luximeter, several lighting level measures were recorded. Some working places presented a lighting level lower than the recommended by the European Norm 12464-1 [EN, 2002]. To achieve an effective reduction of illumination consumption and also on a perspective sustainable and environmentally friendly the interaction of several points should be taken into account: Using the sun as an energy source; Full autonomy over the conventional electricity grid; Complementarity with the electrical system integrated management; The effective use of photometry to illuminate correctly; The use of versatile systems suited to local conditions; Ensuring that energy is used only when it is really necessary, for example by the use of motion detectors; Ensuring that only the exact amount of energy is used for each requirement, for instance by continuously controlling illumination; Minimizing undesirable extraneous factors which affect the energy balance, for example, employing the control shutter windows [ABB, 2012].

During the day (even with bright sky light), approximately 60% of the area requires artificial lighting, since only the administrative area and part of the extruders have sufficient natural lighting. So, one of the proposed measures was to increase natural lighting by replacing some opaque roof panels by translucent roof panels. The estimated area for roof panel substitution was 42m^2. Considering a cost of around 45€/m^2 (including installation cost) the investment estimated is of 1890€. Several artificial lighting reduction scenarios were analyzed, being the most realistic the reduction of 50% of electricity consumption to lit the referred area during daytime (from 9 a.m. to 5 p.m. during winter and from 8 a.m. to 8 p.m. during daylight saving time).

Besides the energy savings, natural light shall improve the lighting quality of some workplaces that have insufficient illumination levels. The estimated savings for this scenario are of 950€/year, which leads to a simple payback time of approximately two years. The installation of a time switch to control the lighting in the industrial building would also be a solution for ensuring energy saving, leaving it less dependable on user behaviour.

3.3 Alternative energy source

It was decided to propose the implementation of a photovoltaic solar plant, for the lighting of the company, as well as to illuminate the production area of the cutting machine more effectively and to control the consumption of the compressors. This choice depended on the fact that these measures do not imply an interruption in production during the intervention.

For the conception of the small photovoltaic system, the needs of the company and the national legislation have been taken into consideration. The photovoltaic system is projected to sell the produced energy to the utility under a sponsored rate of 0.200 €/kWh (value for 2013) during the first 15 years. In the case of a technical/legislative impossibility to sell the energy, the energy produced could be consumed by the company, suppressing the energy needs of the manufacturing area lighting and the administrative area. A system with more than 20 kW would imply the need to auction the energy sell rate, implying a lower rate.

To determine the best location for the panels, a *Solar Pathfinder*™ was used [SP, 2012], [Bellosio, 2011]. The chosen placement was the roof directed south, as no shading was registered. To evaluate energy and projection of the installation the software Sunny Design was used since it is reliable and has a comprehensive database. The study uses Sunpower SPR-327NE-WHT-D photovoltaic panels, which have a rated power of 327 Wp, an efficiency of 20.05%, comprising the installation of 63 panels for a total of 20.60 kWp. For interconnection of the central to the utility grid inverters must be used, in this case are two inverters with a rated power of 10 kW and maximum efficiency of 98.1%. The investment should be of about 45 000 € and, considering a discount rate of 5%, the net present value (NPV) of the project during 15 years is estimated in 20 510 €. The estimated internal rate of revenue (IRR) is of 11.15%. Figure 7 summarizes the NPV analysis of the photovoltaic installation, considering that the energy produced will be sold to the company that manages the national electrical grid. Assuming a discount rate equal to 8%, the NPV is of 9 022 € for the same period.

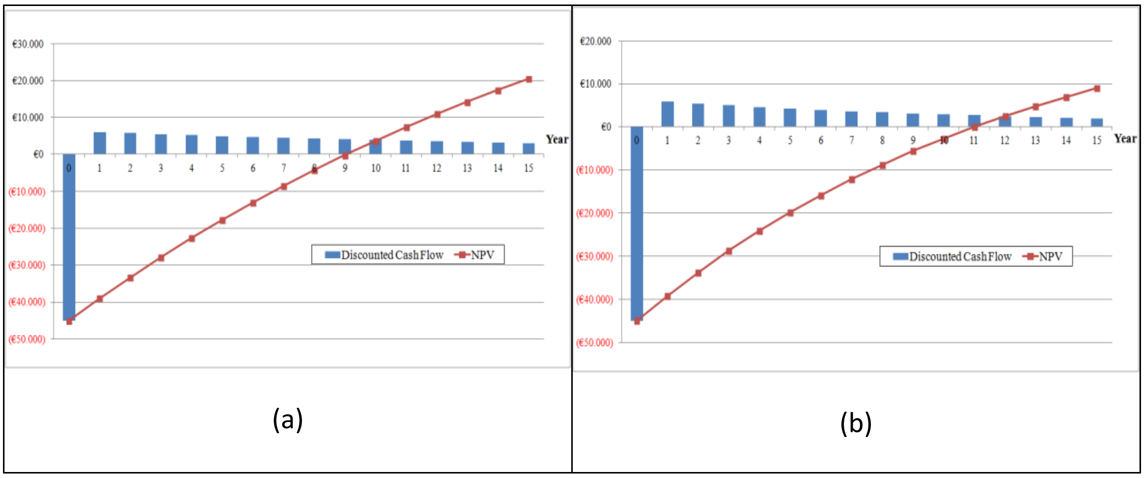

Figure 7 - Net Present Value analysis for the implementation of a 20 kW photovoltaic system with different discount rates: (a) 5% and (b) 8%.

Since the NPV is positive and the IRR assumes an interesting figure, both at 5% and 8% discount rates, the project should be seriously considered by decision makers (company owners) [Baker, 2010].

Another set of actions that lead to greater energy efficiency are interventions at the level of power factor correction, the installation of a reactive power compensation system and motion and presence detectors. The study of the advantages, limitations, design constrains and financial return of these systems was carried out. The replacement of electric motors, in particular the high-performance motors associated with control by VSDs, was considered. It was intended to be a replacement of conventional equipment by state-of-the-art production and drivers' control. Nevertheless, a more meticulous analysis was not conducted due to the major investments involved and to the need to halt the manufacturing for a considerable period for technological adjustments.

Finally, the monitoring process of energy consumption online or by phone (at distance) are actions to be taken into account for a better control of all consumptions. The isolation of the exterior walls of the offices with new types of materials is inexpensive and relevant and would lead to a reduction in the consumption of heating and cooling of indoor air [Drasnar, 2011].

4. Conclusion

The implemented methodology in the characterization of energy variables in the present case study (energy audit) is essential to achieve a more profound knowledge of the energy consumed in this factory. After completion of the audit, the most relevant findings relate to energy efficiency improvement with moderate investment, by acting on the roof, ensuring a greater use of natural light, and also installing a small photovoltaic system.

Field work resulting from the collection with data analyzers was essential for the detection of energy problems and for the proposal of a reformulation of the parameters of the power contract with the electric utility. It was found that the electrical installation was well projected and executed, as there was no phase overloaded and that each phase is approximately 1/3 of the maximum load. With the measures presented here a reduction in power consumption and energy costs is expected, without compromising the company proper functioning. The use of translucent roof panels will allow the use of natural lighting and improve lighting quality in the storage area and cutting machines.

The permanent mutation of primary energy price, mainly fossil fuels, affects the costs of electricity production, aggravating the financial condition of the industries in which energy is an important production factor. So energy efficiency is of most relevance as a way of boosting the level of competitiveness of the industry. In the end, it is intended for these actions to increase energy efficiency as a powerful way of achieving the sustainability goals defined by the National, European and World energy policy makers.

Acknowledgement

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Refurbishment of barracks housing – Energetic, economic and ecological

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Abstract

The European Union has set a target to reduce carbon dioxide emissions by 2020. It is not enough to change to low CO_2 emitting energy sources, to increase the efficiency of energy conversion and to accelerate the expansion of renewable sources, but it also needs to increase the energy efficiency in the utilization. One possibility is to save energy in the building sector. This provides the directive 2010/31/EU on the energy performance of buildings. However the efficiency and sustainability of structural measures in the building sector can be questioned, because the consumption of resources leads to CO2 emission. This publication demonstrates the economy and sustainability by an exemplary envelope refurbishment of an existing building. Within the lifetime of the renovated envelopes the efficiency is achievable without using supports and subsidies.

By taken into account of the primary energy input of the refurbishment, the total energy demand of the building can be reduced.

1. Introduction

This paper deals with the modeling of a barracks housing from the 1930s that served to accommodate the soldiers. Figure 1 shows the exemplary building type that exists very often in Germany and nowadays often it is used as an office building. This edifice has three floors. In the central area subsists a building protrusion and a lower fourth floor.

Figure 1: Barracks housing – Existing Building

This exemplary barracks housing has a length of 80.72 m, a wide of 23.36 m and a high of 12.16 m respectively 14.16 m. The main building fronts have an orientation to the east and to the west. For this exemplary edifice the façade modernization will be investigated, especially with a view to the energetic refurbishment, the economic aspects and the environmental expenses and effects. In this case the simulation of the exemplary building will be instationary.

After explaining the modeling and the climate boundary conditions for the simulation, the different modernization variants of the external wall structures will be presented. It follows an evaluation of the simulation results that contains the energy demand respectively the potential for energy saving, the operating and investment costs and the environmental expenses and effects. The final energy demand will be calculated with the program WUFI Plus [1] and the costs and the environmental expenses and effects will be determined with the program LEGEP [2]. Finally follows a conclusion of the calculation results.

2. Investigations

a. Modeling

To analyze the refurbishment of the barracks housing, a model of the edifice to determine the final energy demand based on instationary climate boundary conditions was developed. The software that was used for the simulation is WUFI (Heat and humidity instationary) Plus [1] of the Fraunhofer Institut für Bauphysik. The coupled heat and moisture flow through the different components of the building can be calculated with this program. Furthermore the exchange of the inner and outside air and also the heating and humidity loads are taken into account. As a result the final energy demand of the building can be determined.

b. Climate boundary conditions

For this model the reference data of the German Meteorological Service for the city of Berlin was selected as climate boundary conditions. The hourly climate data records include data amongst others for the temperature, the humidity and the solar insolation. Figure 2 shows the climate boundary conditions especially the running of the temperature and the relative air humidity over the year.

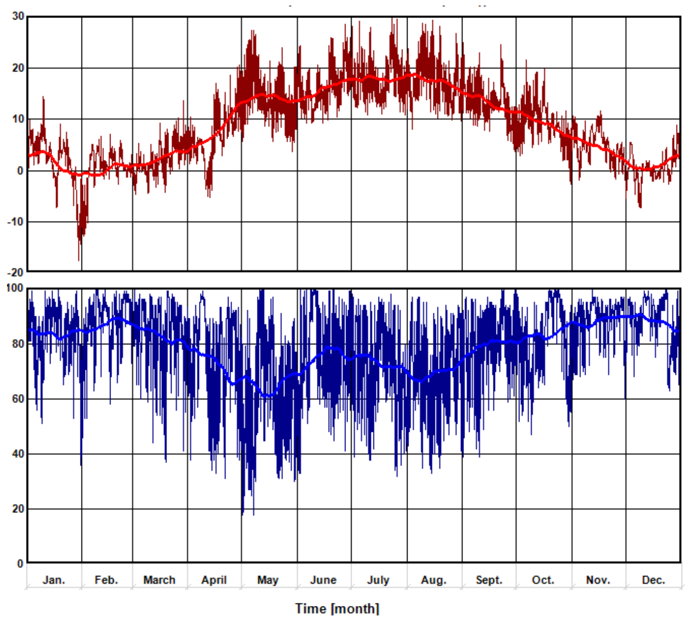


Figure 2: Temperature and air humidity running over the year for the city of Berlin [1]

Further it can assumed that the exemplary building is used as an office building. So it has to be conditioned from 7 a.m. to 6 p.m. The room temperature should reach 21°C using district heating.

3. Existing Building and possibilities of modernization

The outer wall of the existing building consists 40 cm of solid brick, an outer mineral plaster and an inner lime plaster. This construction is shown in Figure 3.

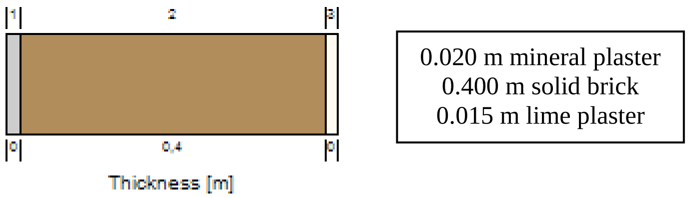


Figure 3: Construction of the outer wall – Existing building (from outside to inside)

Table 1 summarizes the heat transfer coefficients (U-values) of the existing building components.

Table 1: U-values of the existing building

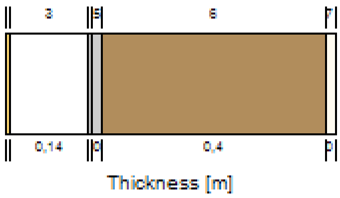
Component	**U-value**
Outer wall	1.46 W/(m²K)
Window	1.30 W/(m²K)
Outer door	1.80 W/(m²K)
Basement ceiling	2.40 W/(m²K)
Top floor ceiling	0.49 W/(m²K)

To modernize this barracks housing an energetic retrofitting of the outer walls of the building is considered. This refurbishment has the goal to reduce the energy demand of the building and to be economic and ecological. The German Ordinance on Energy Saving, based on the European Directive 2002/91/EG, requires an U-value of 0.24 W/(m²K) for the modernization of the outer wall. [3]

c. Variants of modernization

<u>Thermal insulation composite system</u>

The refurbishment of buildings with a thermal insulation composite system is very widespread. The construction of the variant 1 of modernization is shown in Figure 4.

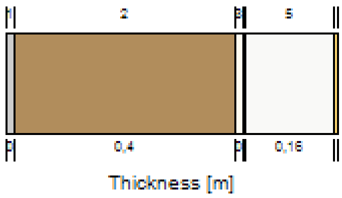


0,008 m mineral plaster
0,140 m polystyrene, expanded
0,020 m mineral plaster
0,400 m solid brick
0,015 m lime plaster

Figure 4: Variant 1 of modernization – Thermal insulation composite system (from outside to inside)

Internal insulation

The modernization of existing buildings or rather historical façades with an internal insulation is very important. However, it demands a high professional knowledge in building physics, especially in humidity aspects, and a high quality execution. This wall construction is shown in Figure 5.

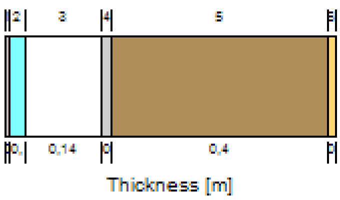


0,020 m mineral plaster
0,400 m solid brick
0,015 m lime plaster
0,160 m calcium silicate internal insulation
0,008 m mineral plaster

Figure 5: Variant 2 of modernization – Internal insulation (from outside to inside)

Curtain wall

The construction of a curtain wall is used as a weather protection of the façade. There exists an air layer between the insulation shell and the outer shell. This is used for the transportation of the resulting humidity out of the construction. Figure 6 shows the construction.



0,008 m fiber cement board
0,030 m air layer
0,140 m mineral insulation
0,020 m mineral plaster
0,400 m solid brick
0,015 m lime plaster

Figure 6: Variant 3 of modernization – Curtain wall (from outside to inside)

Table 2 shows the U-values of the different constructions of the outer wall.

Table 2: U-values of the different wall constructions

Construction	U-Value in W/(m²K)
Existing wall	1.46
Thermal insulation composite system	0.24
Internal insulation	0.22
Curtain wall	0.23

The different variants of modernization are selected in a way that the U-values can be upgraded in a similar level to reach a comparable energetic standard.

4. Evaluation of the results

a. Energy savings

The simulation of the barracks housing with the program WUFI issued the results of the final energy demand. This demand only includes the energy consumption for conditioning the building and no auxiliary-energy. The final energy demand and the energy saving potential for the different variants of modernization are shown in Figure 7.

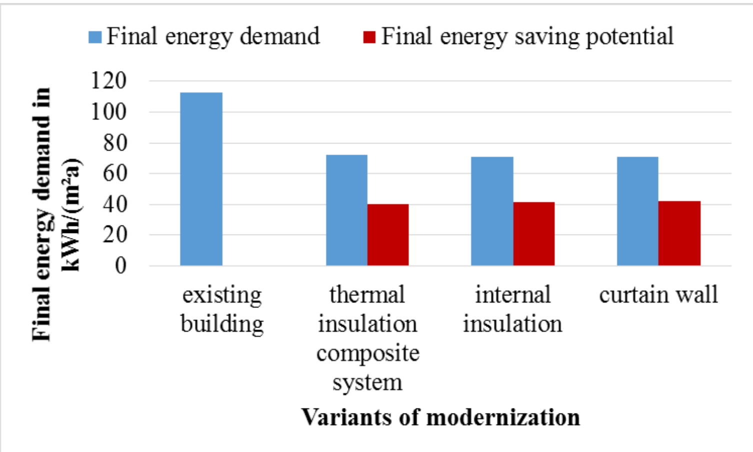


Figure 7: Final energy demand and final energy saving potential in kWh/(m²a)

Due to the fast that the energetic standard of the different modernization variants are similar the potential for saving energy is nearly the same. On average they can reach an energy saving potential about 36 to 37%.

b. Operating costs

Based on the final energy demand the operating costs for the different variants of modernization can be calculated. For this a price of 0.09 Euro per kWh district heating will be adopted. The operating costs for the different variants are shown in Figure 8. As expected the operating costs sink according to the energy saving from originally 40,000.00 Euro down to 15,044.00 Euro.

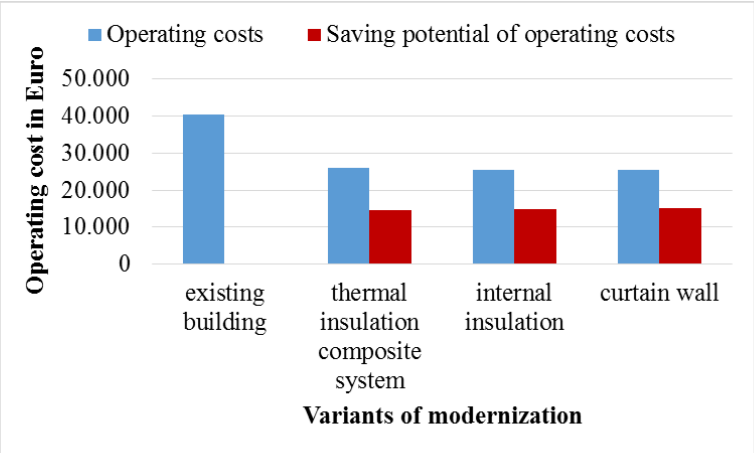


Figure 8: Operating costs and saving potential in Euro

c. Investment costs

The investment costs for the different variant of modernization are shown in Figure 9.

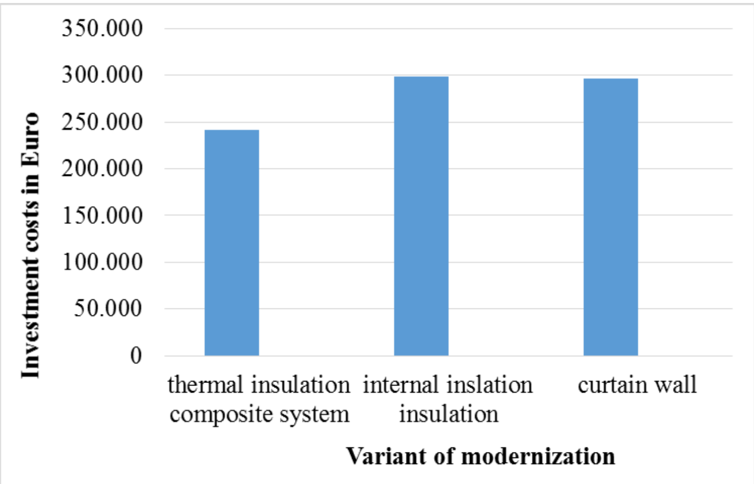


Figure 9: Investment costs in Euro

The lowest investment costs are reached by using a thermal insulation composite system and the most expensive variant is the installation of an internal insulation with calcium silicate. The amortization by using a thermal insulation composite system is about 22 years and by using the other possibilities of modernization the period of amortization is about 25 years. The period of amortization is calculated dynamically, that is under consideration the follow-up costs and the interest rates. The considered life-cycle is 50 years.

The end of life of the different variants of modernization is earliest reached after 40 years.

d. Environmental expenses and effects for the different constructions

Table 3 shows the environmental expenses and effects for the different modernization variants for a life-cycle of 50 years. The results are given per square meter outer wall.

Table 3: Environmental expenses and effects for the different variants of modernization

Variant of modernization	**Primary energy input renewable**	**Primary energy input non-renewable**	**Global warming potential**	**Acidification potential**	**Eutrophi-cation potential**
	kWh/(m²a)	kWh/(m²a)	kg CO2 Eq./(m²a)	g SO2 Eq./(m²a)	g PO4 Eq./(m²a)
Thermal insulation composite system	13,33	512,66	23,18	97,81	6,33
Internal insulation	13,78	109,13	8,66	21,50	2,00
Curtain wall	30,84	144,03	12,63	47,39	4,00

It is recognizable that with the exception of the primary energy input renewable the highest expenses and effects are shown for the variant 1 – the thermal insulation composite system. It can be justified therefor that the thermal insulation composite system must be replaced after 40 years. The other possibilities will survive a life-cycle of 50 years. The variant of the internal insulation with calcium silicate has the best ecological results, followed by the curtain wall.

e. Environmental expenses and effects: Construction and operation

As a summary the total environmental expenses and effects per square meter base area for the different variants –operation and modernization including servicing and maintenance– are shown in Figure 10 to Figure 13.

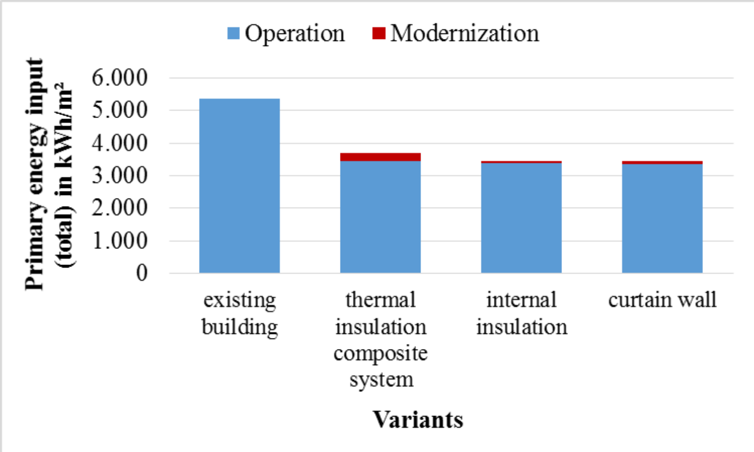


Figure 10: Primary energy input (total) in kWh/m²

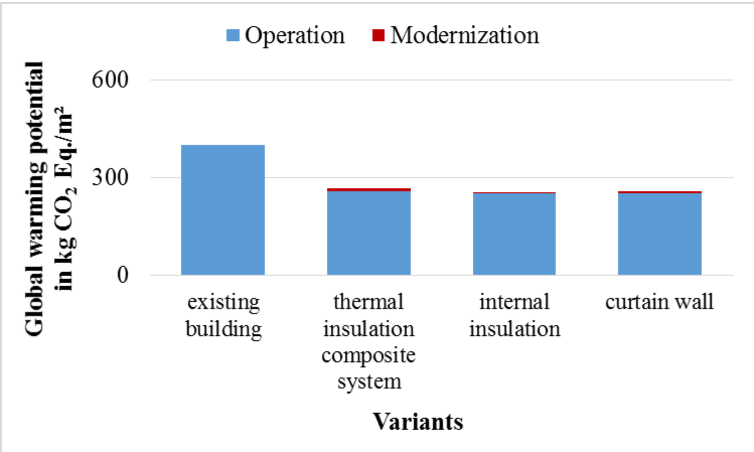


Figure 11: Global warming potential in kg CO_2 Eq./m²

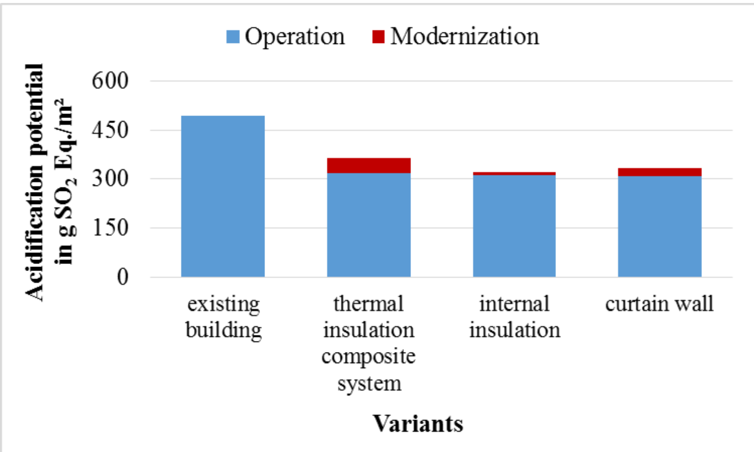


Figure 12: Acidification potential in g SO_2 Eq./m²

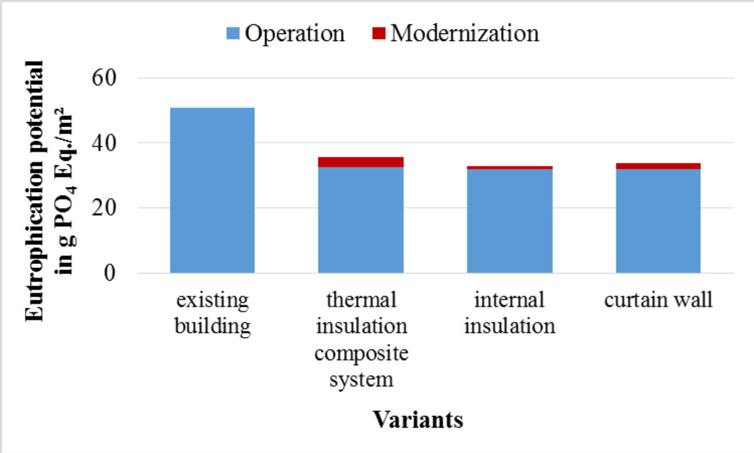


Figure 13: Eutrophication potential in g PO_4 Eq./m²

For all environmental expenses and effects it can be recognized that the modernization does not go into effect, so one can say the results of the operation period are dominant. It is to be noted that the thermal insulation composite system has the most influence to environmental expenses and effects but it is to neglect compared to the operation period. From an environmental point of view it is worthwhile to modernize the outer wall construction, so it is possible to save energy. The energy demand is the largest consumer of environmental expenses and effects. The environmental expenses and effects can be reduced up to 35% compared to the existing building. These results are similar to the energy savings.

5. Conclusion

Summarized it is worthwhile in the energetic, economic and ecological point of view to modernize the outer wall construction. The final energy demand can be reduced up to 36 to 37%. That is a reduced primary energy demand down to 50 kWh/(m²a) by using district heating. The investment costs amount to 241,354.51 Euro for the thermal insulation composite system and 298,282.41 Euro for the internal insulation as most expensive variant. The average of the savings of the operation costs is about 15,000 Euro. This investment costs amortize after 22 to 25 years.

For the environmental expenses and effects it is useful to modernize the outer walls. It is possible to reduce the environmental parameters up to 35%. For the modernization the expenses and effects does not come into effect in comparison to the operation method, so all modernization variants are ecological.

Acknowledgments

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A preliminary assessment of energy performance in refurbished schools

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Abstract

A major rehabilitation and refurbishment program of secondary school buildings has been carried out in the last few years in Portugal, led by the state-owned company *Parque Escolar E.P.E.* (*PE*). This paper reports the research being carried out in the framework of an *R&D* project aimed at comprehensively assessing these interventions in terms of the overall energy efficiency of those buildings and their equipment with the scope of optimizing the energy consumption and the indoor environmental quality in their exploitation phase. A database has been used to characterize the changes in energy consumption in the school buildings between the pre and post-intervention phases. Based on this characterization and a set of criteria, a group of eight representative schools has been chosen in which a more detailed study of energy consumption and operation conditions will be carried out in the next project stages. This research lays out the foundations for setting detailed improvement action plans regarding the end-use of energy and equipment in refurbished schools.

Keywords: School buildings, Energy use indicators, Maintenance indicators; Energy benchmarking.

***JEL classification codes*:** Q4 - Energy; Q5 - Environmental economics.

1. Introduction

This paper is focused on energy consumption issues in the school buildings refurbished under the *Modernization of Public Secondary Schools Program*, launched by the Portuguese government in January 2007 (OECD, 2012). This ambitious program is aimed at tackling the physical deterioration of the building stock, addressing environmental comfort, sanitary standards and the functional adequacy of the buildings for teaching and learning, often with extension of the existing built area. It also aims at opening up the schools to the local communities, and includes long-term maintenance of the buildings after modernization.

A state-owned company, *Parque Escolar E.P.E.* (PE), was specially created (by Decree-Law n. 41/2007) for planning, management, development and implementation of this program. By that time, the Portuguese network of public secondary schools included 477 schools, predominantly built since 1968 (PE, 2009a). With the endeavour of raising the standards of educational facilities, *PE* had envisaged the intervention in 332 schools by 2015 (i.e., 70% of the total building stock of secondary schools in the country). By the end of 2009 the program involved 205 schools, and 4 consecutive phases: the pilot phase (Phase 0) involved only 4 schools; Phase 1 started in June 2007 and covered 26 additional schools; Phase 2 was initiated in March 2008 encompassing further 75 schools, and interventions had started in June 2009; finally, Phase 3 was initiated in April 2009 and is supposed to cover 100 other schools (PE, 2009b).

The large scale of this program and the multiple typology of spaces of its operational interventions have been subject to various criticisms, namely concerning: labs were determined to have permanent, versatile and continued use (combining exhibition and laboratory practices, with guaranteed security conditions); it was PE's choice that the sport venues were covered (but not enclosed) and workshop spaces should ensure versatility, flexibility and functional adaption (PE, 2010). Beyond the ambition of the considerable scale at stake, this program is also characterized by the diversity of educational provision of the schools and by their geographic dispersion on the Portuguese continental territory. The *Modernization of Public Secondary Schools Program* also intended to integrate and implement a whole new set of legislation relating accessibility, environmental comfort, safety, etc. The main difficulties early anticipated were the short period for completion and the need of performing the interventions keeping the schools in operation.

This initiative was launched in circumstances of strong public investment and was part of an economic stimulus strategy aimed at boosting economic growth throughout the country. Nowadays, the context has dramatically changed, and the situation of economic crisis and severe financial constraints, both for institutions (public and private) and families, might be invoked to reinforce the value of carefully analyzing the possibilities to reduce the maintenance and operating costs of these refurbished school buildings and their equipment.

An assessment of the *Modernization of Public Secondary Schools Program* focused on energy consumption issues is underway in the framework of a research and development (R&D) project involving a partnership between University of Coimbra's R&D Units (ADAI, INESC-C and

GEMF) and TDGI (a facility management company specialized in global management of buildings, technical and industrial facilities). This paper reports the work being carried out in the few initial months of this project as well as the main R&D future developments.

In section 2, an initial analysis of the refurbished school buildings' energy consumption (electricity, in a first phase) is introduced. Firstly, a database provided by PE is used for characterizing the changes in electrical energy consumption in the school buildings between pre and post-refurbishment phases. Secondly, based on this characterization and according to a set of criteria, which are related to geographic location and the climatic zones of mainland Portugal, a group of eight representative schools was selected, where a more detailed study of energy consumption and operational conditions will be carried out in the next phase. In section 3 an assessment framework is proposed for the analysis of the overall energy performance of these buildings and their equipment, aimed at the definition of improvement action plans. Thus, after the definition of the relevant energy efficiency and maintenance indicators, methodological options will be made to generate a composite indicator of the schools' overall energy performance. This section proceeds with an empirical assessment of the performance achieved in the maintenance and operation of these schools' buildings and equipment. Finally, in section 4, a summary of the main conclusions drawn from this preliminary phase of the project is presented.

2. The refurbished schools: characterizing changes in energy consumption

Starting from a database of the schools that were, or are expected to be in the near future, subject to refurbishment interventions under the *Modernization of Public Secondary Schools Program*, a pre-selection of 57 schools was done towards a final selection of 8 school buildings. The methodology was divided into three main stages – data collection, data analysis and development of energy use indicators.

Stage 1. The process was initiated by establishing a single Climatic Map of Portugal, combining the different climatic zones (winter and summer), propped on *Regulamento das Características de Comportamento Térmico de Edifícios* (RCCTE, 2006), as presented in Figure 1.

Besides the geographical distribution on the territory, the main criterion for the selection was the development phase of the refurbishment interventions. The buildings that no longer had refurbishment works in 2011 have been considered as "completed/concluded". As the aim of the project is the optimization of the energy consumption in the exploitation phase of refurbished school buildings, it is important to focus on buildings where the retrofit intervention is already finished and records of pre and post-intervention energy demand are available.

Stage 2. Having verified the absence of refurbished schools in some municipalities and their corresponding climatic zones, some other schools – with interesting properties for the characterization appraisal – were selected, although having been completed just in 2012. This contributed to increase the geographical diversity and representativeness of the sample. At the end of this stage, 57 schools were pre-selected for further analysis.

Stage 3. In order to support the selection of the final group of 8 schools to be analyzed in the next phase, a number of energy use indicators were calculated. These indicators enable the examination of energy consumption of very different buildings, in terms of typology, size or the number of students (Desideri & Proietti, 2002).

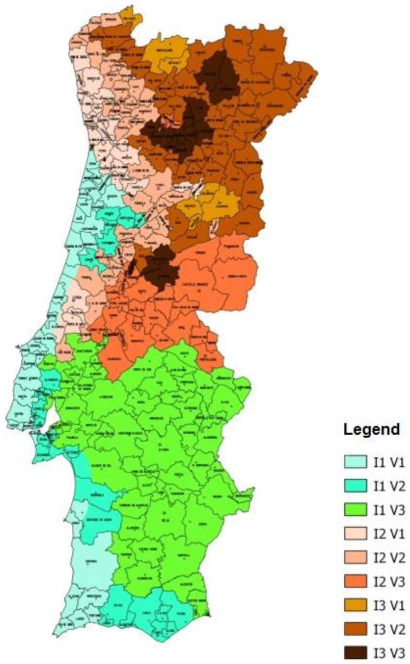

Figure 1 – Map of Portugal with climatic zones for the heating and cooling seasons.

Table 1 lists some of the key energy use indicators calculated. These computations were performed on an annual basis for each one of the 57 school buildings included in the preliminary sample.

Table 1 – Energy use indicators

Indicator	**Acronym** [units]	**Definition**
Specific Energy Consumption of Electricity	$\mathbf{SEC_{GFA}}$ [kWh/m^2]	Ratio between the annual Energy Consumption of electricity and the total Gross Floor Area (GFA) of the building.
Specific Energy Consumption of Electricity per student	$\mathbf{SEC_{S}}$ [kWh/student]	Ratio between the annual Energy Consumption of electricity and the number of enrolled students.
Variation of Specific Energy Consumption of Electricity	$\mathbf{\Delta SEC_{GFA}}$ [kWh/m^2]	Variation of annual Specific Energy Consumption of electricity with the refurbishment (after *vs.* before

		intervention)
Proportional change of Specific Energy Consumption of Electricity and Gross Floor Area	**ΔSEC_{GFA} / ΔGFA**	Ratio between the pre- to post-refurbishment variations of SEC and of GFA.

The 2008 consumption levels provide the baseline before intervention whereas 2011 values are post-intervention. An increasing trend may be recognized regarding specific energy consumption of electric energy with respect to total Gross Floor Area (GFA) from before to after the interventions. Also, a general trend is clear concerning the increase of GFA of the school buildings with the refurbishment process. Finally, the evolution of the annual Specific Energy Consumption of Electricity in association with GFA [kWh/m^2] variation from 2008 to 2011 allows an interesting preliminary illustration of the potential significance of our approach (Figure 2).

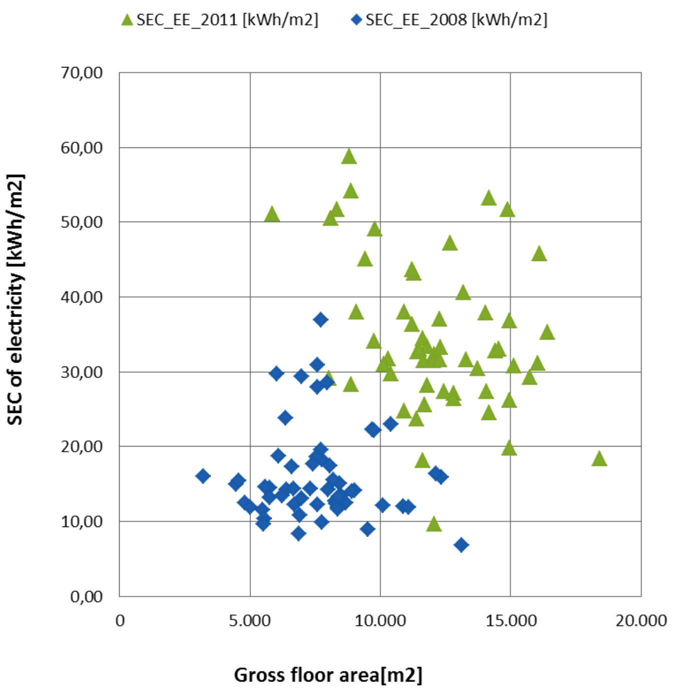

Figure 2 – SEC_{GFA} *of electricity vs. total Gross Floor Area in 2011 and 2008.*

In Figure 3, the SEC of electricity per student, SEC_S [kWh/student], is depicted against the number of students in each school.

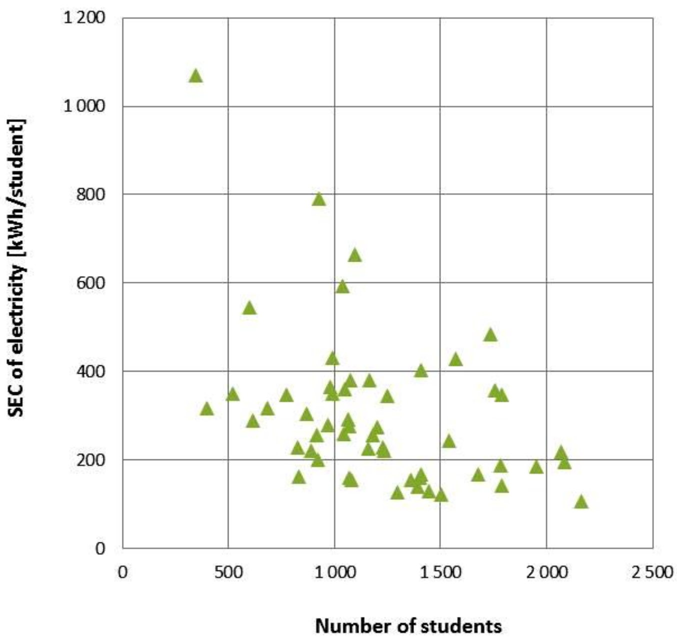

Figure 3 - SEC of electricity per student [kWh/student] vs. number of students (2010).

These 57 schools have an average of 1.179 students (standard deviation of 449) and present an average SEC of electricity of 286,5 kWh per student (standard deviation of 184,1). It is also observed a large variation of the SEC_S among schools with approximately the same number of students (see Figure 3).

For the same period, Figure 4 allows to compare the percent rate of change of the SEC_{GFA} of electricity [%] (*i.e.* $SEC_{GFA\,2011}/SEC_{GFA\,2008}$) and of the GFA [%] (*i.e.* GFA_{2011}/GFA_{2008}).

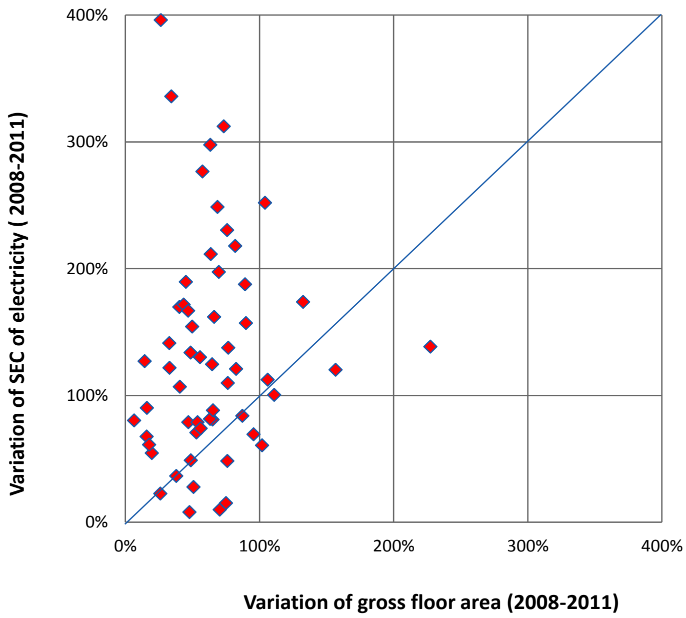

Figure 4 – Variation of SEC_{GFA} of electricity [%] vs. variation of GFA [%] (2008-2011)

For the majority of the 57 schools included in the preliminary sample, it is seen that the increase of GFA induced a more than proportional increase of the SEC_{GFA} of electric energy. This suggests an overall increasing trend of both indicators, but more pronounced in the case of the specific energy demand. In fact, an increase of SEC_{GFA} value was expected, since before refurbishment those schools were very elementary regarding the existence of information technologies equipment and of heating, ventilation and air-conditioning (HVAC) systems, and the indoor environmental quality provided to students and other occupants was clearly out of the recommended comfortable zone mainly in periods of more severe outdoor weather conditions (Dias Pereira, 2011 and Dias Pereira et al., 2013).

Figure 5 shows the frequency distribution (for classes with 6,2 kWh/m^2 amplitude) of the specific energy consumption [kWh/m^2] in 2011, in those 57 schools.

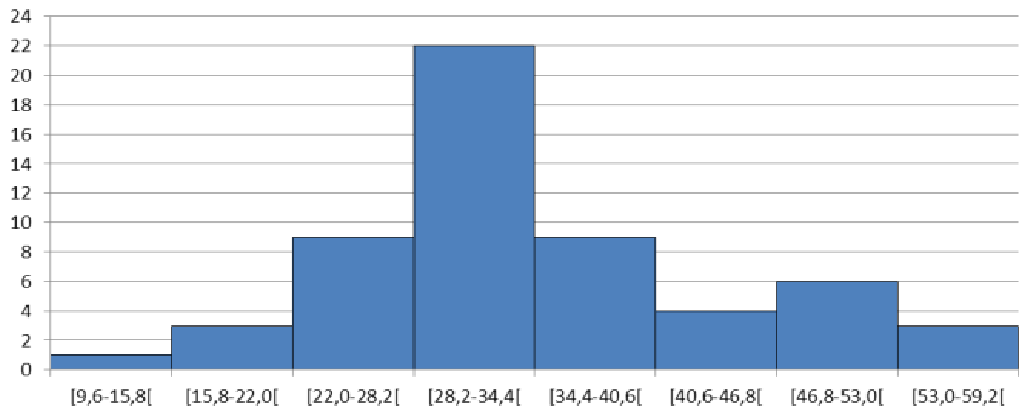

Figure 5 - Specific electricity consumption *[kWh/m^2] in 2011 in the pre-selected 57 schools.*

Based on the data analysis, a final selection was done of 8 schools for further screening, including *in-situ* audits. The criteria for this selection were (sequentially applied):

- Balanced distribution by different climatic zones;
- Higher value of SEC_{GFA} after the refurbishment;
- Higher ratio between the increases of SEC_{GFA} of electricity and of GFA;
- Availability of the building's DCR (Declaration of compliance with regulation, an energy pre-certificate of the building project that is mandatory for the construction license).

The main characteristics of the 8 schools included in the final sample are presented in Table 2.

Table 2 – Main characteristics of the 8 schools selected.

School / Climatic Zone	**PE construction phase**	**SEC_{GFA}** [kWh/m^2]			**$\Delta SEC_{GFA,\,08\text{-}11}$ [%]**	**$\Delta GFA_{08\text{-}11}$ [%]**	**$\Delta SEC_{GFA,\,08\text{-}11}$ / $\Delta GFA_{08\text{-}11}$**
		2008	**2010**	**2011**			
I1 V1	2	12,54	44,37	51,67	312	73	4,27

I1 V2	1	9,89	74,19	49,05	396	26	15,23
I1 V3	1	14,47	37,91	45,06	211	64	3,29
I2 V1	1	13,41	52,93	47,19	252	104	2,42
I2 V2	2	11,87	17,15	31,67	167	47	3,55
I2 V3	1	18,72	19,95	54,19	189	45	4,20
I3 V1	2	11,88	18,04	51,76	336	34	9,88
I3 V2	2	13,27	15,68	18,11	36	38	0,95

Average for the 57 schools	16,18	28,01	34,53	231	165	1,45

The selection criteria for the energy performance were based on data of electricity consumption, the only one available at this stage. The most consuming buildings can even so be identified and impressive increases of SEC_{GFA} have been found.

In the next phases of this project, extensive data collection will be intensified, particularly for the final sample of selected school buildings, including total school population (students, teachers and staff), different HVAC systems installed, equipment of canteens and sports facilities, etc., in order to achieve a thorough characterization of each building, based on their technical projects and specific conditions. The final project stage will lead to the development of a rating (benchmark) framework based on the detailed consideration of multiple individual indicators of different nature, which may provide an assessment of each school within the nationwide/regional building stock and also between different buildings of the same school with different functionalities, taking into account occupancy and utilization patterns, climate zone, etc.

3. Assessment framework for the analysis of overall energy efficiency performance

The development of an overall building energy efficiency performance index will be based on two sets of indicators: energy efficiency indicators (EEI) and maintenance indicators (MI). The foreseen EEI and MI indicators to be used are presented in Tables 3 and 4, respectively.

Table 3 – Energy efficiency indicators

	Indicator [units]	Expression	Description
Global	**Global EEI$_a$** [kWh/m^2]	$EEI_a = \frac{C_t}{A_i}$	Ratio between the total (annual) energy consumption C_t and the building area A_i (i = net floor, gross floor, ...)
	EEI$_o$ [kWh/occupant]	$EEI_o = \frac{C_t}{N_o}$	Ratio between C_t and the number of building occupants N_o
Energy end use	**EEI$_m$** [kWh/meal]	$EEI_m = \frac{C_t}{N_m}$	Ratio between C_t in canteens and similar services and the number of meals served N_m
	EEI$_H$ [kWh/m^2]	$EEI_H = \frac{C_t}{A_H}$	Ratio between C_t for heating and total heated area A_H
	EEI$_C$ [kWh/m^2]	$EEI_H = \frac{C_t}{A_C}$	Ratio between C_t for cooling and total cooled area A_C
Electricity	**EEIEEA** **[kWh/m2]**	$EEI_{EEA} = \frac{C_t}{A_i}$	Ratio between the electric energy annual consumption Ct and the area of the building Ai (i = useful, gross built, ...)
	EEI$_{EEo}$ [kWh/occupant]	$EEI_{EEo} = \frac{C_t}{N_o}$	Ratio between the electric C_t and the number of building occupants N_o

As defined for the energy performance, it is anticipated the possibility of defining environmental performance indicators relative to greenhouse gases (GHG) emissions.

Table 4 – Maintenance indicators

Indicator [units]	**Description**
Preventive Maintenance Plan (PMP) **compliance** [%]	Ratio between the number of planned preventative maintenance activities/interventions and those performed in a given period
Number of stand-by-for emergency calls	Number of calls to check/solve failures related with the operation/maintenance of the facility.
Number of job orders (JO)	Number of interventions due to inappropriate

	storage/maintenance/installation
Number of requests for action	Number of requests for conservation/maintenance arising during normal working hours
Time since the JO creation until the resolution	Time from the failure communication until its solution
Number of failures in critical equipment	Failure is understood as the malfunctioning or the unexpected stopping of equipment requiring a corrective action.
Number of alarms in Building Management System (BMS)	Number of alarms in the BMS caused by the malfunction or the unexpected stopping of equipment related with maintenance/conservation.
Response time on site	Time from the failure communication to the arrival on site.

Some studies have been reported in the scientific literature for assessing energy performance in school buildings. Fundamental issues about energy efficiency and indoor environmental quality in school buildings are addressed in Alfano et al. (2010), where the practical application of concepts is illustrated with the analysis of three case studies in different European countries. Dascalaki & Sermpetzoglou (2011) assessed the energy performance of Hellenic schools using a holistic approach to the "energy efficiency–thermal comfort–indoor air quality dilemma", by comparing energy consumption benchmarks with published literature worldwide. The Indoor Environmental Quality (IEQ) assessment is made through an objective evaluation (monitoring of three main parameters: indoor air temperature, relative humidity and CO_2 concentration, and the same outdoor parameters) and also through a subjective occupant evaluation. Energy consumption indicators were determined for different climatic zones, using Heating Degree Days (HDD) as the indicator, before a national average value was set. This study introduces Energy Performance Certificates (EPCs) similarly to the approach of the Portuguese national regulation (RSECE, 2006).

International studies generally deal with the setting of Display Energy Certificate (DEC) studies or focus on energy monitoring and conservation potential of buildings in particular climate zones (Dimoudi & Kostarela, 2009; Theodosiou & Ordoumpozanis, 2008). An innovative energy rating system was proposed by Santamouris et al. (2007) based on fuzzy clustering techniques. This method presents advantages compared to the frequent rating procedures that have shown important limitations, such as unequal ranges leading to non-balanced rating. Hernandez et al. (2008) proposed a "composite" approach, demonstrating a significant advantage of using both a calculated energy rating (by applying the grading methodology from the draft European standard prEN15217 (CEN, 2005) and a measured energy rating (actual consumption data) to assess the performance of the building, discerning whether its performance is due to intrinsic characteristics or to occupancy, activity and management issues. A grading system of energy efficiency of the building is proposed by comparing the energy performance indicators with the benchmarks.

Until now, no performance assessment of the school buildings after PE's interventions has been performed in a comprehensive manner. In this project, EEI and MI will be combined with operational issues to generate an overall energy performance index (EPI). The aim is that both EPI construction process and the resulting indicators could both provide school managers, at different levels, with valuable information relative to aspects requiring their attention and lead to establishing a "good-practices" manual for local energy managers in school buildings. Methodologies under study to develop both the overall EPI and action recommendations will include data envelopment analysis (DEA) and multi-criteria decision analysis (MCDA), which may be seen as somehow complementary approaches whose combination may expectedly provide further insights than their individual use. DEA is generally used to evaluate the efficiency of organizational entities performing similar tasks, by consuming inputs to produce outputs, in a relatively homogeneous operating environment. An efficiency score is computed for each unit by comparing it with all the other units under evaluation. In radial DEA models the relative efficiency of a unit is defined as the ratio between the sum of its weighted output levels to the sum of its weighted input levels. These weights are computed using linear programming, such that a unit is "shown in its best light" in the sense that its efficiency score should be maximized. DEA models enable evaluating the current performance, identifying benchmarks to use in seeking improvements, and understanding why some units are operating inefficiently. MCDA is used whenever multiple evaluation criteria must be explicitly considered to assess the merits of a given unit or course of action, in general taking into account the preferences of a decision-maker. The introduction of some type of managerial preference information is important when assessing the relative performance of organizational units since there area clearly evaluation aspects more relevant than others. In this spirit, an approach based on the one proposed in Madlener et al. (2009) is being developed.

In parallel with methodological developments underway along the directions mentioned above, the information available in the database provided by PE is being complemented with *in-situ* audits to gather relevant information for several energy use indicators.

4. Final Comments

Buildings are responsible for a significant share of energy use in most countries and schools alone are a major responsible for the total energy consumption in public buildings. This paper reports the work being carried out in the framework of an R&D project to evaluate the interventions in a nationwide program of rehabilitation and refurbishment of school buildings. A database has been used for characterizing the changes in energy consumption in the school buildings between the pre and post-intervention phases. Based on this characterization and a set of criteria, a group of eight representative schools has been chosen in which a more detailed study of energy consumption and operational conditions will be carried out in the next project stages. The development of a comprehensive assessment framework is underway for the analysis of overall energy efficiency performance of those buildings and their equipment. This work will lay the foundations for setting detailed improvement action plans regarding the end-use of energy and equipment in refurbished schools.

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Measuring energy efficiency in exports[1]

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Abstract

This paper analyses the relationship between the internationalisation of production and changes in the energy content in exports, focusing on the EU, US and Japan. The energy use for exports is mapped in terms of its sources: domestic intermediates versus foreign intermediates, focusing on the energy content of exports via embodied energy in intermediate imports. The role and different impacts on manufacturing and service exports are also briefly analysed. Along with increasing globalisation, the EU economies (as a whole) have been able to export more and at the same have reduced the energy embodied in their exports. Overall, the EU economies have been leading (relative to Japan and the US) in the reduction of the energy content per unit of exports and in the global trends towards the increasing weight of foreign-energy inputs in the total energy embodied in exports.

Keywords: energy efficiency, energy modelling, exports.

JEL codes: F14, Q40

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[1] The views expressed in this paper are those of the author and should not be attributed to the European Commission.

1. Introduction

Energy is used in practically all production processes and the importance of energy efficiency as a competitiveness factor is growing over time with the rising energy price and volatility levels and globalisation. Global competition and off-shoring offer new opportunities in terms of the efficient exploitation of existing technologies and resources. The development and adoption of eco-innovations tend also to be fostered by global competition (Brunnermeier and Cohen (2003)). As a result, greater energy-efficiency improvements can be expected within and across firms, sectors and countries, helping to achieve environmental and climate change goals world-wide.

However, the quest for economic efficiency does not necessarily translate into energy efficiency and related environmental efficiency. Market failures (in energy or other markets) or regulatory failures may stand in the way and impair the simultaneous achievement of eco-efficiency, in particular on a world-wide basis. For example, various stages of production may be offshored to less energy-efficient countries or firms as a result of distorting taxes or subsidies on energy products. Existing plants in pollution-intensive industries can be relocated to regions with less stringent or unenforced regulations. Some evidence for this is presented by Henderson (1996), and List et al. (2003). A survey of this strand of the literature is offered by Brunnermeier and Levinson (2004).

This paper studies the energy content in exports and energy-efficiency trends over the past 15 years in the context of the globalisation of production activities. The World Input-Output database (WIOD) is used to trace the source and the energy content of goods and services produced in vertically-integrated industries and cross-border production networks. The WIOD provides an integrated global framework for the analysis of energy use that does not suffer from the limitations of standard analyses such as the ones based on domestic input output data (see e.g. Amador 2012) that do not take the cross-border linkages fully into account.

The WIOD accounts for approximately 85 percent of the world's production. The world input-output data is reported for C=41 countries (the EU-27 countries, 13 other major world economies and the rest of the world) and N=35 sectors (NACE rev. 1) over the period 1995-2009. The economic data in WIOD is also linked to environmental accounts and energy use. The WIOD database considers the use-side of energy and reports 'gross energy use' covering the transformation of primary energy into other forms of energy like electricity and heat, as well as the final use of energy.

The paper is organised as follows. Section 2 analyses the changes in the energy content in exports in the context of the increasing global trade in intermediates and the internationalisation of production networks. The main patterns and changes in the sourcing structure of energy inputs embodied in exports are analysed in section 3. Section 4 concludes.

2. Energy content in exports

Suppose there was interest to trace the energy inputs (per sector and country) and to calculate the energy content of a German car exported to China. The energy (e.g. electricity) used directly in the car-manufacturer's plant would be one element. To that must be added the series of (indirect) energy consumptions embodied in the car components purchased by the manufacturer (e.g. the electricity used in the mining industry in Australia or in the production of the intermediates purchased from the electronics industry in Germany or other countries). The inverse Leontief matrix (from WIOD) can be used to calculate the total energy inputs (direct and indirect, in all rounds of production of the car and car components).

With data on energy use by industry, the Leontief inverse matrix can be pre-multiplied by the energy coefficients vector (i.e. energy used per unit of output) and post-multiplied by the vector of exports. This then allows a separation of the energy directly and indirectly used by a partner country to produce another country's exports and its domestic energy use. The calculation of energy-input coefficients (i.e. energy use per unit of gross output) was performed using deflated gross output series. Gross output was deflated to constant 1995 prices, using industry-level price indices for each country.

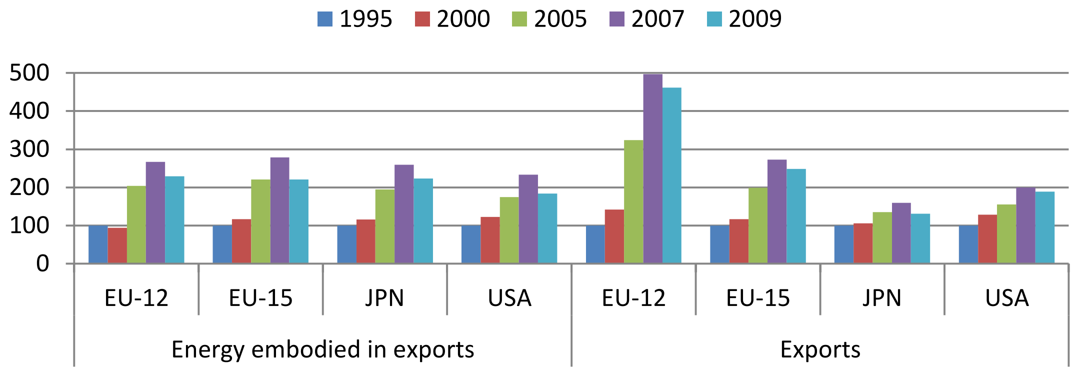
The energy embodied in country r exports (measured in terajoule, TJ) is given by

$$e'(I-A)^{-1}x$$

where e denotes the NCx1 vector of energy use per unit of gross output (measured in constant prices, the prime denotes transposition), $(I-A)^{-1}$ is the inverse Leontief matrix and x the NCx1 vector with country r exports.

The left-hand panel in figure 1 shows an index of the energy embodied in exports for EU-15, EU-12, Japan and the US, over the period 1995-2009. Total energy inputs in exports increased globally in the four economies in the pre-crisis period (between roughly 130% in the US and 180% in the EU-15 up to 2007). In 2008-2009 the energy embodied in exports declined significantly and globally as a result of the economic crisis and the collapse in worldwide trade. The impact of the crisis and the sudden reversal of the long term upward trends in global trade can be seen in the right-hand panel in Figure 1 (presenting the underlying trade trends in terms of the index for total exports, for each of the four economies over the whole period 1995-2009).

Figure 1 – Indexes (1995=100): total energy embodied in exports (left panel) and total exports (right panel), 1995–2009



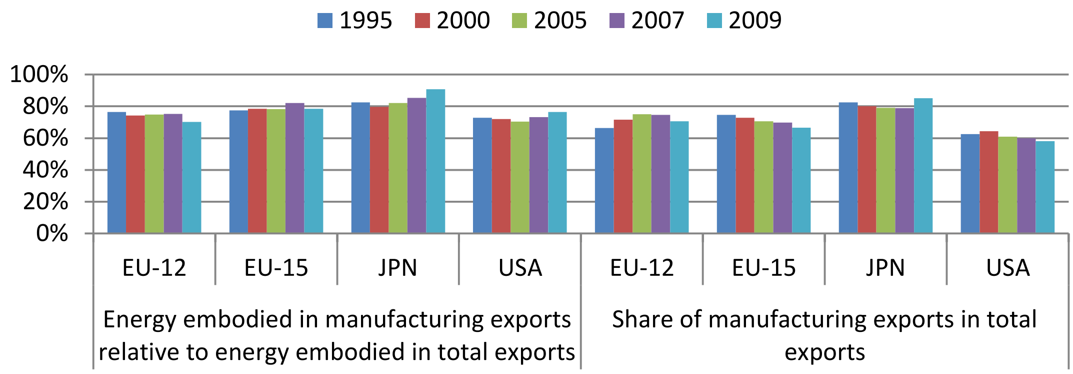
Source: WIOD

The growth of total exports was higher in the EU overall (in particular the EU-12) than in Japan and in the US over the period analysed. The significant increase in total exports in the EU-12 economies as a whole is to a large extent due to their relatively high and increasing degree of vertical specialisation (e.g. in their role as providers of intermediates namely to EU-15). This fact is corroborated by the much less than proportional growth rate in the energy embodied in exports (observed in the left-hand panel of Figure 1) for the EU-12. A slight opposite trend occurs in Japan, for which the increase in energy inputs was slightly higher than the growth in the underlying total exports. In part, this may be due to the specialisation of the Japanese economy and eventually to its relatively high degree of vertical specialisation. For the other two advanced economies (the EU-15 and the US), the underlying growth in total exports has been accompanied by a (broadly) a more proportional variation in the energy embodied.

Figure 2 highlights the importance of manufacturing in terms of exports and how this is translated into the energy embodied in exports for the four economies being analysed. The right-hand panel shows that manufacturing exports accounted in the years 2007-2009 for around 80% of total exports in Japan, 70 % in the European economies and 60 % in the US. The share of manufacturing in total exports has been falling in all economies, except for the EU-12 (reflecting the vigorous increase in manufacturing exports). A number of manufacturing industries (e.g. producing durable goods) were severely hit during the most recent crisis and the share of manufacturing in total exports dropped in all economies in 2007-2009 except for Japan, for which the exports of services declined more than manufacturing exports during the crisis, see Figure 3 below.

Manufacturing activities involve transforming a range of material inputs into products, so manufacturing exports generally tend to have a higher energy content than total exports. The share of energy embodied in manufacturing relative to total exports (in the left-hand panel in Figure 2) is higher overall than the weight of manufacturing in total exports. This is true for all four economies, except for the EU-12 in 2009 and Japan in the years 1995, 2005, cases in which the shares in the left-hand and right-hand panels in the Figure are roughly identical.

Figure 2 – Energy embodied in manufacturing exports relative to total energy embodied in total exports (left panel) and share of manufacturing exports in total exports (right panel), 1995–2009



Source: WIOD

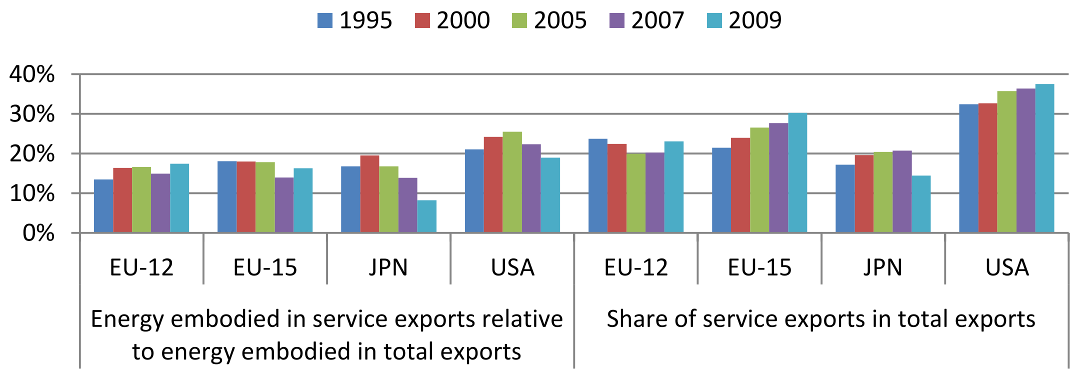
Moreover, the energy embodied in manufacturing exports as a share of the energy embodied in total exports remained broadly stable (or even increased slightly in some sub-periods and for the whole period 1995-2009) while at the same time the share of manufacturing exports fell overall. The exception was the EU-12, for which manufacturing as a whole outperformed the overall reduction of energy content in total exports.

Figure 3 illustrates the growing importance of service exports and their overall lower energy content relative to manufacturing exports. The right-hand panel shows that the share of services in total exports has been growing for all economies in the last 15 years, except in the EU-12 (for which manufacturing remained the dominant driver of export growth). Altogether, manufacturing and services accounted for more than the 95 % of total exports for all four economies (the highest share is reached in Japan, 99 % of total exports; exports from other sectors such as agriculture, forestry or mining are much less important in advanced economies).

The growth of service exports was particular strong in the European economies (+320 % in the EU-12 and +250 % in the EU-15 in the period 1995-2007). In the EU-15, the growth of manufacturing exports was much lower (around +150 % in the period 1995-2007) and as a result the share of services in total exports rose from 20 % in 1995 to close to 30 %. In 2007, the share of services accounted for more than 1/3 of total exports in the US and for around 20 % in the EU-12 and Japan. Japan has a much lower share than the US and the EU-15 in services such as financial intermediation and Renting and Machinery and Equipment and other business services (including ICT and R&D-related services). During the recent crisis, exports dropped considerably in a number of service sectors (including more cyclical-related sectors such as water transport and wholesale trade and commission trade, NACE codes 61 and 51, respectively), leading to the observed fall in the share of services in total exports in Japan.

Not surprisingly, Figure 3 shows that service exports as a whole tend to have a relatively lower energy content (the share of energy embodied in service exports relative to total exports (left-hand panel) is lower overall than the weight of services in total exports (right-hand panel)). Moreover, energy embodied in service exports relative to total exports decreased (or remained broadly stable in the case of EU-12 and US) while the share of service exports increased overall (except in the crisis period 2007-2009 in the case of Japan and for the EU-12, where growth in manufacturing exports dominated the whole period).

Figure 3 – Energy embodied in service exports relative to total energy embodied in total exports (left panel) and share of service exports in total exports (right panel), 1995–2009



Source: WIOD

Table 1 presents energy embodied per unit of exports (panel A) and the share of the energy inputs that is sourced from foreign countries (panel B) for manufacturing, services and total exports. The energy embodied in exports that is sourced from foreign countries is given by

$$(e^{-r})'(I-A)^{-1}x$$

where e^{-r} is the vector of foreign energy use per unit of gross output (i.e. the elements in the NCx1 vector *e* corresponding to the country r - N=35 sectors- are replaced by zero).

Panel B shows a steady rise in the share of foreign-energy inputs in the total energy embodied in manufacturing, services and total exports up to 2007. This is a result, to a great extent, of the increasing cross-border integration of production networks. As expected, partly reflecting a higher degree of cross-border production linkages, manufacturing has a higher share of foreign energy content relative to services (except for the EU-12 in 1995). However, the gap between the share of foreign energy in manufacturing and services narrowed, in particular in the EU-15. This may be explained in part by the input-output linkages between services and manufacturing. Services source many of their more energy-intensive inputs from manufacturing, some of which are in turn directly and indirectly sourced from foreign countries. Japan leads over the period 1995-2007 in terms of the highest content of foreign energy inputs in exports. The US has overall a larger share of domestic-energy inputs in exports, particularly in services.

Table 1 – Energy embodied (TJ) per unit of exports (USD million) (left panel) and share of foreign energy embodied in exports (right panel) 1995–2009

	(A) Energy inputs per unit of exports					**(B) Share of foreign energy inputs**				
	1995	**2000**	**2005**	**2007**	**2009**	**1995**	**2000**	**2005**	**2007**	**2009**
Manufacturing (NACE D)										
EU-12	63.6	38.0	34.8	30.0	27.3	14%	23%	29%	36%	33%
EU-15	17.6	18.2	20.8	20.5	17.8	23%	27%	29%	34%	35%
Japan	11.1	12.1	16.7	19.5	20.1	29%	31%	36%	38%	34%
USA	25.9	23.8	29.0	31.8	28.6	16%	19%	21%	20%	20%
Services (NACE 50 to P)										
EU-12	31.4	26.7	29.1	22.0	20.8	16%	22%	19%	26%	22%
EU-15	14.3	12.7	12.6	8.8	8.1	13%	19%	22%	32%	33%
Japan	10.9	12.1	13.1	12.1	10.8	26%	30%	34%	35%	30%
USA	14.4	15.8	17.9	16.0	11.0	8%	9%	12%	14%	15%
Total exports (NACE A to P)										
EU-12	55.5	36.6	34.8	29.6	27.6	14%	22%	26%	32%	28%
EU-15	17.0	16.9	18.8	17.4	14.9	21%	25%	28%	33%	34%
Japan	11.0	12.1	15.9	17.8	18.8	28%	30%	35%	38%	33%
USA	22.2	21.3	25.2	26.1	21.8	14%	16%	19%	19%	19%

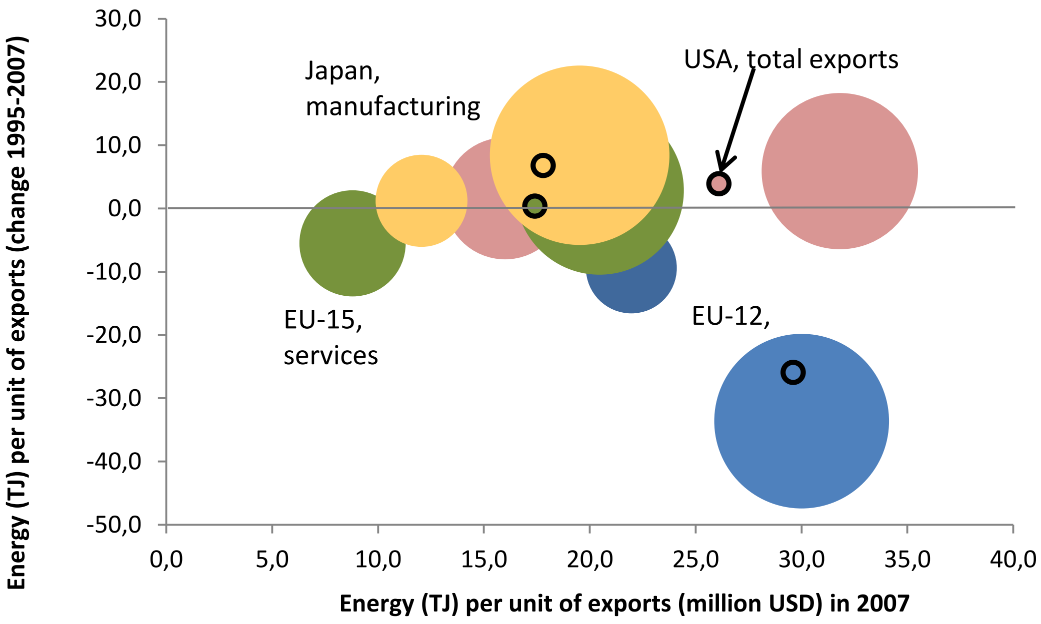
Source: WIOD

Figure 4 plots the changes (in the period 1995-2007) against the level of the energy content in exports in 2007 (highlighting the main trends in the data presented in panel A of Table 1). Manufacturing is depicted by the larger bubbles. The EU-15 and Japan lead in terms of having the lowest energy content in services and manufacturing exports but the energy content in manufacturing exports increased in the period 1995-2007, particularly in Japan. The EU-15 kept the energy content in total exports broadly constant in the period up to 2007 mainly thanks to a reduction in the energy embodied in service exports (together with their greater and increasing weight in total exports relative to Japan, see also Figure 3).

Following its integration in cross-border production networks and strengthening of its vertical specialisation, the EU-12 achieved a noticeable reduction and catching-up in the energy content of manufacturing exports. The EU-12 reached the same energy content in manufacturing exports as the US in 2007. The reduction in the energy content in service exports was comparatively much smaller.

The energy content in the US increased both for manufacturing and service exports in the period 1995-2007 (in a broadly similar trend to Japan's). The higher energy content in US exports vis-à-vis the EU-15 and Japan is less pronounced in services. Combined with a larger share of service exports in the US, this mitigates the gap in energy embodied per unit of US total exports.

Figure 4 – Energy content in exports (for manufacturing, services and total exports): change 1995-2007 versus level in 2007

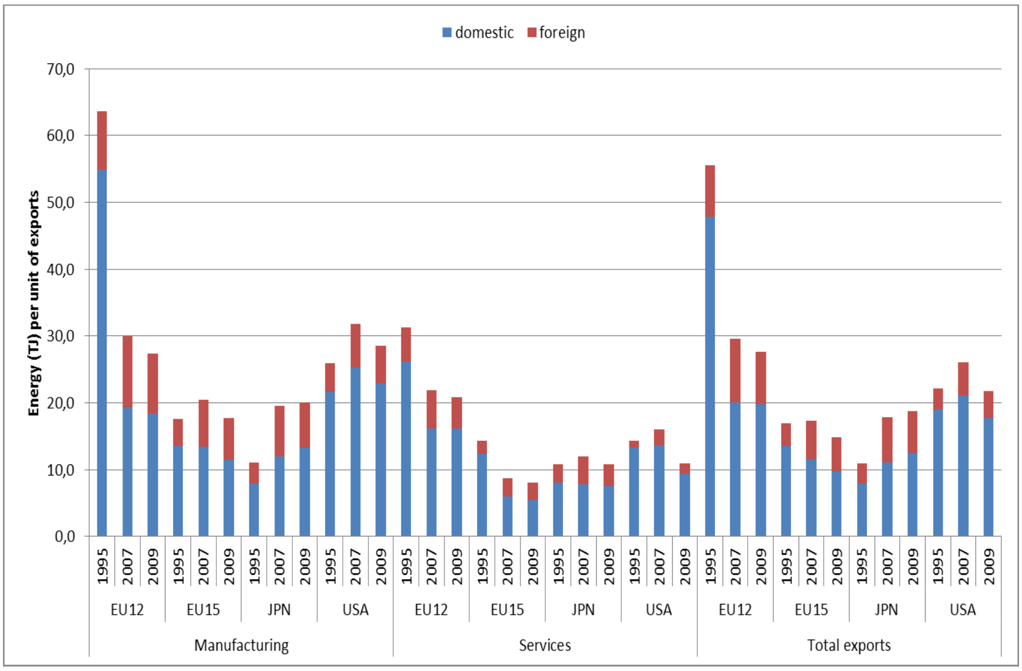


Source: WIOD. Note: Manufacturing is depicted by the larger bubbles. The size of the bubbles reflects the weight of manufacturing and services in total exports in 2007. The points enclosed in the small black circles of uniform size represent total exports.

Figure 5 presents the breakdown of energy inputs per unit of exports by domestic and foreign countries' sources. The amount of foreign-energy inputs per unit of exports increased overall in all four economies for both manufacturing and services in the period 1995-2007. In the period 1995-2007, the domestic energy content in total exports decreased in the European economies and increased in Japan and to a lesser extent in the US. For the EU-12, this is due to a significant drop in the energy incorporated domestically in manufacturing exports and to a much lesser extent in service exports. In contrast, in the EU-15 this is mainly the result of the considerable drop in the domestic- energy content of service exports. As from 2007, the EU-15 also clearly leads in terms of the lowest domestic-energy inputs per unit of service exports. Regarding manufacturing exports, the EU-15's domestic-energy content remained constant and the increase in total energy embodied was due to the increase in foreign-energy inputs. For Japan and the US, the increase in the domestic energy content in total exports was primarily due to the rise in the (corresponding domestic) energy inputs in manufacturing.

During the crisis period 2007-2009, following the slump in global trade, the previous upward trend in the share of foreign energy inputs in total energy embodied in manufacturing and service exports ended or in some cases temporarily reversed. Panel B in Table 1 above showed that in the period 2007-2009 the share of foreign-energy inputs in total energy embodied in exports stabilised in the EU-15 and USA and decreased in Japan and the EU-12. This may be due in part to the fact that manufacturing exports, which were more severely hit overall during the crisis, account for a larger share of total exports in Japan and in the EU-12.

Figure 5 – Energy (TJ, domestic and foreign) content in (manufacturing, services and total) exports (Million USD, 1995, 2007



Source: WIOD.

3. Changes in the sourcing of energy inputs

The changes in the sourcing structure of energy inputs embodied in exports reflect many factors such as differences in energy-efficiency trends across countries and sectors, together with global trade and vertical specialisation developments.

Table 2 presents a detailed breakdown of the sourcing structure of embodied energy inputs in total exports (the domestic component is highlighted). The changes over time and the geographical patterns follow expectations for each of the four economies. In the EU-12, the considerable reduction (by almost 20 percentage points in the period 1995-2007) in the domestic share of energy embodied in exports is mirrored in the large increases in the weight of traditional trade and energy supplier partners (like the EU-15, BRII — Brazil, Russia, India and Indonesia — and the Rest Of the World — ROW) and China (and smaller increases in the shares of other trade partners). In the period 1995-2007, all EU-12 trade partners in Table 1 steadily increased their shares of the energy embodied in EU-12 exports (except Mexico and the US in 2005).

The domestic proportion of the energy content in EU-15 exports decreased steadily over the whole period (from 4/5 in 1995 to 2/3 in 2009) reflecting the increasing weights of the BRII economies, the ROW and China. In 2009, China's share of energy embodied in EU-15 exports was already more than twice the — relatively stable — share accounted for by traditional trade partners like the EU-12 or the US. The other trade partners listed in the table have smaller shares that increased slightly overall or tended to remain relatively stable.

The increased importance of China as a source of energy content in exports globally is particularly striking in the case of Japan (accounting for more than 8% of the energy content in total exports in 2009). The increase in China's share, and to a smaller extent that of the ROW and the BRII economies, almost compensates for the reduction in the domestic share in the energy content in Japanese exports in the period 1995-2007. The shares of other important Japanese trading partners like South Korea and the US remained fairly stable or decreased only slightly in the period 1995-2007.

Table 2 – Geographic (source) structure of energy embodied in exports (1995–2009, share in percentage, domestic source is highlighted)

	EU-12					EU-15				
	1995	**2000**	**2005**	**2007**	**2009**	**1995**	**2000**	**2005**	**2007**	**2009**
BRII	5.0	6.6	6.8	8.4	6.4	3.7	4.0	6.0	7.4	6.8
Canada	0.1	0.2	0.3	0.4	0.3	0.7	0.8	0.7	0.8	0.7
China	0.3	1.1	2.9	4.7	6.1	1,6	2.2	3.4	4.8	6.5
EU-12	86,2	78.0	74.4	67.7	71.7	2.4	2.2	2.5	2.7	2.8
EU-15	4.5	6.9	7.8	8.8	7.1	79.4	75.0	72.4	66.5	65.8

Japan	0.1	0.3	0.4	0.5	0.4	0.4	0.6	0.5	0.6	0.6
S. Korea	0.1	0.3	0.5	0.8	0.8	0.3	0.6	0.6	0.8	0.8
Mexico	0.0	0.1	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.3
USA	0.5	1.3	1.0	1.3	1.1	2.3	3.1	2.6	2.9	2.9
ROW	3.2	5.3	5.8	7.3	6.0	9.0	11.3	11.0	13.3	12.8
			Japan					**USA**		
	1995	**2000**	**2005**	**2007**	**2009**	**1995**	**2000**	**2005**	**2007**	**2009**
BRII	4.4	4.7	5.2	6.1	4.7	1.4	1.8	2.4	2.4	2.1
Canada	0.9	0.7	0.5	0.5	0.4	2.3	2.6	2.7	2.5	2.1
China	3.1	4.0	7.6	7.9	8.5	1.6	1.9	3.4	3.7	4.7
EU-12	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.3	0.2	0.2
EU-15	2.1	2.0	2.1	1.8	1.3	1.7	1.9	2.2	2.0	1.6
Japan	71.9	69.5	64.7	62.1	66.6	0.6	0.6	0.5	0.5	0.4
S. Korea	2.4	3.2	2.8	2.4	1.7	0.5	0.6	0.6	0.7	0.6
Mexico	0.1	0.2	0.1	0.2	0.1	0.6	0.8	1.0	1.0	1.2
USA	2.9	3.3	2.6	2.5	1.6	86.0	83.9	81.5	81.2	81.5
ROW	11.9	12.2	14.1	16.3	14.9	5.1	5.6	5.5	5.7	5.6

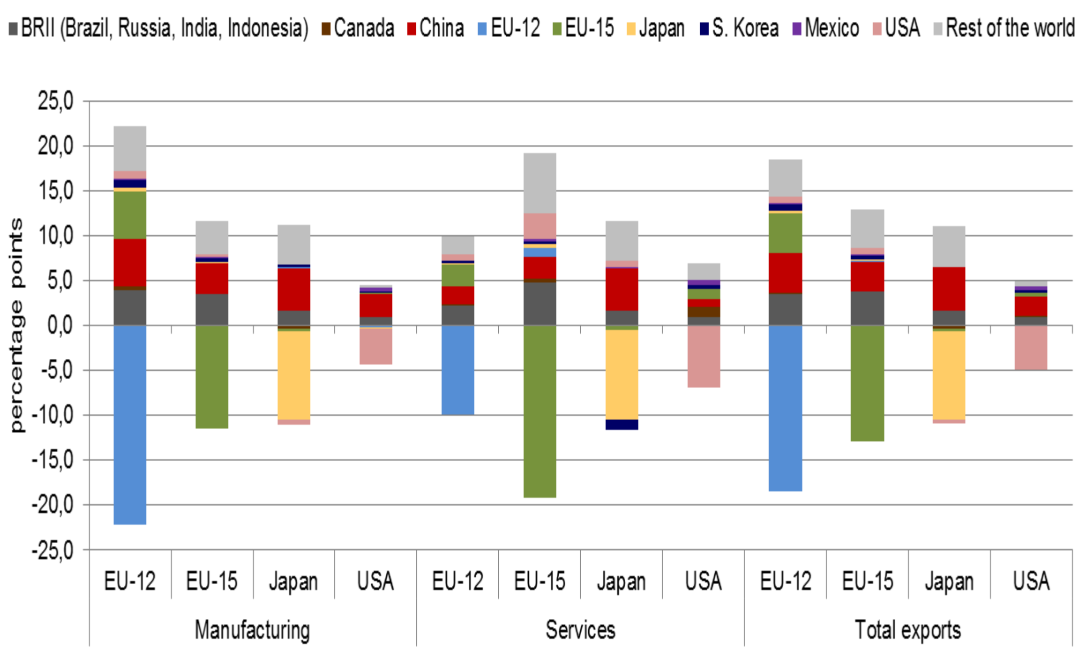
Source: WIOD.

The US maintained a relatively higher domestic share of the energy content in exports and relatively lower shares for typical energy-sourcing countries within the BRII and the ROW, partly reflecting the US's lower dependence in terms of imported fossil fuels compared to overall the EU-15, EU-12 and Japan. China has comparatively a smaller share of the energy embodied in US exports and Canada has a more prominent weight in the US (relative to the EU-15, EU-12 and Japan).

The recent crisis together with its impact on global trade, in particular for industries with more developed cross-border production networks, led to a halt and in some cases a reversal of the previous trends. Overall, the domestic content of energy embodied in exports started rising at the expenses of the foreign content for the majority of trade partners. The exception is China, which continued to increase its share for the four economies analysed, squeezing the shares of other foreign economies. In fact, China is the single economy whose share increased more over the whole period for all the four economies analysed (China's share increased by 5 percentage points or more for Japan, the EU-12 and EU-15 and by 3 percentage points in the US in the period 1995-2009).

Figure 6 presents the changes in the shares of energy inputs embodied in manufacturing, services and total exports for each of the four economies (e.g. the share of domestic-energy inputs in total energy embodied in the EU-15 exports of services decreased by 19% in the period 1995-2007, while the share of energy inputs that EU-15 exporters sourced directly and indirectly from the BRII countries increased by 5% in the same period). The figure shows a large shift overall from domestic to foreign energy inputs embodied in exports in the period 1995-2007. Interestingly, the figure also reveals for this period a higher (or at least comparable in the case of Japan) shift towards foreign-energy inputs in service exports relative to manufacturing exports. The exception is the EU-12, whose share of domestic-energy inputs in manufacturing exports declined (significantly by 22 %) by more than twice the contraction observed in the share of domestic-energy inputs in service exports. A major and almost equivalent drop (19%) was observed in the share of domestic-energy inputs in EU-15 exports of services. This, together with the relative weights of the manufacturing and services in total exports in the EU-12 and EU-15, explains why the European economies had the largest falls in the share of domestic-energy inputs in total exports. The US had a much lower reduction in the share of domestic-energy inputs in exports (around 4% in manufacturing and 6% in services).

Figure 6 – Changes in the share of energy inputs embodied in exports in the period 1995–2007 (in p.p.)

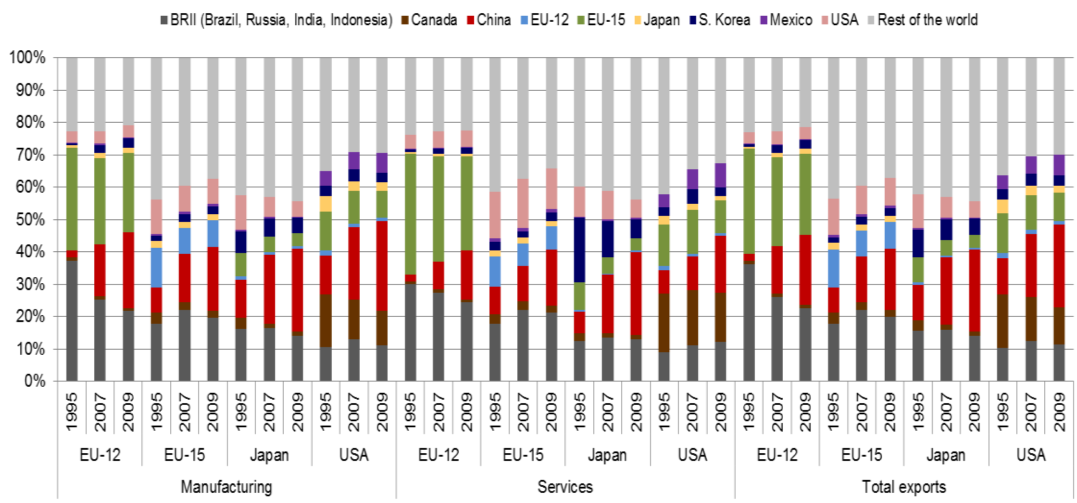


Source: WIOD.

The reciprocal increase in the share of foreign-energy inputs embodied in exports was not distributed equally across all trade partners. However, almost all of them increased their shares of total energy inputs embodied in the exports in the period 1995-2007. The very few exceptions concern Japan. There were marginal decreases in the shares of S. Korea and EU-15 energy inputs in Japanese service exports or in the share of US, Canadian and EU-15 energy inputs in Japanese manufacturing exports. This means that in the case of Japan domestic energy inputs, but also (to a minor extent) those from some foreign countries, were shifted to other economies (e.g. China and the RoW).

Figure 7 summarises the main changes in the structure of (shares per trade partner in) foreign-energy inputs embodied in exports. A joint reading of Figures 6 and 7 shows that in the period 1995-2007 a significant part of the energy inputs embodied in exports were diverted from domestic to foreign countries, in particular to China. Figure 7 shows that this is particularly noticeable in manufacturing, where off-shoring trends in the period 1995-2007 led to virtually a doubling of the share (8 times higher in the case of EU-12) of Chinese energy inputs in the foreign-energy inputs in manufacturing exports. The increase in the weight of China as source of foreign-energy inputs led to an overall contraction in the shares of other trade partners. Overall, the shares of the RoW or the BRII contracted as well as the share of energy inputs embodied in bilateral manufacturing trade between the EU-12, EU-15, Japan and the US.

Figure 7 – Shares (per trade partner) in foreign-energy inputs embodied in exports, 1995, 2007, 2009



Source: WIOD.

Compared to manufacturing, the rise in the weight of China as source of foreign-energy inputs embodied in service exports was less pronounced, except for Japan. For Japan in the period 1995-2007, the share of Chinese energy inputs in the foreign-energy inputs in Japanese service exports also more than doubled, while the corresponding shares of S. Korea and EU-15 were roughly halved. In the EU-15, despite the significant decline in the relative weight of domestic-energy inputs in service exports (recall Figure 6), the relative increase in Chinese energy inputs was less pronounced and the US and the EU-12 kept their shares broadly stable. Similarly, in the US in the period 1995-2007, the shares of Canadian and EU-15 energy inputs in US service exports remained fairly stable while the increase in the corresponding share of China was much smaller compared to manufacturing.

Regarding the recent crisis period, Figure 7 shows that China continued to increase its share of foreign-energy inputs in exports both for manufacturing and services, now at the expense of the other trade partners in general. Over the whole period (1995-2009), it more than doubled its share of the foreign-energy inputs embodied in both manufacturing and service exports of the EU-15, Japan and the US (the corresponding increase was much higher in the case of the EU-12).

4. Conclusion

This paper studied energy content in exports of the largest advanced economies over the last 15 years. Increasing global competition and cross-border integration of production chains are developments with far-reaching social, political and economic consequences. The overall increase in the relative price of energy is one of its many side effects, often seen as partly due to the increasing energy demand from developing countries.

The analysis showed that for EU countries (as a whole) globalisation appears to also represent additional channels for minimising the negative competitiveness effects of the energy-price increases. Overall, EU countries have been able to export more and at the same reduce significantly the energy embodied in their exports. The analysis covered EU-12, EU-15, US and Japan and showed that energy use per unit of exports declined in European countries over time in the period 1995-2009. For the EU-12, this is due mainly to a significant drop in the energy incorporated in manufacturing exports. In the EU-15, the most important contribution came from the drop in the energy content in service exports. This contrasts with the increase in the energy embodied per unit of exports observed in Japan, and to a smaller extent in the US, over the same period.

As expected, the share of energy content in exports sourced from foreign countries (through energy embodied in intermediate imports) has been rising everywhere. The EU countries have been leading in this — globalisation induced — upward trend and already have a higher share of foreign-sourced energy embodied in exports compared with Japan, a country that also has a high external dependency on fossil fuels. The importance of emerging economies such as Brazil, Russia and in particular China as sources of the energy embodied in the exports of the advanced economies analysed has been growing over time.

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DAY 10 - 16:30		
Room 626 - Environmental and Social Impact Assessment 3		
Biogas Energy in Turkey: Current Situation, Sustainability and Policy Implications	Gulden Boluk[1]; Serhat Kucukali[2]	[1]Akdeniz University; [2]Canakaya University
Environmental and traffic implications of cheap energy: Case study in the State of Kuwait	Dr. Abdirashid Elmi[1]	[1]Kuwait University
A Cost-Benefit Analysis for Social Impact Assessment: the case of preventive measures in a hospital	Delfina Ramos, Pedro Arezes, Paulo Afonso	University of Minho
A prospective analysis of the employment impacts of energy efficiency retrofit investment in Portugal by 2020	Carla Oliveira Henriques[1]; Dulce Coelho[2]; Patrícia Pereira Silva[3]	[1]ISCAC, Polytechnique Institute of Coimbra and INESC Coimbra; [2]ISEC, Polytechnique Institute of Coimbra and INESC COimbra; [3]Faculty of Economics, University of Coimbra
Sustainable Development in Portuguese Business Organizations: Performance Dimensionality and Utilization Patterns	Pedro Mamede[1]; Carlos F. Gomes[2]	[1]PROCESS ADVICE Lda and University of Coimbra – School of Economics; [2]University of Coimbra – School of Economics and ISR-Institute of Systems and Robotics

Biogas Energy in Turkey: Current Situation, Sustainability and Policy Implications[1]

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Abstract

Biogas is one of the most sustainable energy resources among the other resource alternatives due to its high social and environmental benefits. In this paper, we present the current status and potential of biogas power plants in Turkey and discuss the socio-economic benefits of those power plants. Also, the paper discusses the socio-economic aspects of technological development including state budget and employment effects. By June 2012, the biogas plants contributed to 0.6 % of the total renewable power capacity of Turkey and 20 biogas power plants are in operation with a total installed capacity of 108 MW. The most of the biogas power plants are landfill type and these plants are generally located in big cities. If Turkey utilizes all of its biogas power potential which is around 6400 MW by the year 2011, about 64,000 more employment can be created in the Operation and Maintenance (O&M) and fuel supply sector. Moreover, almost 29% of country's total electric energy consumption can be met from those biogas power plants. In additional, utilization of municipal wastes and establishing more efficient agricultural policy would contribute to the sustainable development and reduce natural gas dependency in Turkey.

Keywords: Renewable energy, biogas power plants, Turkey.

JEL Classification Codes: Q16, Q20, Q42.

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1.Introduction

Energy is an essential input to all forms of economic and social activities so it plays a very important role in the development of countries (Wang et al., 2009). However, the production and consumption of energy resources have important consequences in the world such as greenhouse gases, global change, energy security and import dependency (UNIDO, 2008). In many countries, renewable energy evolves rapidly to ensure sustainable development. Sustainability can be persuaded as a balance of social and economic activities and energy is considered as a key issue for sustainable economic development (Figure 1). The development of renewable energy industry and new technologies has become a way to achieve environmental objectives and a mean for energy self-sufficiency and employment (Moreno and Lopez, 2008).

As a result of rapid economic growth and social change, energy demand in Turkey has been growing rapidly. Primary energy demand is projected to reach 282.2 mtoe in 2020 which means a 40 percent increases from the current level of 167 mtoe. Total domestic energy production of the country met only 28 percent of total primary energy demand in 2011.

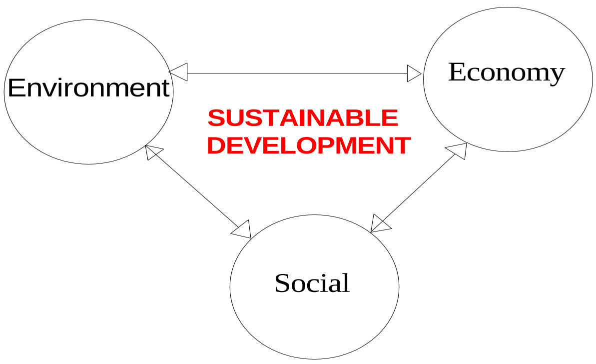

Figure 1: Three main elements of sustainable development

In order to eliminate environmental problems and to ensure a sustainable economic growth, Turkish government plans to produce 30 % of Turkey's electricity demand from renewable energy resources by 2023. This goal also complies with the European Union renewable energy policy and the Kyoto Protocol. Utilization of renewable energy resources is vitally important for Turkey to reduce its dependence on imported energy supplies, to provide supply security and to decrease the greenhouse gas emissions. Hence harnessing domestic renewable energy resources such as biomass, hydro, wind and solar are key issues for Turkey.

The aim of this paper is to examine the current situation and the potential of biogas in Turkey and to evaluate the contribution of biogas production for sustainable economic development in the context of recent renewable energy policy in the country. The paper is organized as follows. In the second section, macroeconomic drivers of energy demand and national renewable energy policy are presented. In the third section energy market and biogas energy potential are analyzed. In the fourth section sustainability of biogas production and economic implications are evaluated. Final section concludes important results.

2. Current Energy Trend and Economic Profile of Turkey

Turkey is situated at the meeting point of three continents (Europe, Asia and Africa) and stands as a bridge between Europe and Asia. Turkey has 779,452 km^2 land size. The population is around 74.7 million and 60 % of these inhabitants live in urban areas (TURKSTAT, 2012a).

Turkey has become one of the largest economies among Europe and in the world over the last 30 years. Turkey was the 15 th largest economy in terms of GDP-PPP and the 17^{th} largest economy in terms of nominal GDP in the world with a gross domestic product (GDP) of 1,259.9 billion USD in 2011 (WB, 2012). Moreover, average annual growth rate of GDP (in current prices) was 4.3 % in the last 20 years (IMF, 2010). Turkey experienced a negative annual growth rate of 3.8 % in 2009 as a result of global economic crises began in mid-2008. However, this trend changed in 2010 by an increase in GDP (8.9 %) (OECD, 2011). Growth rate of GDP in Turkey was 8.5 % in 2011 and GDP is expected to growth at a rate 5.5 % in 2013 (TURKSTAT, 2012b, SPO, 2011). In spite of growth rate of population has decreasing in Turkey in last two decades, population is still increasing parallel to the industrialization. According to the TURKSTAT, while annual growth rate of population was 17 % in 1986, it became 13.5 %o in 2011. Moreover, it is projected that the population of Turkey will reach to 77.6 million in 2015 and 85.4 million in 2025 (TURKSTAT, 2012a).

Table 1: Basic data for the population, economy, and energy of Turkey.

Years	Population (000s)	GNP per capita	Total GNP (billion $, at 1990 prices)	Total energy demand (Mtoe)	Energy per capita (Kep)	Energy intensity
1973	38,072	1994	76	24.6	646	81
1990	56,098	2674	150	53.7	957	50
1995	62,171	2861	178	64.6	1,039	44
2000	67,618	3303	223	82.6	1,218	40
2010	78,459	5366	421	153.9	1,962	35
2020	87,759	9261	813	282.2	3,216	33

Source: TUBITAK, 2008.

Economic growth, increasing population, migration from rural regions to urban and/or tourism regions have been leading more energy consumption in Turkey. Energy consumption of Turkey has grown substantially since the early 1970s. Annual GDP growth and population growth projections indicate that this trend will continue in near future (Baris and Kucukali, 2012). The total energy consumption is expected to reach 282.2 mtoe by the year 2020 (TUBITAK, 2008).

Table 2: Turkey's final energy consumption by resources

Type of resources (ktoe)	**2006**	**2010**	**2015**	**2020**
Hard Coal	14,721	17,282	26,884	48,156
Lignite	11,188	18,001	24,190	32,044
Oil	32,551	41,184	50,420	60,918
Natural Gas	28,867	37,192	44,747	51,536
Fuelwood	4023	3383	3075	3075
Geothermal (heat)	1081	1750	2836	4584
Geothermal (electricity)	330	330	330	330
Hydro	3556	4903	7060	9419
Solar	403	495	605	862
Wind	11	421	571	721
Asphaltite	259	301	301	301
Nuclear	0	0	8229	8229
Animal and vegetable residues	1146	1034	926	850
Growth rate, %		29	35	31

Source: Gokcol et al, 2009, p.425.

The Ministry of Energy and Natural Resources statistics shows that petroleum products, natural gas and coal are the main bulk of the energy consumption (MENR, 2010). Turkey has no significant oil and natural gas reserves and the country is highly dependent on imported primary energy resources. Dependency rate for natural gas, oil and hard coal are 93.3 %, 92 % and 91 %, respectively. Energy is the most important component of the trade deficit. Turkish total energy import has increased nearly ten folds in last 16 years and reached to 54,116 million US Dollars in 2011. The energy import share in total import has increased to 22.5 % of total import bill (TURKSTAT, 2012c). Hence, energy import dependency poses important burden on economy. Country's electricity consumption has grown at a rate of 9-10 % per year, except for the years of economic and financial crises. Electricity demand reached to 230,306 GWh in 2011, increased tenfold over the 25 years (TEIAS, 2012). Electricty demand is projected to reach 440.1 and 483.6 TWh in the low-and high scenario by 2020. In these scenarios, installed capacity (49,524 MW) is found to be raised up to 80,000 MW and 96,000 MW for low and high-scenario, respectively (TEIAS, 2011). According to the TEIAS (2011), electricity will be imported starting from 2016.

Energy sector suffers from the increasing electricity consumption caused by the changes in the economic structure in past decades.. Hence GHG has increased in last years. In 2011, Turkey's greenhouse gas emissions as CO_2 equivalent increased 115 % compared to 1990's emissions. Approximately 85% of total CO_2 emission has been emitted from energy sector and the rest portion, which is 15 %, was originated from industrial processes in 2011 (TURKSTAT, 2012d).

Like many developing countries, Turkey tries to substitute the use of fossil energy resources with renewable energy resources (Demirbas, 2008). The first renewable energy policy was created by the definition of renewable energy resources in Modification of the License Regulation in the Electricity Market in 2003. Before this legislation, there was no national renewable energy policy but a few incentives existed to promote market deployment of renewable energy (Koyun, 2007). Legislation activities in renewable energy have intensified in the last few years. The cornerstone of these activities was the Law on Utilization of Renewable Energy Resources for the Purpose of Generating Electrical Energy (No:5346) which was enacted in 2005. The main objective of this law was to increase the use of renewable energy sources for generating electricity. This law includes some incentives such as licensing, land appropriation and purchasing guarantee by a constant feed-in tariff (Budak, 2009). Also, Turkey adopted several targets for electricity from renewable sources which was defined in its Security of Supply Strategy. In this context, Turkey targets the share of renewable resources in electricity generation to be at least 30 % by 2023. Furthermore, the country's all economically available hydroelectric and wind potential will be utilized by 2023 (YPK, 2009).

3. Historical Background and Current Status of Biogas in Turkey

Turkey has quite rich country in terms of renewable energy potential but these available sources have not been exploited enough yet. Biogas is a renewable energy resource and it can be used for heating and electricity production. When it is compressed, it can also be used to fuel vehicles to replace compressed natural gas (Euroactive, 2010).

First biogas plant was operated in 1980. It was targeted to establish 1000 biogas plants by a Project which started by Ankara Research Institute of Rural Services in 1980. Many biogas plants started to operate in 1980s. But none of these facilities operates anymore. Although first anaerobic biotechnology studies started in 1980s, today it was known that there were 48 industrial facilities which rules outs the wastewater in Turkey. Moreover, İstanbul, Bursa, Konya and Ankara provinces produce biogas form landfill gas and use this gas for energy production (Ar et al, 2010). The distribution of different types of biogas power plants based on their installed capacities in Turkey is shown in Fig.2. Feed-in tariff application (13.3 $/kwh) positively affected the biogas sector but it is argued that this price incentive is still not sufficient for some renewables. There are 14 landfill power plants with a total installed capacity of 90 MW and 4 sewage power plants with a total capacity of 8.85 MW. Most of the installed landfill and sewage power plants are located in big cities like Istanbul, Ankara, Adana, Bursa, and Antalya. As of May 2012, based on Energy Market Regulatory Agency statistics (EMRA,2012), there are 33 licensed biogas power plants in Turkey. Biogas is produced in 13 provinces (Istanbul, Bursa, Adana, Ankara, Gaziantep, Bolu, Eskisehir, Denizli, Samsun, Konya, Sakarya, Izmit and Kayseri) and the total installed capacity of these biogas plants is 108 MW (Figure 2). Moreover, 7 more provinces will start producing biogas (Tekirdag, Mersin, Amasya, Antalya, Corum, Karaman and Osmaniye) and the capacity of 58.98 MW is now under construction in these provinces (EMRA, 2012).

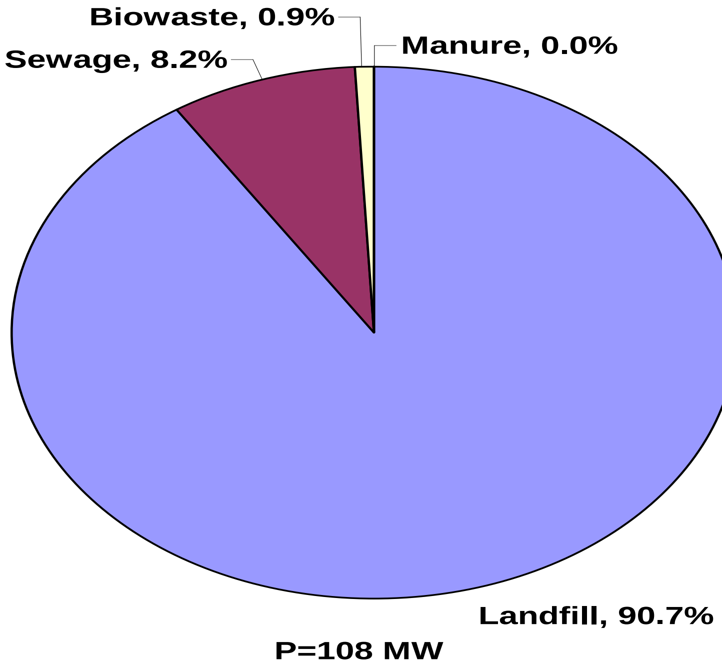

Figure 2: Distribution of the different types of biogas power plants based on their installed capacities by May 2012 in Turkey. Data source: EMRA (2012)

Although Turkey has important agricultural waste capacity, generating energy from agricultural waste is not common (Bascetincelik et al, 2010). Based on the conversion ratios of Koçer et al (2006), biogas potential from livestock manure is calculated as 2.95 billion m^3 per year in Turkey. Livestock manure can produce 1.8 million TEP biogas (or 2400 MW) and other wastes such as municipality waste, energy crops, organic industrial waste etc. can produce around 3 million TEP biogas (or 4000 MW) in Turkey. Moreover, Turkish-German Biogas Project Report (2011) states that this amount can be increased to 61.25 TWh /year when all the livestock manure, straw and energy crops, bio-waste, and landfills are harnessed (Table 4). This finding indicates that 30% of electricity demand in Turkey can be supplied from domestic biogas power plants.

Table 3: Biogas potential of livestock manure in Turkey

Type of livestock	Number of livestock	Quantity of manure (tonnes/year)	Biogas quantity (m^3/year)
Cattle	11,369,800	40,931,280	1,350,732,240
Sheep+goat	29,382,924	20,568,047	1,192,946,726
Hen+turkey	237,860,000	5,233,000	408,174,000
Total	278,612,724	66,732,327	2,951,852,966

***Source**: Prepared based on TURKSTAT (2012e) data by authors.*

Table 4: Biogas energy potential of Turkey

Fuel type	Biogas potential (PJ/year)	Biogas Potential (TWh)
Livestock Manure	78.4	21.79
Straw	27.7	7.70
Energy crops	81.3	22.60
Kitchen waste	22	6.11
Municipal waste	11	3.05

Data Source: Turkish-German Biogas Project Report (2011).

4. Sustainability Implications of the Deployment of Biogas Energy in Turkey

The clean energy industry is targeted as an important area for investment for both environmental and economic reasons. Building up a domestically produced clean energy supply such as biogas can provide energy independency and security, environmental benefits; contribute sustainable economic growth (Wei et al, 2009). Baris and Kucukali (2012) compared the renewable energy resources by multi-criteria analysis and they concluded that biomass energy was the most sustainable energy alternative among the other renewables in Turkey.

Transformative technologies such as renewable energy technologies could substantially change production chains, patterns of urbanization, agricultural practices and the transportation sector with new investments and entrepreneurship opportunities (Müller et al., 2009). More than 3.5 million green jobs have been created in recent years in renewable sector. Germany is a model country for biogas production and more than 20,000 jobs has been created by biogas production in Germany (REN21, 2011). In an example, biogas plants are one of the important elements in the Danish energy-policy of having reduced CO_2 emissions and created permanent jobs (Lund, 2010). Job creation, by creating substantial skilled as well as unskilled employment during the process of construction and other related activities is important for country's employment issue. Moreno and Lopez (2008) estimated that, 1 MW biogas production can create 25 job possibilities at construction and installation stage, and 6 job possibilities at operation and maintenance stage of the production.

Table 5: Employment distribution in renewable energy sector for Germany by 2011. Data source: Lehr and Ulrich (2012), AGEE-Stat (2012).

Renewable Type	Installed Capacity (MW)	Annual Electricity Generation (TWh/year)	Investment Employment[a]	O&M Employment	Fuel Supply Employment	O&M and Fuel Supply Employment per MW
Photovoltaics	24820	19	103300	7600		0.31
Wind	29075	46.5	82600	18500		0.64
Hydro	4401	19.5	3200	4100		0.93
Biogas	2869	17.5	21900	14100	14600	10.00

[a]*It includes R&D, manufacturing, project development and construction employment*

Patterns of employment in operations and maintenance are more stable and permanent (Breitschop et al., 2012); therefore employment in operation and maintenance has been taken into account in this study. The renewable energy employment data of Germany clearly show that the biogas power plants support and generate a significant number of jobs during operation and maintenance (O&M) when compared to other renewable power plants (Table 5). On a per megawatt basis, biogas employment from O&M provides nearly 10 times higher jobs than other renewable energy technologies as shown in Table 5. This is mainly because biogas is a labor-intensive technology and biogas creates additional jobs for fuel supply to the power plant during operation. This employment pattern of biogas plant supports local community and economy.

If 6,400 MW biogas potential is put into operation in Turkey, about 64,000 jobs can be created in the O&M and fuel supply sector. This opportunity would mitigate the unemployment problem in Turkey. Unemployment rate was 9.8 % in 2011of which 19.8 % was in young population (TURKSTAT, 2012e). Moreover, biogas related employment (indirect job) would occur in delivering and processing of biogas and these jobs are likely to be created in rural areas. Therefore, income will be generated and rural development will be stimulated in the country. This opportunity also can contribute to the issue of migration from rural areas to urban. Average migration rate from eastern part of the country to five main industrialized regions was around 8 % in 2011 (TURKSTAT, 2012f).

Total energy import in Turkey has increased nearly ten folds in the last 16 years and reached to 48281 million US Dollar in 2008 and 54,116 million US Dollar in 2011(TURKSTAT, 2012c). Development of biogas production will also mitigate energy security problem in Turkey. When 6,400 MW (4.8 million TEP) biogas is installed, 10 % of current total energy consumption (83372 thousand TEP in 2010) will be met by domestically produced biogas. Turkey's electricity demand is also increasing at a rate of 9-10 % annually. According to the TEIAS, based on production policy scenarios electricity will be imported starting from 2016 in Turkey (TEIAS, 2011). If the maximum potential of biogas (61.25 TWh) is utilized, this can meet 29 % of Turkey's electricity demand (210,434 GWh in 2010).

With increasing urbanization and industrialization, the annual waste quantity increases in Turkey. According to the TURSTAT (2012g), while waste quantity was 17,757 thousand tones annually in

1994, this amount reached to 25,277 thousand tones with 42 % increase in 16 years in Turkey. Moreover, according to the TURKSTAT (2012d) GHG emissions increased 114.9 % in 2011 compared to 1990 in Turkey. Around 76 % of CO2 equivalent GHG emission has been emitted from energy sector. Quantity of GHG emissions is expected to increase in short and medium term because of the increasing energy demand. Biogas production may therefore a profitable means of reducing or eliminating problems of urban wastes in many provinces by recycling them. Biogas production helps in promoting sanitation by eliminating wastes that are potential public nuisances and liabilities to public health and in controlling pollution through transforming wastes into useful organic fertilizer and feed material. This organic fertilizer enhances soil structure as well (Akinbami et al, 2001).

Replacing biogas in rural areas which usually uses coal and firewood will provide clean and smoke free energy unlike fossil fuels. In Turkey, although firewood usage quantity decreased in the last years, still firewood is used for warming up settlements especially in rural regions. According to the MENR (2010), wood was used for energy consumption as 3383 thousands TEP in Turkey in 2010 (MENR, 2010). Thus installation of biogas help reducing air pollution and hence reduces the risk of disease such as respiratory disease, cough, eye infection, etc. (Katuwal and Bohara, 2009 , Wargert, 2009).

5. Conclusions

Increasing energy demand of Turkey, mostly resulted from high population growth and rapid urbanization, is crucial issue for the country. Turkey has an important potential of renewable energy resources but this potential has not harnessed sufficiently. For example if the 6,400 MW biogas potential of the country can be converted into useful energy by means of electricity and heat, around 64,000 jobs could be created in O&M and fuel supply sector. Besides, deployment of biogas in rural areas can create local employment, stimulate local economy and increase agricultural productivity. Moreover, utilization of the agricultural waste can address local waste management problem and it can reduce greenhouse gas emissions.

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Environmental and traffic implications of cheap energy: Case study in the State of Kuwait

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Abstract

Rapid population growth in Kuwait, accompanied with rising standard of living, has resulted in a sweeping increase in the use of cars for transportation. According to the latest available census, there were 1,353,390 cars in the State of Kuwait in 2008 with an estimated population of 2,495,851, which amounts roughly to a car for every two persons in the country, which will surely have a huge impact not only on mobility of people which causes huge economic loss, but also will cause an untold damage to the urban environmental quality.

Road traffic flow in Kuwait city is characterized by frequently high level of congestion. This work focuses on investigating exhaust emission pollutants from passenger cars for idle and slow acceleration (stop-and-go) traffic conditions. We found that vehicle emissions of nitrous oxides (NO_x), carbon dioxides (CO_2), carbon monoxides (CO) and hydrocarbons (HC) were minimal during idle mode for all vehicle categories. However, it was interesting to observe that during the slow acceleration mode HC and CO emissions increased for light vehicles with relatively high mileage (higher than 40,000 km).

We can conclude from this study that with the growing vehicle ownership, and congestion it causes, the vehicular exhaust emissions is a major sources of air pollution in densely populated centers in the state of Kuwait, where idle and stop-and-go driving cycle is a common occurrence.

Many cities are reducing traffic congestion and air pollution by charging cars to enter the city. It is more likely this policy option will not work in Kuwait for there is no taxation system. Consequently, the pressure from transport system air quality is projected to continue in the near future.

A Cost-Benefit Analysis for Social Impact Assessment: the case of preventive measures in a hospital

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Abstract

Following an occupational risk assessment, it is necessary to take into account the associated costs and benefits of the preventive measures. Only a cost-benefit analysis (CBA) can capture all impacts resulting from work accidents and from the measures regarding Occupational Health and Safety. In the present paper a case study related to the application of this methodology to a Hospital is presented. An analysis of work accidents in six selected services has been made. Three of the major types of accidents have been selected: needle stings, falls and excessive efforts. Following the risk assessment, a series of preventive measures have been designed. A CBA analysis permits to evaluate the social impact of these measures, i.e. the assessment of the impact of preventive measures beyond the company, i.e. for the society. The Benefit/Cost ratio of these measures has been calculated. In some cases the ratio is much higher than one, showing a very high benefit.

Keywords: Cost Benefit Analysis, Social Impact Assessment, Externalities, Hospital

JEL Classification: D6 - Welfare Economics

1. Introduction

According to the European Agency for Safety and Health at Work (EU-OSHA, 2012), slips, trips and falls are the largest cause of accidents in all sectors from heavy manufacturing to office work. Other hazards include falling objects, thermal and chemical burns, fires and explosions, dangerous substances and stress. To prevent accidents occurring in the workplace, employers should establish a safety management system that incorporates risk assessment and monitoring procedures. Several steps are suggested to address risk situation when an organization performs an integrated analysis of risks in evaluating its Occupational Health and Safety (OHS) Management System. The organization should make a detailed analysis of the monetary impact (positive or negative) for the organization of each of the measures considered. According to Fabela and Sousa (2012), prevention has been encouraged by some European Union countries, including Portugal, through the principle of internalizing the costs of workplace accidents. The principle of internalization of costs is based on the allocation of costs to the employer or the individual that caused the costs.

However, it is also important to perform an analysis of the impact of each measure on society (externalities). The measures taken by an organization in the prevention of risks can have a positive indirect effect (positive externality) on society, while no action due to costs for the organization, can have a significant negative effect on society (negative externality). Thus, these effects should be duly considered in decision making (Ramos et al., 2012). It is considered that there is an external effect (externality) whenever an economic activity affects the welfare of another and when that independence is not internalized by a price mechanism or other mechanism (Cullis and Jones, 2009). For Varian (1992), the definition of externality is that the action of an agent directly affects the living conditions of another agent. Externalities can also be defined as: “the uncompensated impact of a person's actions on the well-being of a bystander” (Mann and Wüstemann, 2008). The externalities consist of social costs or benefits that come up beyond the scope of the project and influence the well-being of others without monetary compensation (EVALSED, 2009).

Tompa et al. (2006) have made a survey of a large number of studies of workplace-based occupational health and safety interventions. They concluded that very few economic analyses were undertaken amongst such a large number of workplace-based interventions, which shows that the economic analysis is rarely regarded as a critical component of an intervention study. Nevertheless, the perspective used shall consider the costs and consequences for the injured worker and his family and also to third parties, in particular public and private players (Silva et al., 1998).

The aim of the current paper is to present the application of the CBA to assess the impact to society of preventive measures regarding occupational health and safety in a hospital. Particularly, it aims at discussing the use of the cost-benefit analysis within the OHS domain. Accordingly, the paper is structured in the following way. Next section presents a literature review on this subject. Section 3 presents the case study and Section 4 presents and discusses the results obtained. The paper concludes with theoretical and managerial contributions and opportunities for further research.

2. Literature Review

The CBA on OHS is relatively underdeveloped and just a few and recent studies adopt this methodology to analyze and discuss the full impact of cost and preventive measures. Reniers & Audenaert (2009) have developed a decision-support methodology for safety investments in chemical plants. This methodology includes a cost-benefit analysis that tries to take into account quantifiable and non-quantifiable socio-economic consequences of accidents that can be avoided by preventive measures. Nevertheless, this model only considers costs for the company and for the worker, but not for the society. Cagno et al. (2013) have made a review of the economic evaluation of occupational safety and health and its way to SMEs, starting with more than 500 studies published since 2000. Despite differences in detail and/or terminology, most authors and institutions adopt the fundamental distinction between direct and indirect for valuing both costs and benefits. Cagno et al. (2013) concluded that this topic needs more multidisciplinary research.

In this context, cost-benefit analysis should provide answers to the following questions: What investments in OHS should be done? How much should be spent on preventive measures? When should each investment be made? among others (Ramos et al., 2012). A robust, properly tested and systematized methodology for economic assessment in the context of risk management will support decision making within the OHS context. Indeed, this represents a natural extension of ISO/IEC 31010:2009 in terms of techniques and tools for economic evaluation in risk management and assessment.

Table 1 presents social benefits and costs in terms of their external and internal dimensions.

Table 1. Social benefits and costs

Benefits and costs	External	Private	Social
Benefits	Agents who benefit from the positive externalities but do not pay for these advantages	Gains earned by agents who pay for	Sum of private and external benefits
Costs	Agents who suffer the negative externalities and who are not compensated	Costs paid by agents that have a direct benefit	Sum of private and external costs

The Health and Safety Executive (HSE, 2012) in Britain carried out a study on the total annual costs of accidents at work, taking average estimated values for the period between 2009 and 2012, as a reference. This study estimated that in Britain 638,000 workers suffered occupational accidents every year, of which 368,000 of low-gravity (with absence from work less than 4 days) and 271,000 with 4 or more days of absence. There were also 135 fatalities. As a result of these accidents, it is estimated that 16,000 workers had to leave work permanently. This study counts the cost of workplace accidents as cost to the company, to the worker and to the society.

The cost to the employer includes payments during the absence of the worker, insurance premiums, costs of production losses and administrative and legal costs. Moreover, the costs to the employee include lost wages, compensation costs, health and rehabilitation costs and other costs. There are also non-financial costs that match the value of pain and suffering, whose monetary value was estimated based on a methodology developed by Gordon et al. (1995). Finally, the costs to the state, which includes all costs not borne by employers or workers (e.g. costs related to the reduction of taxes, payment of benefits, medical treatment rehabilitation, administrative and legal related activities).

According to Targoutzidis and Karypidou (2009), in individual terms, one can estimate the value that people realize to their life and health in monetary terms, using two criteria: the willingness-to-accept and willingness-to-pay. The former estimates the monetary value that individuals accept for being exposed to a higher risk level. For example, a construction worker may accept a job with where the risk of falling is high by a monetary compensation. The latter assesses the monetary value that individuals would be willing to pay to reduce a risk to their life or health.

To estimate the non-financial costs of an work accident, the UK Health and Safety Executive (HSE, 2011; HSE, 2012) uses a methodology developed by Gordon et al. (1995). This methodology is based on the system developed by the Department of Transport of the United Kingdom, following the methodology "willingness to pay" and has been used in more recent reports prepared by the HSE.

In this research project, it was followed this methodology, which allows to estimate in monetary terms the non-financial costs related to the pain and suffering of the worker and his family in consequence of work related accidents. Thus, it was followed the relationship between the non-financial costs of an accident to the worker and the financial cost to the company, established in such studies (HSE, 2011; HSE, 2012). We present in Table 2 the relationship between these costs, depending on the type of the accident. Similarly, we followed the same basis for estimating externalities in terms of impact to the society, presented in the last column of Table 2. These studies of the Health and Safety Executive consider “costs to the government” as all costs of workplace accidents that are not supported by the company or by the worker. So, they can somehow be extrapolated as costs to the society. Table 2 shows the relationship between the cost to the worker and to society in terms of the costs related to the company, depending on the severity of the accident - data calculated from statistics of HSE (2011) and HSE (2012).

Table 2. Relationship between the cost to the worker and to society and the costs for the company

Type of Accident	C_{worker} / $C_{company}$	$C_{society}$ / $C_{company}$
Accident that does not lead to sick leave or whose sick leave is equal to or less than 3 days	0,67	5,33
Accident leading to sick leave for more than 3 days	4,22	1,30
Fatal accident	7,93	0,96

C_{worker} – Costs for the worker; $C_{society}$ – Costs for the society; $C_{company}$ – Costs for the company

These relationships allow us to make an estimation of the external costs to the company (externalities) from the computed internal cost of the accidents (from the perspective of the company). Furthermore, the authors have recently developed a model for Cost-Benefit Analysis in OHS (Ramos et al., 2012). This model permits to perform economic evaluations of risks and prevention initiatives from both the company and the society perspectives. It is an important tool to support managers and experts on economic analysis and decision making before the beginning of any intervention project related to occupational health and safety. The aim of the current paper is to present the application of this model in the hospital sector (Ramos et al., 2013).

3. The case study

The case study presented here regards to a public Portuguese hospital. The hospital is accredited according to CHKS Healthcare Accreditation Standards and has its own internal OHS Services. This study concentrates on six of the services, which were chosen in collaboration with the OHS services of the hospital, namely: three medicine services, two orthopedic services and the emergency services.

The risk assessment process permitted comparing the results of the risk analysis and the criteria to determine the likelihood that the risk and/or the respective magnitude is acceptable or tolerable (DNP ISO Guide 73, 2011). The risk assessment supports the decision about risk treatment. A semi-quantitative method to risk assessment has been applied in the hospital.

The occupational accidents in 2011 of these services have been studied using official statistical indexes, which allowed prioritizing the measures to be implemented. Costs corresponding to these occupational accidents have been estimated.

In the present paper, we have used the simple methodology proposed by Heinrich (1959) to calculate the indirect costs of the accidents, as it is the system used by the hospital. According to this methodology, indirect costs can be estimated as being four times the direct costs, so the total costs are five times the direct costs (Ramos et al., 2013).

As mentioned before, the risk evaluation has been made in six services. Following this risk evaluation, a detailed plan of the preventive measures to be implemented has been designed, with an estimation of the corresponding costs (Ramos et al., 2013).

An estimation of the benefits of these measures, in terms of the hospital and also for the society, has been made, based on the model developed by the authors (Ramos et al., 2012).

Regarding externalities related with the worker, we have to consider the benefits related to intangible aspects, including the implications for family stability, including pain and suffering. To convert these externalities in monetary terms, it was followed the methodology proposed by Gordon et al (1995), using for this purpose the most recent data published in the study conducted by the Health and Safety Executive and taking as reference average values estimated for the period between 2009 and 2012 in Britain (HSE, 2012), cited in the literature review.

Table 3 presents the total costs of accidents occurred in 2011 in the six services that have been studied. Costs with stings are presented autonomously, as these accidents have been studied in more detail. Total costs include both direct costs (costs presented in the second and third columns) as well as indirect costs. As mentioned before, total costs have been estimated as five times the direct costs, as proposed by Heinrich (1959).

Table 3. Costs of accidents in 2011 on the six services (in Euros)

Services	Costs with stings	Cost with other accidents	Total costs
Medicine A	0	230	1,150
Medicine B	1,500	0	7,500
Medicine C	900	1,587	12,435
Orthopaedic A	600	3,937	22,685
Orthopaedic B	0	2,778	13,890
Emergency	2,400	1,510	19,550
Total	5,400	10,042	77,210

On the other hand, the total costs of all the preventive measures are presented in Table 4.

Table 4. Annual cost of all the preventive measures in the six selected services (in Euros)

Service	Total costs
Medicine A	7.351,20
Medicine B	4.588,52
Medicine C	4.261,18
Orthopaedic A	3.569,16
Orthopaedic B	3.268,72
Emergency	12.432,96
Total	35.471,74

4. Cost-Benefit Analysis: Results and Discussion

The benefits to the hospital of the preventive measures result from the reduction of the accidents. This article discusses the particular case of preventive measures aimed at reducing the costs with stings. The benefits of these preventive measures were estimated considering that its adoption will result in a reduction of 80% of these accidents. This estimate was based on the opinion of the services of Hygiene and Safety of the Hospital.

Table 5 shows the (financial) Benefit/Cost ratio on the studied services, for accidents with stings. The second column of Table 5 shows the estimation of the benefits using the methodology explained above, whereas the third column shows the total cost of these preventive measures. The last column shows the Benefit/Cost ratio (financial).

Table 5. Financial Benefit/Cost ratio (B/C) of preventive measures for accidents with stings

Service	Benefit	Cost	B/C ratio
Medicine A	0,00	1.013,97	0,00
Medicine B	1.200,00	1.188,69	1,01
Medicine C	720,00	1.163,73	0,62
Orthopaedic A	480,00	864,21	0,56
Orthopaedic B	0,00	776,85	0,00
Emergency	1.920,00	5.931,96	0,32
Total	4.320,00	10.939,41	0,39

Therefore, the amount of benefit was calculated considering the total cost of the accident and the estimated 80% of reduction in accidents after the implementation of the preventive measures (e.g. in Medicine B 1200,00 = 0,80 x 1500,00).
If the B/C ratio is higher than 1, the preventive measures are effective, because the benefits outweigh the costs. Thus, high values of the B/C ratio correspond to very effective preventive measures.

Regarding externalities related with the workers, we have to consider intangible benefits, including the implications for family stability, pain and suffering of the worker who suffered an accident. To convert these externalities in monetary terms, it was followed the methodology proposed by Gordon et al. (1995), using for this purpose the most recent data published in the study conducted by the Health and Safety Executive on the total annual costs of accidents at work, taking as reference average values estimated between 2009 and 2012 in Britain (HSE, 2012).

To calculate the externalities they were used some questions from the model "Cost-Benefit Analysis in Occupational Safety and Health" of Ramos et al. (2012) and new items were also added, based on the study conducted by the Health and Safety Executive (HSE, 2012). The economic analysis of these preventive measures is presented in Table 6 considering their external benefits, either for the employee or for society. The intangible benefits were partially converted into monetary units, according to Table 2 (accidents without sick leave).

Table 6. Economic Benefits of preventive measures for accidents with stings

Externalities	Related with	Benefit (€)
Implications in terms of family stability, including pain and suffering	Worker	Intangible, estimated at 1.005,00
Development of new needles with safety mechanism	Society	Intangible
Other	National Health System Society	Intangible, not estimated

To calculate the first value, we used the amount of the second column of Table 2 and the average cost of accidents with stings (0,67 x € 1.500,00). Given that in 2011 there were 18 accidents with stings in the studied services studied of the hospital, we can estimate the external benefits to the company as higher than 18 x 1.005,00 = 18.090,00 euros. Thus, taking into account only the external benefit that was quantified, the B/C ratio of these measures will be:

Benefits: 4.320,00 + 18.090,00 = 22.410,00 €
Costs: 10.939,41€
B/C ratio = 2,05
This means that the profitability was 2 euros for every euro invested. That is, while the financial B/C ratio considering only the benefits to the hospital, is only 0,39, which does not justify the investment, the economic B/C ratio, regarding the external benefits which were quantified, is 2,05 amply justifying the investment in economic terms, i.e. if the social impact of these measures are considered.

5. Conclusions

This paper presented and discussed the application of Cost Benefit Analysis (CBA) in Occupational Health and Safety (OHS). CBA permits to perform economic evaluations of risks and prevention initiatives (including namely an ergonomic program) from both the company and society perspectives.

Nevertheless, like all the techniques and tools, CBA has strengths and limitations (ISO/IEC 31010:2009).Some of these strengths should be highlighted. Firstly, CBA allows costs and benefits to be compared using a single metric (money). Secondly, it provides transparency for the decision making process. On the other hand, some weaknesses may be identified namely, it requires detailed information to be collected, and benefits which accrue to a large population are difficult to estimate, particularly those relating to public goods which are not exchanged in markets. Furthermore, the practice of discounting future cash-flows assumes that benefits in the long term have little or negligible impact; which means that this method does not takes into account risks affecting future generations unless very low or zero discount rates are set.

The analysis of the financial Benefit/Cost ratio showed that, for the hospital considered in this case study, only part of the preventive measures defined in the risk assessment process are cost effective. This article discussed the particular case of preventive measures aimed at reducing the costs with stings. It was showed that the financial B/C ratio considering only the benefits to the hospital is relatively low, but the economic B/C ratio, fully justifies the investment.

Given the apparent lack of studies on the use of cost-benefit analysis related to OHS, this paper offers analyses the impact for society of preventive measures in a Portuguese hospital. A particular case (accidents with stings) is presented and explored. Nevertheless, additional work should be done. The study can be refined and extended in several ways. For example, for the preventive measures with B/C ratios lower than 1, they can be proposed changes or alternatives to improve their cost effectiveness. One direction for future research could be conducted extending the methodology to other preventive measures, studying different service, and under a multi-industry or multi-case background.

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A prospective analysis of the employment impacts of energy efficiency retrofit investment in Portugal by 2020

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Abstract

Energy efficiency plays a significant role in increasing the security of energy supply and mitigating climate change. Although this role is indubitable, there is an ongoing discussion about the employment impacts of promoting energy efficiency measures, in particular of retrofit investments. The purpose of this paper is to provide an estimation of the number of net jobs associated with the most common retrofit investment options in the building stock of Portugal. The examined investment options aim at improving the thermal properties of the building envelope and include the insulation of external walls and roof and the substitution of windows frames and window glazing. The implementation of a methodological framework for the assessment of employment benefits is based on Input-Output (I-O) analysis, providing consistent estimates for depicting the significant contribution of energy saving measures in the building sector (residential, private services and public services) in net employment generation.

Keywords: Input-Output analysis, Energy Efficiency, Buildings, Retrofit investment, Employment.

JEL Codes: C67, L94, Q48

1. Introduction

Improving energy efficiency is currently worldwide believed to be the cheapest, fastest and most environmental friendly way to meet a significant portion of the worlds' energy needs. Improved energy efficiency reduces the need for investing in energy supply. Therefore, countries need to pursue energy efficiency policies more diligently in the long-term regardless of the development of fuel prices (Kaygusuz, 2012).

The European Union (EU) has set itself the objective of achieving 20 % primary energy savings in 2020. In Portugal, the National Energy Strategy (NES) also foresees the approval of a National Energy Efficiency Action Plan (NEEAP) in its energy efficiency guidelines. Moreover, the Portuguese NES 2020 aims to foster the industrial cluster of energy efficiency, creating 21000 new jobs by 2020.

Since there is a strong interest on the promotion of energy efficiency through retrofit investments in buildings, it is somehow of public interest the monitoring of its impact on the employment. Therefore, the aim of this paper is to provide a consistent estimate of the contribution of the previously identified retrofit energy saving measures in the building sector (residential, private services and public services) in net employment generation, i.e., considering both the potential job creation and the potential job destruction resulting from the reduction of energy consumption. The paper is organized as follows: section 2 briefly reviews the latest literature on the subject; section 3 presents the methodological framework used herein; section 4 presents the implementation of the methodology in the Portuguese context after a brief characterization of the building sector in Portugal; section 5 presents some illustrative results, and finally section 6 highlights some conclusions and presents future work developments.

2. Review of previous studies

The macro-economic effects of energy efficiency are mostly expressed in the form of employment or economic growth (Vitorino et al., 2012). A number of studies have sought to estimate the employment potential of several energy efficiency measures in terms of employment factors, though chief methodological challenges remain when determining job creation (Lambert and Silva, 2012). Dacy et al. (1979) presented an analysis of the employment impacts of two types of energy conservation efforts, namely retrofitting of buildings and increased energy efficiency in the industrial sector in the United States of America (USA). Tiwari et al. (1996) evaluated several dimensions of low cost techniques in building construction in India and estimated the generation of on-site employment that occurred from these interventions. Clinch and Healy (2001) provided a template for economic evaluation of domestic energy-efficiency programs. In their study they estimated the number of jobs resulting from the implementation of various energy efficiency technologies in the Irish dwelling stock over a ten-year period. Scott et al. (2008) analyzed the macroeconomic impacts of increasing energy efficiency in the USA's residential and commercial building stock, using Input-Output (I-O) analysis. Kuckshinrichs et al. (2010) examined the social impacts (employment and fiscal revenues) of an energy conservation program in Germany. Ürge-Vorsatz et al. (2010) estimated the net employment impacts of a large-scale energy efficiency renovation programme in Hungary, simulating five scenarios. Lehr et al. (2011) presented the results of the implementation of an efficiency strategy in Germany until 2020 which is focused on cost-effective measures. The outcomes obtained show that improved energy efficiency results in a variety of positive effects on the economy and the environment, namely on additional employment and economic growth. Billington et al. (2012) have demonstrated in their study that there is a triple win available of warmer homes, greater energy efficiency and economic growth if carbon taxes revenue can be used to benefit consumers and fuel poor households in particular in United Kingdom (UK). Burr et al. (2012) analyzed the potential of a national building energy rating and disclosure policy to create jobs and reduce energy-related expenditures in commercial and multifamily residential buildings in USA.

Among the energy efficiency measures available, energy retrofit measures are known to be some of the most cost effective ways of saving energy and reducing greenhouse gas emissions. In addition, such measures can result in a significant number of local and national employment opportunities. According to IEA (2009) energy efficiency retrofit investments in buildings can be more labour-intensive than any other key climate intervention. Retrofits require the upgrade of old buildings, involving the physical and operational upgrade of thermal conditions of buildings, leading to lower energy consumption. In this context, there are four key categories that we have identified as important to integrate into a retrofit project: window frames, window glazes and roof and wall insulation.

3. Methodological Framework

I-O matrices allow the representation of each sector's production process through a vector of structural coefficients that describes the relationship between the intermediate inputs consumed in the production process and the total output. The supply side is split into several processing industries that deliver their total output (production), for intermediate consumption or final demand. These relationships can be illustrated through the following equation:

$$x_i = \sum_{j=1}^{n} x_{ij} + y_i \qquad (3.1)$$

where x_i is the output of sector *i*, x_{ij} is the input from sector *i* to sector *j,* and y_i is the total final demand for sector *i*.

The monetary values in the transactions matrices can then be converted into ratios called technical coefficients. This is done by dividing each cell of the domestic intermediate matrix by its column total (output at basic prices).

Considering the hypothesis of constant returns to scale, equation (3.1) becomes:

$$x_i = \sum_{j=1}^{n} a_{ij} x_j + y_i \quad (3.2)$$

in which the coefficients a_{ij} are the amount of input delivered by sector *i* to sector *j* per unit of sector's *j* output, known as technological coefficients (or direct coefficients).

The productive system at a national level can then be represented through the following basic I-O system of equations:

$$\mathbf{x} = A\mathbf{x} + \mathbf{y} \quad (3.3)$$

where A is a matrix of technological coefficients, **y** is a vector of final demand, and **x** is a vector of the corresponding outputs.

In order to finally calculate the output multipliers, one needs to derive Leontief inverse matrices.

Equation (2.3) can then be rearranged to:

$$\mathbf{x} = (I - A)^{-1}\mathbf{y}, \quad (3.4)$$

where I is the identity matrix with convenient dimensions and $(I - A)^{-1}$ is also known as the Leontief inverse. Each generic element, b_{ij}, of $(I - A)^{-1}$ represents the total amount directly and indirectly needed of good or service *i* to deliver a unit of final demand of good or service *j*.

3.1. Employment multiplier concepts and basic assumptions

Usually in models that account for job creation, jobs are measured in terms of job-years or full time equivalency. In our study, a job is a metric that represents the amount of resources necessary to employ one person for forty hours per week for a full year (i.e. full time employment – FTE).

Although precise definitions vary, direct jobs herein considered refer to the jobs generated from a change in spending patterns resulting from an expenditure or effort taken in a retrofit project (Bell, 2012). Thus, the direct job contribution of a retrofit measure in terms of employment can easily be obtained by considering the direct job coefficients (jobs per output) of each activity sector engaged in all the activities of that retrofit measure. Indirect jobs are generated in the supply chain and supporting industries of an industry that is directly impacted by an expenditure or effort (Bell, 2012). Induced jobs are generated by the re-spending of income resulting from newly created direct and indirect jobs (Bell, 2012).

Since the employment to output ratio is given for each sector in an I-O table, the overall significance and contribution of an industry to total employment can also be calculated by assuming that the sectorial employment ratios are fixed.

Thus, the indirect contribution of an industry to either total output or employment is not simply observable unless the multiplier and flow-on effects are taken into account. Therefore, the employment multiplier may be interpreted as the impact on the overall employment if the final demand in sector *j* increases by one unit. The employment multiplier for sector *j*, E_j^m, is thus defined as follows:

$$E_j^m = \sum_{i=1}^{n} (e_i) b_{ij} \ , \qquad (3.5)$$

where e_i denotes the number of persons with FTE per one Euro output for each sector *i*, b_{ij} is the *i*, j^{th} element of the closed Leontief inverse matrix and *n* is the number of sectors. These multipliers would represent the number of new jobs created expressed as total employment for every new employee to meet increased final demand of new output. Nevertheless, one may wish to relate the simple or total employment effect to an initial change in employment, not to final demand (and output) in monetary terms. In this situation the employment multiplier, E_j, is:

$$E_j = \sum_{i=1}^{n} \frac{(e_i) b_{ij}}{e_j} \qquad (3.6)$$

4. Implementation of the methodology in Portugal

The building sector represents about 40% and 30% of total energy consumption in the European Union and Portugal, respectively. Since this particular sector is expanding, it is expected an increase of its energy consumption. Therefore, the reduction of energy consumption in the building sector is an important measure for reducing the CO_2 emissions and energy dependency (Directive nº 2010/31 EU). According to the Energy Efficiency Plan (EEP) (Communication of the European Commission nº 109/2011) the building sector offers the greatest energy saving potentials. The EEP is focussed on the instruments aimed at promoting the process of renovation in public and private buildings and thus improving the energy performance of the components and appliances used in them.

In Portugal, the first regulation related to energy performance and thermal comfort of buildings was endorsed in 1990 and required that new buildings and great refurbishments of existing buildings implemented measures to improve building energy performance. In the sequence of the previous European Directive on the energy performance of buildings (Directive nº 2002/91/EC) that was addressed to the Member States, a package of new regulation was enforced in Portugal in 2006 and is currently binding. In the building sector, the Portuguese legislation includes regulations regarding the energy and indoor air quality performance in buildings through the National System of Energy Certification and Indoor Air Quality in Buildings (SCE) (Decree-law nº 78/2006), according to the requirements and statements contained in the Regulation of Building Climatization of Energy Systems (RSECE) (Decree-law nº 79/2006), and according to the Regulation of the Characteristics of Thermal Behaviour of Buildings (RCCTE) (Decree-law nº 80/2006). This new legislation package is stricter than the previous one and is either applicable to the new or older buildings needing great rehabilitation interventions. Therefore, the major potential for energy efficiency improvements exists in buildings which have been constructed before 1990, when the first thermal insulation regulation was enacted. These buildings represent 71% of the existing building stock and 20% of this percentage have been constructed before 1945.

In order to estimate the direct, indirect and induced employment effects associated with the implementation of energy efficiency retrofit investment in the Portuguese building sectors it was first necessary to use an I-O symmetrical product by product table for total flows.The I-O table herein used was also used in Oliveira et al. (2013) and is given at current prices of 2008.

Our analysis is focussed on buildings from the residential, private services and public services sector, considering two different construction stages: buildings dating back to 1945 and buildings constructed within the range of 1946 to 1990. Four key categories have been identified as important to be integrated into a retrofit project: window frames, window glazes and roof and wall insulation.

The total investment costs associated with the implementation of the retrofit investments considered were first disaggregated to account for the economic sectors directly involved with each retrofit investment. Moreover, we assumed that the impact on employment regarding these interventions is expected to occur within the country.

Figure 1 depicts the sectoral distribution of the investment for each of the interventions herein tackled, which was based on several experts' opinions (academics and practitioners in the field of energy efficiency).

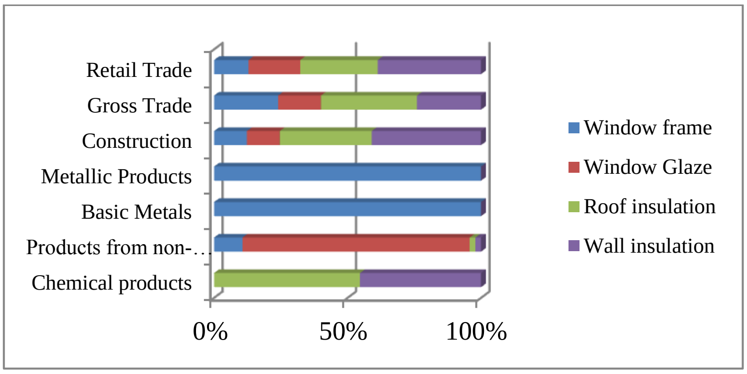

Figure 1. Sectoral distribution of each retrofit investment

The unit investment costs (at basic prices) are given in Table 1 and were estimated for 2008 (the base year of our study) and were based on Assadi et al. (2012) and Martins et al. (2009).

Table 1. Unit costs of each retrofit measure

Retrofit measure (€/m^2)	**Year of construction**	
	<1945	**1946 - 1990**

Roof thermal insulation	18	13
Opaque facades	35	25
Double glazed windows	75	75
Windows Frame	151	151

5. Illustrative results

The results of the analysis are expressed in man-years per 1000 m^2 of useful floor space (see Table 2).

For an illustrative purpose we will only provide the sectoral distribution of the total estimated employment effects (direct, indirect and induced employment) for each energy efficiency strategy in single dwellings with four facades, although this could be depicted for all types of buildings herein considered (see Figure 2).

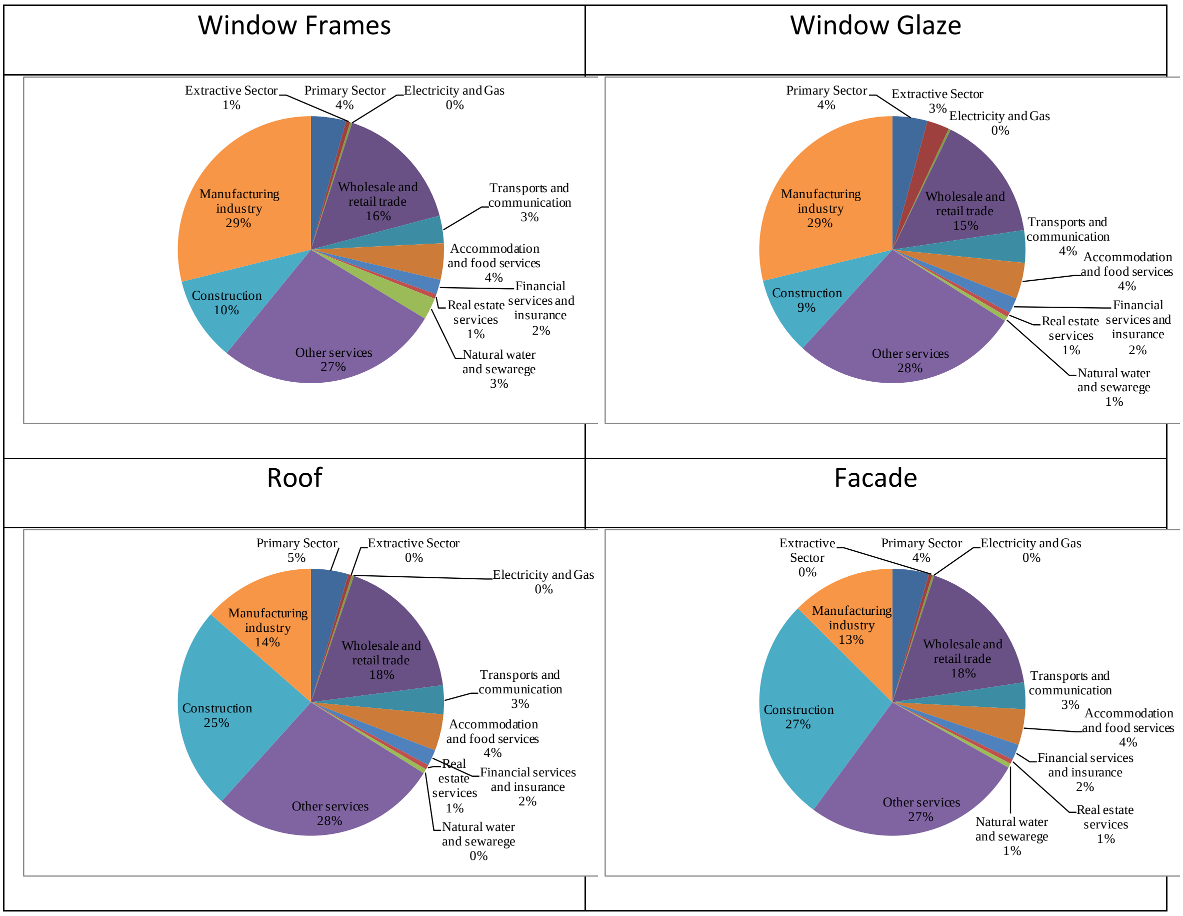

Figure 2. Sectoral distribution of the total estimated employment effects for a single dwelling with four facades (considering 1000 m^2 of useful floor space).

Table 2. Employment impacts for each building type and retrofit measure

Building Function	Building Type	Nº of Facades	Retrofit Investment	Direct Jobs (Man-Year / 1000m2)	Indirect Jobs (Man-Year / 1000m2)	Induced Jobs (Man-Year / 1000m2)	Total (Man-Year / 1000m2)
Residential	**Single Dwelling (<1945)**	4	Window Frame	0.1268	0.1056	0.2225	**0.4550**
			Window Glaze	0.0754	0.0632	0.1173	**0.2558**
			Facade Insulation	0.3472	0.3244	0.6241	**1.2956**
			Roof Insulation	0.0914	0.0903	0.1740	**0.3557**
		2	Window Frame	0.0737	0.0614	0.1294	**0.2645**
			Window Glaze	0.0438	0.0368	0.0682	**0.1487**
			Facade Insulation	0.2018	0.1886	0.3628	**0.7533**
			Roof Insulation	0.0914	0.0903	0.1740	**0.3557**
	Apartment Building, 3 floors (1946 - 1990)	4	Window Frame	0.1125	0.0937	0.1973	**0.4034**
			Window Glaze	0.0668	0.0561	0.1040	**0.2268**
			Facade Insulation	0.1721	0.1608	0.3093	**0.6421**
			Roof Insulation	0.0440	0.0435	0.0838	**0.1712**
		2	Window Frame	0.0664	0.0553	0.1164	**0.2381**
			Window Glaze	0.0394	0.0331	0.0614	**0.1339**
			Facade Insulation	0.1015	0.0949	0.1825	**0.3790**
			Roof Insulation	0.0440	0.0435	0.0838	**0.1712**
Private Services	**Apartment Building, 3 floors**	4	Window Frame	0.9513	0.7922	1.6688	**3.4124**
			Window Glaze	0.5652	0.4742	0.8794	**1.9188**

	(<1945)		Facade Insulation	0.2264	0.2115	0.4070	**0.8450**
			Roof Insulation	0.0610	0.0602	0.1160	**0.2371**
	Apartment Building, 4 floors (1946-1990)	2	Window Frame	0.5310	0.4422	0.9314	**1.9046**
			Window Glaze	0.3154	0.2647	0.4908	**1.0710**
			Facade Insulation	0.0451	0.0422	0.0811	**0.1684**
			Roof Insulation	0.0330	0.0326	0.0628	**0.1284**
Public Services	**Apartment Building, 3 floors (<1945)**	4	Window Frame	0.3765	0.3136	0.6605	**1.3506**
			Window Glaze	0.2237	0.1877	0.3481	**0.7595**
			Facade Insulation	0.0896	0.0837	0.1611	**0.3344**
			Roof Insulation	0.0610	0.0602	0.1160	**0.2371**
Public Services	**Apartment Building 3 floors (1946-1990)**	4	Window Frame	0.3765	0.3136	0.6605	**1.3506**
			Window Glaze	0.2237	0.1877	0.3481	**0.7595**
			Facade Insulation	0.0640	0.0598	0.1151	**0.2389**
			Roof Insulation	0.0440	0.0435	0.0838	**0.1712**

After analysing the total results of Table 2 it might be concluded that the buildings with highest job generation potential belong to private and public services, involving the replacement of single by double glazed windows and with or without frame replacement. This fact occurs due to the higher extension of the glazed area in this type of buildings. In the residential sector the highest job impacts are obtained with external thermal insulation of the opaque facade in dwellings with four facades built before 1945, when the construction materials had lower quality levels.

The prospective results for 2020 were obtained taking into account the necessary estimated retrofit investments per useful floor space according to the information provided in Martins et al. (2009). Figure 3 illustrates the assignment per useful floor space of the retrofit measures that are expected to take place in the current building stock until 2020. The NEEAP incentives for the investment on the replacement of non efficient glazed areas in the residential sector was herein considered, which accounts for 200 thousand dwellings until 2015. In addition, we have also considered the NEEAP incentives regarding thermal insulation (roof and facades), which considers 100 thousand dwellings to be refurbished until 2015. For the public and private service sectors we have considered that 39% of the total stock building area needs retrofit investment, where 3% of these are extremely damaged builds (Martins et al., 2009).

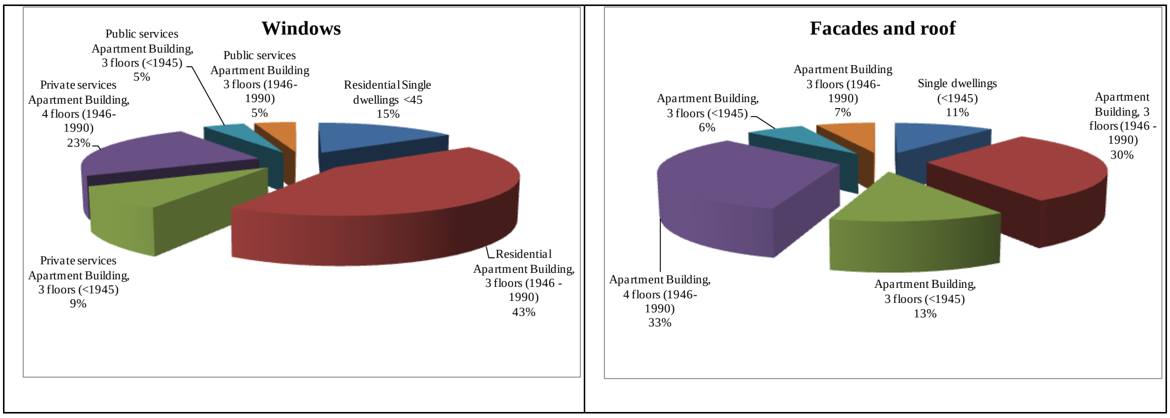

Figure 3. Assignment of retrofit investments according to the useful floor space

In order to obtain the possible negative impacts of energy efficiency savings on employment we have considered that the building heating and cooling systems are obtained from electric loads. This assumption does not comply with the recent building stock (particularly in the residential sector), but it is reasonable to assume that the building stock built before 1990 mainly uses electricity for space heating and cooling. Figure 4 illustrates the total expected energy savings obtained for each retrofit measure taking into account the total heated area and the replacement of single by double glazed windows with and without frame replacement (left hand side and right hand side of Figure 4

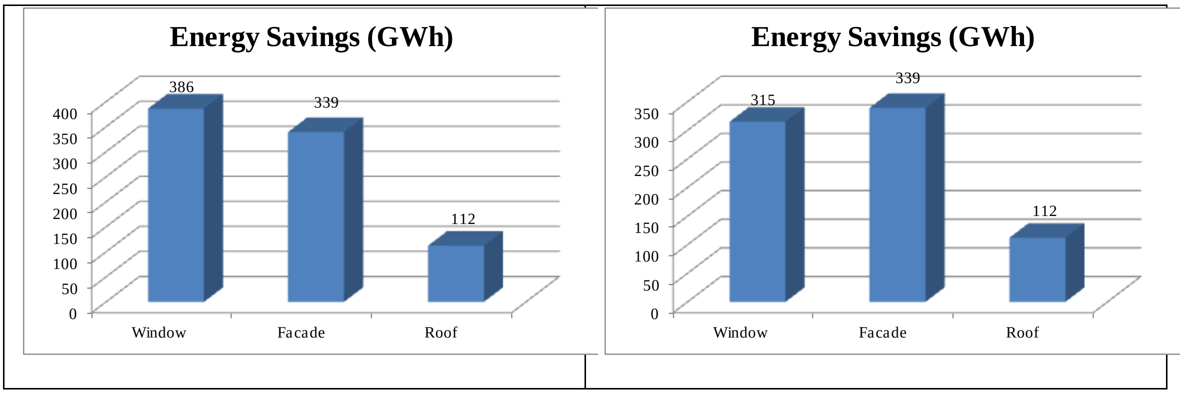

Figure 4. Expected energy savings in GWh per retrofit measure

Table 3. Net job creation in 2020 considering windows with or without frame replacement

Nº of jobs	Job creation	Job destruction	Net Job creation
Direct jobs	6.437	359	6.078
Indirect Jobs	5.604	2.824	2.780
Induced Jobs	11.641	5.426	6.215
Total Jobs	23.683	8.609	15.074

Nº of jobs	Job creation	Job destruction	Net Job creation
Direct jobs	4.348	329	4.020
Indirect Jobs	3.875	2.584	1.292
Induced Jobs	7.632	4.965	2.667
Total Jobs	15.856	7.877	7.979

The data depicted in Table 3 was achieved considering a best and worst scenario regarding window replacement. On the left hand side it can be observed the expected job generation with the replacement of single double glazed windows and frames. On the right hand side of this table, the expected job generation only with the replacement of single by double glazed window is presented.

After analysing Table 3 it is possible to conclude that the retrofit measures tackled in this study have a great potential in job generation creating much more jobs than the expected destruction by the energy savings accomplished. Nevertheless, it is worth noting that the rebound effect was not handled in this study.

6. Conclusions

The main purpose of this study was to assess the impact of four specific energy efficiency retrofit measures on direct, indirect and induced jobs in several types of buildings, representing 71% of the building stock in Portugal. The measures chosen to perform the analysis involved the thermal insulation of roof and the opaque facades and the replacement of the existing glazed windows with more efficient ones. The difference of the results obtained by considering the replacement of frames in windows was significant regarding the opposite option. The first option allowed for lower levels of energy consumption and also higher levels of net job generation. This situation occurs because of the higher investment required for the implementation of this measure. Regarding the destruction of employment, both situations are identical although the first one generates slighter negative impacts. The target buildings belong to the residential, private services and public sectors and have been constructed before 1990, the year of the enactment of the first Portuguese regulation related to thermal performance of buildings.

This study also highlights that energy efficiency investments have advantages over a set of other climatic alternatives, namely the increase of energy security and higher social benefits, because the electricity bill can be reduced, higher comfort levels can be attained and also because of its positive net impact on employment generation, what is in accordance with current European, and namely Portuguese, energy policy.

Future work is currently under way in order to encompass other impacts of energy efficiency measures, in particular the rebound effect and the impact of the re-investment of the money saved by these measures on the overall sectors of the economy.

Acknowledgments

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Sustainable Development in Portuguese Business Organizations: Performance Dimensionality and Utilization Patterns

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ABSTRACT

The objective of this study is to gain understanding of practices related to corporate sustainability performance measures and measurement. The performance measurement practices in terms of utilization, relevance, and availability of information are studied for a sample of seventy-two (72) Portuguese executives. The data collected is analyzed using cluster, and gap analysis. The results of this study underscore consistent patterns pointing to a lack of a broad perspective on sustainability performance measurement. Executives should promote the utilization of effective information systems, which can help them on the interaction with stakeholders, and to obtain key information related with their organization' sustainability.

Keywords: Sustainable development, Sustainability, Performance Measurement, Organizational Performance, Portuguese Executives.

JEL classification: M 20; M 21; L 25; Q 48; Q 56

1. Introduction

During the first decade of the 21st century we have witnessed the development and the implementation of sustainability strategies and operations in business organizations of several industries. Due to this trend, managers of these business organizations were forced to change the way they were doing the corporate reporting (Bonacchi & Rinaldi, 2007). Therefore, new challenges have emerged in the performance measurement and management process.

The integration of sustainable development at the firm level, appears as a paradigm shift (Richards & Gladwin, 1999). In this context business organizations have been involved in identifying and managing the impacts of their activities in the new environmental context (WBCSD, 2002). This integration forced business organizations to upgrade their performance measurement systems with new performance measures in order to monitor activities and daily operations related with the corporate sustainability dimension.

The debate on the application of the concept of sustainable development at the firm level is far from consensual in academic terms. It is also definitely marked by political and scientific challenges that keeps current this debate (Barkemeyer, Holt, Preuss, & Tsang, 2011).

Assuming corporate sustainability as having two fundamental dimensions: a balanced management between economic prosperity, environmental protection and social equity, and a permanent interaction and dialogue with stakeholders (Kleine & Von Hauff, 2009), it becomes relevant to analyse the influence of these dimensions on design and implementation of the organizational performance measurement systems.

In this context, the objective of this study is to gain understanding of practices related to corporate sustainability performance measures and measurement. The performance measurement practices in terms of utilization, relevance, and availability of information are studied for a sample of Portuguese firm executives.

2. Relevant Literature

During the last decade, business organizations have been increasingly under pressure to embrace the sustainable management philosophy and to integrate it in their performance measurement systems (Bonacchi & Rinaldi, 2007; Hubbard, 2009). According to the World Commission on Environment and Development (WCED) sustainable development configures the development that meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987). In this context, business organizations are facing three types of challenges:

- The dichotomy between humankind and the natural environment, as it seeks to meet present aspirations (Barkemeyer, Holt, Preuss, & Tsang, 2011);
- The inter-generational justice, in order to promote the future development and establish temporal equity (Sikdar, 2003);

- The assumption that all the world is interconnected and responses should be given on a global level and as a common unit (Blasco, 2006).

In order to overcome these challenges and incorporate sustainability on their activities and processes, managers should cover three sustainability dimensions (Blasco, 2006; Labuschagne, Brent, & van Erck, 2004; Tregidga & Milne, 2006):

- The economic dimension, which is based on prosperity as a result of value creation tradable in markets;
- The environmental dimension, which is based on the preservation of biodiversity as a result of the balance between human needs and the regenerative capacity of the environment;
- The social dimension which is based on equity as a result of inclusive processes for human rights and freedoms universally accepted.

The conceptual foundations of sustainability and its applicability on business organizations can be focused on the following three different approaches:

- Business organizations should take only as concern the creation of value by focus on the economic sustainability and shareholders satisfaction (Friedman, 1970). In this context, business organizations tend to gradually integrate environmental and social sustainability forced by values, customs, and legislation evolution.
- Business organizations should integrate the impacts of their activities, according to the global critical issues in terms of ecological and social systems (Richards & Gladwin, 1999; Robèrt, 2000). Therefore, managers of business organizations should avoid the planning and control of their operations based on external pressures. They must anticipate the changes undergoing in society and in the environment (Richards & Gladwin, 1999).
- Business organizations should promote their operations within a framework that meets the expectations of stakeholders (Epstein & Roy, 2001; Schaltegger & Burritt, 2009; Schaltegger, Herzig, Kleiber, & Müller, 2003; Skouloudis, Evangelinos, & Kourmousis, 2009), (Hubbard, 2009). This approach underline the importance of dialogue with stakeholders as a way to assure sustainability (Tregidga & Milne, 2006; Wilson, 2003).

Managers that want to follow a sustainability approach in the design, implementation, and utilization of organizational performance management systems, may face several challenges, including:

- The promotion of strategic analysis and strategic formulation according the stakeholders involvement (Borga, Citterio, Noci, & Pizzurno, 2009);
- The consistent integration of objectives, targets and actions in accordance with the vision of corporate sustainability (Schaltegger & Wagner, 2006);
- The systematization of transparency in reporting compliance (Lamberton, 2005).

Despite of the progressive integration of the sustainability approach, (Bansal, 2005), business organizations that want to be competitive in the global market continue to face difficulties to change their traditional performance systems. The following practices are the main barriers to this change:

- The value creation continue to be assessed by the financial dimension (Bansal, 2005).
- The perception that measuring the financial value is more tangible (Robinson, Anumba, Carrillo, & Al-Ghassani, 2006)
- The lack of experience in measuring non-financial performance dimensions (Perez & Sanchez, 2009).

Usually, managers of business organizations are choosing the most used performance measurement systems in the market as a shortcut to satisfy their needs on corporate sustainability performance. Standard PMS has contributed to an aggregation of principles and methodologies for sustainability performance measurement systems (Hussey et al., 2001; Perez & Sanchez, 2009). However, the proliferation of PMS appears as a difficulty for these managers to design and use effective PMS which are customized to their business organizations (Perrini & Tencati, 2006; Staniškis & Arbačiauskas, 2009). Nevertheless, these standardized approaches can be used as startup to their own sustainable performance measurement systems (Araújo, Bueno, Sousa, & Mendonça, 2006; GRI, 2006; Székely & Knirsch, 2005).

Existing PMS are characterized by similar principles to measuring the corporate sustainability performance, namely:

- The involvement of stakeholders (Lo, 2010),
- The linkage between the needs of stakeholders and company operational activities (Blasco, 2006; Hubbard, 2009; Schaltegger & Wagner, 2006),
- The integration of the three sustainability dimensions (economic, environmental and social) (Adams & Frost, 2008; Bansal, 2005; Epstein & Roy, 2001; Hubbard, 2009; Kleine & von Hauff, 2009; Schaltegger & Burritt, 2009; Schaltegger et al., 2003; Skouloudis et al., 2009).

According to literature, the existing corporate sustainability performance measurement systems can be categorized into four distinct groups:

- Global systems - Based on global/world sustainable indicators translated into strategic and processes indicators at enterprise level (Richards & Gladwin, 1999; Robèrt, 2000)
- Stakeholders systems - Based on the identification of expectations and critical issues through dialogue with stakeholders, translated in the formulation of indicators associated with the results of the engagement process (Bonacchi & Rinaldi, 2007; von Geibler, Liedtke, Wallbaum, & Schaller, 2006)

- Triple Bottom Line (TBL) systems - Based on the methodological structure across the three dimensions of sustainability (economic, environmental, and social), including the product life cycle (Bakshi & Fiksel, 2003; Hubbard, 2009; Sikdar, 2003)
- Adapted systems - Based on traditional methodologies used in strategic and operational contexts originally not sustainable based (eg. Sustainable Balanced Scorecard), integrating one or several dimensions of corporate sustainability dimensions (Bonacchi & Rinaldi, 2007; Schaltegger & Wagner, 2006; Staniškis & Arbačiauskas, 2009)

The utilization of sustainability reports has been the most common response to sustainable performance monitoring (Hubbard, 2009). However this practice presents some limitations:

- They are not integrated with the conventional economic reports components (Hubbard, 2009; Schaltegger & Wagner, 2006);
- They only focus on the positive aspects of performance (Hubbard, 2009);
- Reports are descriptive, without measures to be used in the benchmarking of performance (Cooper & Owen, 2007; Lamberton, 2005)
- Frameworks used in the collection, analysis, reporting and audit has an internal orientation and does not involve other stakeholders (Perrini & Tencati, 2006; (Hubbard, 2009);
- They are much more focused on the environmental dimension than on the social dimension (Hubbard, 2009).

In this context, the selection of sustainability measures need to be specific in nature, including the following characteristics (Staniškis & Arbačiauskas, 2009; Székely & Knirsch, 2005; Tanzil & Beloff, 2006):

- Consistent and reproducible
- Complementary to legislation and regulations
- Useful in decision-making
- Systematically consider each stage in the product life

3. Methodology

3.1 Sample and Procedure

The data for this exploratory investigation were obtained from a convenience sample. Participants belong to PROCESS ADVICE global marketing database. Six hundred and twenty seven (627) executives of Portuguese business organizations were invited to participate by email, using a PDF template or filling an online questionnaire.

Seventy two (72) completed responses were received. Thus, resulting in a response rate of approximately 12%. According to Table 1, the sample includes business organizations from different industries. These business organizations represent different dimensions, with different types of certifications.

3.2 Instrument

For the purpose of this research, the twelve major sustainable measuring guidelines were analyzed (Exhibit 1). Based on that analysis, seventy-four (74) performance measures where included in the research instrument. According the classification used on these guidelines, measures are organized in three categories/dimensions, namely economic, environmental, and social. For each of the measures included in the instrument, executives were asked to classify the nature and characteristics of the measure used on a 1 to 5 Likert-type scale.

Exhibit 1 – Sustainability guidelines

Name	Publication/ revision date	Organization
Guidance on Corporate Responsibility Indicators in Annual Reports	2008	United Nations Conference on Trade and Development (UNCTAD)
KPI´S FOR ESG – A guideline for the integration of ESG into financial analysis and corporate valuation	2010	EFFAS- European Federation of Financial Analysts Societies /DVFA - Society of Investment Professionals in Germany
Sustainability Reporting Guidelines	2006	GRI- Global Reporting Initiative
Indicadores Ethos de responsabilidade Social Empresarial	2012	Instituto Ethos
The Ethibel Sustainability Index (ESI)	2004	ETHIBEL FORUM
Dow Jones Sustainability Index (DJSI)	2012	SAM -Sustainable Asset Management AG/ DJS- Dow Jones Indexes
The Initiative for Responsible Investment (IRI)	2010	The Hauser Center and Initiative for Responsible Investment (IRI)
Measuring eco-efficiency - a guide to reporting company performance	2000	The World Business Council for Sustainable Development (WBCSD)
FTSE4Good index	2001	FTSE Group
The Sigma Guidelines - Putting Sustainable Development into Practice – a guide for organisations	1999	UK Department of Trade and Industry (DTI)
Sustainable Development Progress Metrics -Recommended for use in the Process Industries	2003	Institution of Chemical Engineers (IChem)
ISO 26000:2010, Guidance on social responsibility	2010	International Organization for Standardization (ISO)

3.3 Models, Variables, and Data Analysis

The data obtained from the participants was analyzed using cluster analysis, and gap analysis. The objective of the data analysis was to obtain a profile of the participating executives in terms of their extent of utilization in assessing the different aspects of their organizational performance. In the first phase of the data analysis, clusters analysis was used to evaluate responses. The frequency of use that executives associated with each of the 74 (seventy four) performance measures, their perceptions of the measure predictive value, and ease of acquiring information for each on the studied measures were evaluated. The number of clusters was set to 5 in order to be consistent with the scale used on the research instrument (Dempsey, Gatti, Grinnell, & Cats-Baril, 1997; Gomes, Yasin, & Lisboa, 2004, 2006).

The second phase of the data analysis utilized gap analysis to gain a better understanding of the relative importance of the non-financial measures as perceived by the executives. The differences between the predictive value and the ease of information Acquisition for each of the 74 measures were examined. These differences were then multiplied by their predictive values to find the GAP indicator, as below:

$$GAP_i = (PV_i - EA_i)PV_i$$

The differences were multiplied by their predictive values to provide scores that reflect the relative importance of the predictive value for the measure utilized (Dempsey et al., 1997; Gomes et al., 2004, 2006). In this context, the larger the gap indicator is, the greater the disparity between the usefulness of the measure and its information availability.

4. Results

4.1 Cluster Analysis Results

This study focuses on three categories of performance measures, namely economic, environmental, and social. The results of the cluster analysis for each measure frequency of use, predictive value and ease of acquiring information are reported in Tables 2, 3 and 4. The first column in these tables presents the cluster number. The second column designates the measure. The third column designates the category to which the measure belongs. In the fourth column, the average of the executives' responses is reported. The fifth column reports the standard deviation. Finally, the last column reports the coefficient of variation.

The cluster analysis results related to frequency of use are presented in Table 2. The first two clusters include the nineteen measures most used by the executives. Eleven of these measures are social related, and eight are economic related. The absence of measures related to environmental category is noted.

Based on the results in Table 2, cluster 5, which includes the least used measures, consists of five measures from economic category, twelve measures from environmental category, and eighteen measures from social category.

The cluster analysis results related to the executives' perceptions of the predictive value of each of the 74 measures are presented in Table 3. The first two clusters include ten measures from the economic category, and ten measures from social category. The absence of measures related to environmental category is noted.

Based on the results in Table 3, cluster 5, which includes the least used measures, consists of five measures from economic category, twelve measures from environmental category, and seventeen measures from social category. The fact that most of the measures from environmental category appear to be among the measures least used (Table 2), as well as considered as having low predictive values (Table 3) is noted. It appears that participants tended to utilize measures, which they believe to have high predictive values. While the predictive value appears to influence the extent of use, it is certainly not the only determinant of extent of use. Other factors are also important in determining the extent of use.

The cluster analysis results related to ease of acquisition of information are presented in Table 4. The first two clusters include eight measures from the economic category, eleven measures from social category, and one measure from environmental category. Based on the results in Table 4, cluster 5, which includes the least used measures, consists of four measures from economic category, twelve measures from environmental category, and sixteen measures from social category.

4.2 Gap Analysis results

To understand the reasons behind the apparent lack of relative use of some of the performance measures, on the part of the executives, the relationships among the predictive values and the ease of information acquisition values for each of the 74 measures were examined using the indicator (GAP) equation below:

$$GAP_i = (PV_i - EA_i)PV_i$$

As was mentioned earlier in the methodology section, the larger is this indicator (GAP), the greater is the disparity between the usefulness of the measure and its availability. Negative or relatively small values for the gap indicator indicate a surfeit of information. Thus, the measures studied were divided in two groups. The first group included those measures with negative indicators (Table 5a). Thus, indicating an excess of information on these measures relating their usefulness.

The second group included those measures with GAP values above the average (0.35) of positive GAP values. Table 5b shows the measures with the largest disparity between their usefulness and their information availability. Thus, reflecting the lowest availability of information. Among those measures, four measures from economic category, six measures from environmental category, and six measures from social category are found.

5. Conclusion

The objective of this investigation is to examine the role and nature of sustainability measures in the context of information availability on these measures, their extent of utilization and their perceived relevance. Specifically, the extent of use, importance and availability of information for a group of seventy four (74) economic, environmental and social measures, as seen by seventy-two (72) business executives. The results of this study derived from cluster analysis and gap analysis lead to the following conclusions.

First, there appear to be a consistent pattern of utilization, relevance and availability of information in relation to practices associated with the studied measures. In this context, Portuguese executives, in ways similar to most of their counterparts in other business cultures, appear to be consistently utilizing traditional financial and efficiency-based measures. To be noted that measures more utilized from the social dimension are related with customer's satisfaction, product/service quality control and human resource management. This utilization pattern seems to be related with the certification approach followed by most of the business organizations included in studied sample, namely ISO 9001. Companies that chose to implement this quality management system have to meet compliance requirements related with product/service quality control, customer satisfaction measurement and human resource competencies. The most used financial measures are related with legal obligations. This level of utilization seems to be due to information regarding most of these measures appears to be readily available. However, executives' perceptions that these measures have high predictive value can also contribute to their utilization.

Second, the underutilization of a high number of measures related to social and environment corporate performance, namely related with stakeholders' interaction, and with global environmental issues, may justify the lack of relevance of the sustainable approach on business practices and their performance measurement. In this context it seems that SME´s are more focused on financial and nonfinancial efficiency measures.

Finally, the study seems to point to a relative difficulty in obtaining information related with measures of important performance dimensions, including the relationship with costumers, the human resources management, and the global environmental issues. However, there is a consistent pattern between the underutilization of these measures and their predictive value. This is a bad consistency which can be viewed as a barrier to the increased use of performance measurements relating to sustainability. To promote the use of performance measures related with sustainable key issues and become more competitive in global marketplace, business organizations should use information systems that can help their connection with stakeholders and effectively monitor the global sustainability issues.

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Table 1 – Respondents' Profile

Item	Frequency	Percentage
Number of employees		
From 1 to 9	20	27.8
From 10 to 49	32	44.4
From 50 to 249	17	23.6
From 250 to 499	2	2.8
From 500 or more	1	1.4
Total:	72	100.0
UE classification		
Micro Enterprise	18	25.0
Small Enterprise	31	43.0
Medium Enterprise	19	26.4
Big Enterprise	4	5.6
Total:	72	100.0
Industry		
Manufacturing	29	40.3
Service	33	45.8
Commerce	10	13.9
Total:	72	100.0
Certification		
Not implemented	19	26.3
ISO 9001	53	73.6
ISO 14001	7	9.7
OHSAS 18001	9	12.5
Corporate Social Responsibility Standard (SA 8000, NP 4469-1, etc…)	2	2.8
Others Certification (e.g. product)	3	4.2

Table 2 – Cluster Analysis Results Relative to Frequency of Use Measures

Cluster	Measure	Cat.	Average	Stand. Deviation	Coefficient of Variat.
1	Level of customer satisfaction	SO25	4,25	0,93	0,22
	Operating costs	EC7	4,14	1,25	0,30
	Sales	EC1	4,11	1,24	0,30
	Net Profits	EC13	3,88	1,31	0,34
	Financial costs	EC8	3,82	1,29	0,34
	Employee wages and benefits	EC10	3,82	1,21	0,32
	Number of Complaints	SO24	3,68	1,52	0,41
2	Total number of training hours	SO14	3,46	1,16	0,34
	After sale non-conformities detected	SO23	3,43	1,54	0,45
	Compliance with product information	SO22	3,42	1,52	0,44
	Cash flows	EC2	3,39	1,31	0,39
	Non-conformities detected during production cycle	SO21	3,39	1,57	0,46
	Costs per unit produced	EC9	3,31	1,36	0,41
	Employee performance evaluation	SO17	3,22	1,48	0,46
	Professional composition (Nº technical staff, plant staff, ...)	SO18	3,19	1,36	0,43
	Taxes	EC11	3,13	1,27	0,41
	Total workforce by employment type	SO6	3,10	1,34	0,43
	Total of health and safety training hours	SO12	3,01	1,44	0,48
	Total number of external training and education actions	SO15	2,97	1,30	0,44
3	Return on Investment	EC6	2,92	1,27	0,44
	Marketing communication value	SO26	2,79	1,29	0,46
	Proportion of workers hired from the local community	EC21	2,79	1,53	0,55
	Return on assets	EC4	2,76	1,25	0,45
	Distribution salary by gender and function	SO19	2,75	1,33	0,48
	Total water consumption	EN4	2,69	1,49	0,55
	Percent of workers involved in the prevention of accidents	SO10	2,67	1,47	0,55
	Revenues from sales of assets	EC5	2,65	1,35	0,51
	Product/service risk assessment related to client	SO20	2,64	1,45	0,55
	Materials used by weight or volume	EN1	2,57	1,55	0,60
	Social contributions value	EC16	2,56	1,40	0,55
	Direct energy consumption by primary energy source.	EN3	2,54	1,50	0,59
	Value of insurance premiums for employees benefits	EC17	2,51	1,43	0,57
	Value spending on locally-based suppliers	EC20	2,49	1,40	0,56
	Reconciliation of work and family life	SO16	2,48	1,38	0,56
	Financial assistance value received from government	EC18	2,45	1,33	0,54
	Return on equity	EC12	2,44	1,22	0,50
	Revenues from financial investments	EC3	2,43	1,30	0,53
	Accidents and / or occupational diseases	SO11	2,42	1,51	0,62
	Total weight of waste by type	EN12	2,39	1,52	0,64

(Continued)

Table 2 (cont.)

Cluster	Measure	Cat.	Average	Stand. Deviation	Coefficient of Variat
4	Initiatives to mitigate environmental impacts of products and services	EN14	2,24	1,42	0,64
	Employee turnover by age group, gender, and region	SO7	2,24	1,36	0,61
	Percentage of recycled products and packaging	EN15	2,06	1,37	0,67
	Range of ratios of lower wage compared to local minimum wage	EC19	2,00	1,32	0,66
	Environment externalities costs (CO2, water treatment costs)	EC15	1,99	1,28	0,64
	Community investments	EC14	1,96	1,11	0,57
	Total water discharge by quality and destination.	EN11	1,96	1,41	0,72
	Indirect economic impacts	EC23	1,93	1,21	0,63
	Percentage of employees covered by collective bargaining agreements	SO8	1,89	1,34	0,71
	Location and size of land owned	EN5	1,83	1,26	0,69
	Percent of investment contracts with human rights/ethics safeguards	SO1	1,82	1,28	0,70
	Percentage of supplies evaluated on the criteria of ethics/human rights	SO2	1,79	1,29	0,72
5	Percentage of materials used that are recycled input materials	EN2	1,75	1,08	0,62
	Impact assessment of operations in the community	SO28	1,75	1,18	0,67
	Total number and volume of significant spills	EN13	1,74	1,21	0,70
	Total direct and indirect greenhouse gas emissions	EN7	1,69	1,10	0,65
	Actions to influence public policies for sustainable development	SO32	1,69	1,21	0,71
	Value of environmental fines and penalties	EN16	1,67	1,24	0,74
	Monetary value of fines related to product utilization by client	SO27	1,67	1,17	0,70
	Number of initiatives collective negotiation with unions/employees	SO4	1,64	1,17	0,71
	Average notification period(s) for significant operational changes	SO9	1,60	1,10	0,69
	NOx, SOx, and other significant air emissions	EN10	1,58	1,12	0,71
	Value of contributions to public policies	SO33	1,58	1,02	0,64
	Value of investments provided primarily for public benefit	EC22	1,56	0,97	0,62
	Risks assessment related to corruption	SO29	1,56	1,09	0,70
	Emissions of ozone-depleting substances	EN9	1,54	1,05	0,68
	impacts of activities, products, and services on biodiversity	EN6	1,53	0,90	0,59
	Other relevant indirect greenhouse gas emissions	EN8	1,53	1,02	0,67
	Total number of incidents of discrimination detected	SO3	1,51	1,10	0,73
	Number of occurrences of child labor (including subcontractors)	SO5	1,51	1,19	0,79
	Agreements with unions on health and safety issues	SO13	1,51	0,96	0,63
	Monetary value of fines for legal non-compliance	SO35	1,51	0,93	0,61
	Actions taken in response to incidents of corruption.	SO31	1,39	0,90	0,65
	Anti- corruption training	SO30	1,35	0,86	0,64
	Number of legal actions for unfair competition	SO34	1,32	0,84	0,64

Note: Clusters were predefined to 5 to provide an analogy with the scale used on the questionnaire

Table 3 – Cluster Analysis Results Relative to Measures Predictive Value

Cluster	Measure	Cat.	Average	Stand. Deviation	Coefficient of Variat.
1	Level of customer satisfaction	SO25	4,35	0,89	0,20
	Operating costs	EC7	4,03	1,16	0,29
	Financial costs	EC8	3,92	1,15	0,29
	Employee wages and benefits	EC10	3,85	1,11	0,29
	Number of Complaints	SO24	3,79	1,38	0,36
	Net Profits	EC13	3,78	1,28	0,34
2	Sales	EC1	3,64	1,20	0,33
	After sale non-conformities detected	SO23	3,64	1,42	0,39
	Total number of training hours	SO14	3,51	1,17	0,33
	Cash flows	EC2	3,49	1,16	0,33
	Employee performance evaluation	SO17	3,49	1,30	0,37
	Compliance with product information	SO22	3,47	1,43	0,41
	Costs per unit produced	EC9	3,43	1,22	0,36
	Professional composition (ex. Nº technical staff, plant staff, etc ...)	SO18	3,38	1,30	0,39
	Non-conformities detected during production cycle	SO21	3,38	1,53	0,45
	Taxes	EC11	3,28	1,35	0,41
	Total number of external training and education actions	SO15	3,25	1,30	0,40
	Total of health and safety training hours	SO12	3,24	1,36	0,42
	Return on Investment	EC6	3,20	1,27	0,40
	Total workforce by employment type	SO6	3,15	1,37	0,43
3	Distribution salary by gender and function	SO19	2,96	1,39	0,47
	Percent of workers involved in the prevention of workplace accidents	SO10	2,86	1,48	0,52
	Marketing communication value	SO26	2,86	1,34	0,47
	Total water consumption	EN4	2,85	1,43	0,50
	Return on assets	EC4	2,85	1,21	0,43
	Product/service risk assessment related to client	SO20	2,82	1,45	0,51
	Proportion of workers hired from the local community	EC21	2,82	1,45	0,51
	Revenues from financial investments	EC3	2,81	1,32	0,47
	Revenues from sales of assets	EC5	2,80	1,34	0,48
	Reconciliation of work and family life	SO16	2,80	1,34	0,48
	Accidents and / or occupational diseases	SO11	2,78	1,57	0,57
	Value of insurance premiums for employees benefits	EC17	2,76	1,52	0,55
	Social contributions value	EC16	2,73	1,37	0,50
	Materials used by weight or volume	EN1	2,68	1,57	0,59
	Direct energy consumption by primary energy source.	EN3	2,67	1,40	0,52
	Return on equity	EC12	2,66	1,25	0,47
	Value spending on locally-based suppliers	EC20	2,63	1,43	0,54
	Financial assistance value received from government	EC18	2,58	1,28	0,50
	Total weight of waste by type	EN12	2,56	1,52	0,59
	Employee turnover by age group, gender, and region	SO7	2,56	1,49	0,58

(Continued)

Table 3 (Cont.)

Cluster	Measure	Cat.	Average	Stand. Deviation	Coefficient of Variat.
4	Range of ratios of lower wage compared to local minimum wage	EC19	2,42	1,39	0,58
	Initiatives to mitigate environmental impacts of products and services	EN14	2,40	1,46	0,61
	Percentage of recycled products and packaging	EN15	2,39	1,52	0,64
	Percentage of employees covered by collective bargaining agreements	SO8	2,22	1,50	0,68
	Community investments	EC14	2,21	1,36	0,62
	Indirect economic impacts	EC23	2,18	1,31	0,60
	Total number and volume of significant spills	EN13	2,18	1,41	0,65
	Total water discharge by quality and destination.	EN11	2,17	1,43	0,66
	Environment externalities costs (CO2, water treatment costs)	EC15	2,16	1,31	0,61
	Location and size of land owned	EN5	2,13	1,44	0,68
	Monetary value of fines related to product utilization by client	SO27	2,10	1,39	0,66
5	Percentage of materials used that are recycled input materials	EN2	2,06	1,33	0,65
	Number of occurrences of child labor (including subcontractors)	SO5	2,06	1,58	0,77
	Total direct and indirect greenhouse gas emissions	EN7	2,04	1,25	0,61
	Percentage of supplies evaluated on the criteria of ethics/human rights	SO2	2,04	1,44	0,71
	Impact assessment of operations in the community	SO28	2,04	1,30	0,64
	Actions to influence public policies for sustainable development	SO32	2,04	1,39	0,68
	Percent of investment contracts with human rights/ethics safeguards	SO1	2,03	1,38	0,68
	Total number of incidents of discrimination detected	SO3	1,96	1,34	0,68
	Average notification period(s) for significant operational changes	SO9	1,96	1,32	0,67
	Value of environmental fines and penalties	EN16	1,94	1,37	0,70
	Risks assessment related to corruption	SO29	1,93	1,33	0,69
	Emissions of ozone-depleting substances	EN9	1,90	1,20	0,63
	NOx, SOx, and other significant air emissions	EN10	1,89	1,26	0,67
	Impacts of activities, products, and services on biodiversity	EN6	1,88	1,20	0,64
	Number of initiatives collective negotiation with unions/employees	SO4	1,88	1,32	0,70
	Value of investments provided primarily for public benefit	EC22	1,87	1,16	0,62
	Monetary value of fines for legal non-compliance	SO35	1,85	1,25	0,68
	Other relevant indirect greenhouse gas emissions	EN8	1,83	1,20	0,65
	Agreements with unions on health and safety issues	SO13	1,82	1,15	0,63
	Value of contributions to public policies	SO33	1,79	1,10	0,61
	Anti- corruption training	SO30	1,75	1,12	0,64
	Actions taken in response to incidents of corruption.	SO31	1,75	1,17	0,67
	Number of legal actions for unfair competition	SO34	1,64	1,14	0,70

Note: Clusters were predefined to 5 to provide an analogy with the scale used on the questionnaire

Table 4 – Cluster Analysis Results Relative to the Ease of Information Acquisition Measures

Cluster	Measure	Cat.	Average	Stand. Deviation	Coefficient of Variat.
1	Level of customer satisfaction	SO25	4,06	1,10	0,27
	Operating costs	EC7	3,94	1,19	0,30
	Financial costs	EC8	3,92	1,14	0,29
	Sales	EC1	3,88	1,28	0,33
	Employee wages and benefits	EC10	3,88	1,20	0,31
	Net Profits	EC13	3,78	1,25	0,33
	Number of Complaints	SO24	3,76	1,41	0,37
	Total number of training hours	SO14	3,65	1,15	0,31
2	After sale non-conformities detected	SO23	3,54	1,45	0,41
	Professional composition (ex. Nº technical staff, plant staff, etc ...)	SO18	3,49	1,30	0,37
	Non-conformities detected during production cycle	SO21	3,49	1,51	0,43
	Compliance with product information	SO22	3,44	1,43	0,42
	Total workforce by employment type	SO6	3,43	1,41	0,41
	Taxes	EC11	3,42	1,30	0,38
	Total of health and safety training hours	SO12	3,42	1,37	0,40
	Cash flows	EC2	3,38	1,30	0,39
	Employee performance evaluation	SO17	3,29	1,44	0,44
	Total number of external training and education actions	SO15	3,21	1,30	0,41
	Costs per unit produced	EC9	3,18	1,27	0,40
	Total water consumption	EN4	3,14	1,46	0,47
3	Proportion of workers hired from the local community	EC21	3,04	1,46	0,48
	Revenues from sales of assets	EC5	3,01	1,47	0,49
	Return on Investment	EC6	3,01	1,27	0,42
	Distribution salary by gender and function	SO19	3,00	1,36	0,45
	Value of insurance premiums for employees benefits	EC17	2,96	1,53	0,52
	Percent of workers involved in the prevention of workplace accidents	SO10	2,96	1,43	0,48
	Value spending on locally-based suppliers	EC20	2,94	1,41	0,48
	Marketing communication value	SO26	2,93	1,35	0,46
	Revenues from financial investments	EC3	2,92	1,38	0,47
	Accidents and / or occupational diseases	SO11	2,85	1,53	0,54
	Social contributions value	EC16	2,83	1,44	0,51
	Return on assets	EC4	2,82	1,25	0,44
	Financial assistance value received from government	EC18	2,78	1,45	0,52
	Return on equity	EC12	2,76	1,31	0,47
	Reconciliation of work and family life	SO16	2,72	1,31	0,48
	Direct energy consumption by primary energy source.	EN3	2,68	1,43	0,53
	Materials used by weight or volume	EN1	2,67	1,53	0,57
	Product/service risk assessment related to client	SO20	2,65	1,40	0,53
	Employee turnover by age group, gender, and region	SO7	2,63	1,50	0,57
	Total weight of waste by type	EN12	2,58	1,57	0,61
	Range of ratios of lower wage compared to local minimum wage	EC19	2,54	1,46	0,57
	Monetary value of fines related to product utilization by client	SO27	2,49	1,51	0,61

(Continued)

Table 4 (Cont.)

Cluster	Measure	Cat.	Average	Stand. Deviation	Coefficient of Variat.
4	Percentage of employees covered by collective bargaining agreements	SO8	2,46	1,59	0,65
	Location and size of land owned	EN5	2,38	1,45	0,61
	Initiatives to mitigate environmental impacts of products and services	EN14	2,31	1,39	0,60
	Value of environmental fines and penalties	EN16	2,26	1,58	0,70
	Total number and volume of significant spills	EN13	2,22	1,48	0,67
	Percentage of recycled products and packaging	EN15	2,22	1,42	0,64
	Average notification period(s) for significant operational changes	SO9	2,18	1,45	0,66
	Community investments	EC14	2,17	1,28	0,59
	Total water discharge by quality and destination.	EN11	2,11	1,46	0,69
	Environment externalities costs (CO2, water treatment costs)	EC15	2,10	1,30	0,62
	Percent of investment contracts with human rights/ethics safeguards	SO1	2,10	1,52	0,72
	Monetary value of fines for legal non-compliance	SO35	2,04	1,42	0,70
	Percentage of materials used that are recycled input materials	EN2	2,01	1,25	0,62
	Indirect economic impacts	EC23	1,97	1,16	0,59
	Number of occurrences of child labor (including subcontractors)	SO5	1,97	1,52	0,77
	Percentage of supplies evaluated on the criteria of ethics/human rights	SO2	1,96	1,41	0,72
	Impact assessment of operations in the community	SO28	1,93	1,21	0,63
	Agreements with unions on health and safety issues	SO13	1,92	1,32	0,69
	Number of initiatives collective negotiation with unions/employees	SO4	1,88	1,35	0,72
	Value of contributions to public policies	SO33	1,83	1,19	0,65
	Value of investments provided primarily for public benefit	EC22	1,83	1,16	0,63
	Actions to influence public policies for sustainable development	SO32	1,82	1,25	0,69
	Total number of incidents of discrimination detected	SO3	1,79	1,31	0,73
	Total direct and indirect greenhouse gas emissions	EN7	1,75	1,03	0,59
	Number of legal actions for unfair competition	SO34	1,75	1,24	0,71
	NOx, SOx, and other significant air emissions	EN10	1,68	1,12	0,67
	Risks assessment related to corruption	SO29	1,68	1,06	0,63
	Emissions of ozone-depleting substances	EN9	1,65	1,05	0,64
	Anti- corruption training	SO30	1,65	1,08	0,65
	Actions taken in response to incidents of corruption.	SO31	1,64	1,10	0,67
	Other relevant indirect greenhouse gas emissions	EN8	1,57	0,95	0,61
	Impacts of activities, products, and services on biodiversity	EN6	1,50	0,86	0,57

Note: Clusters were predefined to 5 to provide an analogy with the scale used on the questionnaire

Table 5a – Measures with a Negative Gap Indicator

Rank	Measure	Cat	PV	EA	GAP
39	Direct energy consumption by primary energy source.	EN3	2,67	2,68	-0,04
40	Total weight of waste by type	EN12	2,56	2,58	-0,07
41	Value of contributions to public policies	SO33	1,79	1,83	-0,07
42	Total number and volume of significant spills	EN13	2,18	2,22	-0,09
43	Employee wages and benefits	EC10	3,85	3,88	-0,11
44	Distribution salary by gender and function	SO19	2,96	3,00	-0,12
45	Percent of investment contracts with human rights/ethics safeguards	SO1	2,03	2,10	-0,14
46	Employee turnover by age group, gender, and region	SO7	2,56	2,63	-0,18
47	Agreements with unions on health and safety issues	SO13	1,82	1,92	-0,18
48	Number of legal actions for unfair competition	SO34	1,64	1,75	-0,18
49	Accidents and / or occupational diseases	SO11	2,78	2,85	-0,19
50	Marketing communication value	SO26	2,86	2,93	-0,20
51	Return on equity	EC12	2,66	2,76	-0,26
52	Social contributions value	EC16	2,73	2,83	-0,27
53	Percent of workers involved in the prevention of workplace accidents	SO10	2,86	2,96	-0,28
54	Range of ratios of lower wage compared to local minimum wage	EC19	2,42	2,54	-0,30
55	Revenues from financial investments	EC3	2,81	2,92	-0,31
56	Monetary value of fines for legal non-compliance	SO35	1,85	2,04	-0,36
57	Professional composition (ex. Nº technical staff, plant staff, etc ...)	SO18	3,38	3,49	-0,37
58	Non-conformities detected during production cycle	SO21	3,38	3,49	-0,37
59	Average notification period(s) for significant operational changes	SO9	1,96	2,18	-0,44
60	Taxes	EC11	3,28	3,42	-0,46
61	Total number of training hours	SO14	3,51	3,65	-0,49
62	Financial assistance value received from government	EC18	2,58	2,78	-0,51
63	Percentage of employees covered by collective bargaining agreements	SO8	2,22	2,46	-0,52
64	Location and size of land owned	EN5	2,13	2,38	-0,53
65	Value of insurance premiums for employees benefits	EC17	2,76	2,96	-0,54
66	Revenues from sales of assets	EC5	2,80	3,01	-0,59
67	Total of health and safety training hours	SO12	3,24	3,42	-0,59
68	Value of environmental fines and penalties	EN16	1,94	2,26	-0,62
69	Proportion of workers hired from the local community	EC21	2,82	3,04	-0,63
70	Monetary value of fines related to product utilization by client	SO27	2,10	2,49	-0,82
71	Total water consumption	EN4	2,85	3,14	-0,83
72	Value spending on locally-based suppliers	EC20	2,63	2,94	-0,84
73	Sales	EC1	3,64	3,88	-0,86
74	Total workforce by employment type	SO6	3,15	3,43	-0,88

Table 5b – Measures with Gap Indicators above Average of the Positive Values

Ord	Measure	Cat	PV	EA	Gap
1	Level of customer satisfaction	SO25	4,35	4,06	1,26
2	Costs per unit produced	EC9	3,43	3,18	0,86
3	Impacts of activities, products, and services on biodiversity	EN6	1,88	1,50	0,70
4	Employee performance evaluation	SO17	3,49	3,29	0,68
5	Total direct and indirect greenhouse gas emissions	EN7	2,04	1,75	0,60
6	Return on Investment	EC6	3,20	3,01	0,59
7	Other relevant indirect greenhouse gas emissions	EN8	1,83	1,57	0,48
8	Emissions of ozone-depleting substances	EN9	1,90	1,65	0,48
9	Risks assessment related to corruption	SO29	1,93	1,68	0,48
10	Product/service risk assessment related to client	SO20	2,82	2,65	0,47
11	Indirect economic impacts	EC23	2,18	1,97	0,46
12	Actions to influence public policies for sustainable development	SO32	2,04	1,82	0,46
13	Percentage of recycled products and packaging	EN15	2,39	2,22	0,40
14	Cash flows	EC2	3,49	3,38	0,39
15	NOx, SOx, and other significant air emissions	EN10	1,89	1,68	0,39
16	After sale non-conformities detected	SO23	3,64	3,54	0,35

DAY 10 - 16:30		
Room 642 - Energy Efficiency 3		
Techno-economic evaluation of cogeneration units considering carbon emission savings	Ana Cristina Magalhães Ferreira[1]; Manuel Lopes Nunes[1]; Senhorinha Teixeira[1]; Luís Martins[1]	[1]University of Minho
Energy efficiency of a city hotel – Bringing together energy savings and life cycle costs	Manuela Walsdorf-Maul[1]; Kathleen Schwabe[1]; Falk Schaudienst[1]	[1]Technische Universität Berlin
Energetic efficiency analysis of the agricultural biogas plant in 250 kWe experimental installation	Jacek Dach, Krzysztof Pilarski, Piotr Boniecki, Jacek Przybył, Damian Janczak, Andrzej Lewicki, Wojciech Czekała, Kamil Witaszek, Pablo César Rodríguez Carmona, Marta Cieślik	Institute of Biosystems Engineering, Poznan University of Life Sciences, POLAND
A comparative study of the evolution on energy efficiency between 1960 - 2009 across 4 European countries	João Catarino[1]; André Cabrera Serrenho[1]; Tânia Sousa[1]	[1]Instituto Superior Técnico, Technical University of Lisbon

Techno-economic evaluation of cogeneration units considering carbon emission savings

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ABSTRACT

The introduction of combined heat and power production systems has gained increasing policy attention, because these are often considered to be less polluting and more efficient than conventional production units. As a consequence, these energy systems can contribute to reduce various polluting gas emissions and enhance security of energy supply on a national level.

This paper presents a model based on a cost-benefit analysis applied to a cogeneration system for a small-scale application, considering the Portuguese framework and the harmonized efficiency reference values for the production of electricity and heat. The model includes the identification of the objective function terms, i.e., the elements involved in the financial analysis across the lifetime of the system and the economic evaluation of costs and benefits of the combined heat and power production system. CHP viability depends significantly on the system type and on the specific load conditions of the facility as well as on political support schemes implemented in the respective countries.

A strategic approach is necessary to adequately embed the new technology as a feasible solution in terms of investment and operational practices. Only matching the energy supply needs with the expectations, routines and living conditions of the parties involved, it will be possible to increase micro-CHP competitiveness.

Keywords: Techno-economic evaluation; CHP Systems

JEL Classification: Q4 – Energy; Q5- Environmental Economics

1. INTRODUCTION

In the last few years, the distributed power systems have gained some relevance mainly due to the liberalization of the electricity market, their increase of conversion efficiency and environmental benefits (Cardona et al., 2006; Shaneb et al., 2011; Armanasco et al., 2012). The evaluation of cogeneration or Combined Heat and Power (CHP) systems is a complex and demanding task. Numerous studies and theoretical approaches in the thermal-economic field have been developed to design and optimize thermal systems. Some of these approaches include a few key concepts of thermo-economics: sizing constraints through component costing equations, the identification of thermodynamic variables (power, mass rate, heat rate, enthalpy, entropy, heat loss, efficiency, heat exchanger effectiveness), the adaptation of thermo-economic models to non-linear programming problems and the development of methodologies related to exergy cost analysis, which accounts for the quality of the energy (Shaneb et al., 2011). Some authors established that the introduction of CHP systems in the building sector requires the development of compact, cost efficient and easily installed systems. In fact, it is believed that only with the development of more energy-efficient systems, which are able to reduce life-cycle costs, primary energy savings and CO_2 emissions, will be possible to increase its market competitiveness (Alanne et al., 2010). Lazzareto and Toffolo (Lazzaretto and Toffolo, 2004) developed a study with the objective to identify the best option to optimize thermal systems where single- or multi-objective optimization approaches were discussed. The study was performed using evolutionary algorithms to optimize the design parameters of a CHP plant defining an assessment model based on energy, economic and environment issues. De Paepe et al. (Paepe et al., 2006) compared different commercial available cogeneration systems and they concluded that the system cost is the main obstacle against the introduction of cogeneration systems in the residential sector. Pilavachi et al. (Pilavachi et al., 2006) defend that the development, construction and operation of small and micro-CHP systems must be evaluated according to economic, social and environmental aspects in an integrated way and the results of the evaluation should be compared by means of the sustainability scores.

Alanne et al. (Alanne et al., 2010) present a techno-economic strategy to evaluate the performance of different configurations for a Stirling engine-based residential micro-cogeneration system in order to minimize the annual thermal losses of the system. In the evaluation procedure, the variables considered were the annual costs, primary energy use and CO_2 emissions. In this study, the economic viability of the system is based on the capacity to recover the capital investment cost by the annual savings during a certain period of time (payback period). Pehnt (Pehnt et al., 2004; Pehnt, 2008) studied the environmental impacts of distributed energy systems for micro scale applications. On this research, the potential of different cogeneration systems was investigated by evaluating their impacts through a Life Cycle Assessment. The author concluded that the performance of micro cogeneration with respect to environmental concerns depends mainly on the overall conversion efficiency and the type of energy sources that the CHP plants work with.

The performance of cogeneration technologies with respect to the environmental concerns depends on the total conversion efficiency that can be achieved. Its improved efficiency in fuel conversion reducing the amount of fuel burned for a given level of energy outputs and, as a consequence, the costs with the fuel are lower when compared with the conventional systems. This reduction in fuel consumption levels may represent a significant and competitive economic advantage on the application and macroeconomic context, since the costs and imports of fossil energy resources can also be reduced. Moreover, these energy savings achieved by a more efficient technology also promotes the reduction of pollutant emissions to the environment (Ferreira et al., 2012).

The main objective is the development of a numerical optimization model able to get the optimal values for different physical variables (e.g. compressor pressure ratio, turbine inlet temperature, pre-heater effectiveness) that will lead to the best economical outcome for a client with a specific heat demand, whereas the produced electricity is sold to the national grid. This study is focused on the optimization of CHP systems based on micro-gas turbines as prime mover.

2. ACTUAL SCENARIO FOR SMALL SCALE CHP SYSTEMS

The European Directive 2004/8/EC (DIRECTIVE 2004/8/EC - Directive on the promotion of cogeneration based on a useful heat demand in the internal energy market, 2004) defines “small-scale cogeneration” as the units with an installed capacity bellow 1 MWe and “micro-cogeneration” as those with a maximum capacity bellow 50 kWe. This directive aims the promotion of high-efficiency systems led by heat demand and defines the Primary Energy Saving (PES), classifying them accordingly to the unit size. For large- and small-scale systems it is required a PES of at least 10%, so that the system can be classified as a system of high efficiency, whereas in the case of micro-scale systems, it is only required a positive value of PES.

Thus, PES allows to estimate the total primary energy savings that are possible to achieve by a cogeneration unit (considering the combined electric and thermal efficiencies) when compared with the conventional power production process (Armanasco et al., 2012). The amount of primary energy provided by cogeneration production (in %) may be calculated according to the Equation (1)

$$PES = \left(1 - \frac{1}{\frac{\eta_{th_{CHP}}}{\eta_{th_{ref}}} + \frac{\eta_{e_{CHP}}}{\eta_{e_{ref}}}} \right) \cdot 100 \qquad (1)$$

where $\eta_{th_{CHP}}$ is the cogeneration heat efficiency defined as the annual useful heat output divided by the fuel energy input; $\eta_{th_{ref}}$ and $\eta_{e_{ref}}$ the efficiency reference values for the separate production of heat and electricity, respectively; and finally $\eta_{e_{CHP}}$ is the electrical efficiency of the cogeneration production defined as annual electricity from cogeneration divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration.

The European Energy Performance of Buildings Directive (EPBD) obliges all member states to ensure that, for new buildings with a floor area over 1000 m^2, the economic feasibility of alternative systems, such as decentralized energy supply systems based on CHP or renewable energy, is considered at the building design stage (DIRECTIVE 2010/31/EU, 2010). The Directive also outlines that the net energy requirements for all the new buildings should be near to zero.

In 2010, the Decree-Law 23/2010 established the guidelines for high-efficiency cogeneration based on useful heat demand, which is considered a priority due to its potential primary energy savings and consequently reducing CO_2 emissions. This Decree-Law also established the remuneration scheme for the cogeneration production (Diário da República 1.ª série — N.º 59 — 25 de Março de 2010, 2010).

Besides PES, another parameter commonly used to analyse the energy and environmental benefits from using cogeneration systems is the equivalent CO_2 avoided emissions as Equation (2):

$$CES = \left(1 - \frac{f_{CG} \cdot FE_{CO_2}}{\frac{1}{\eta_c} FE_{CO_2\,ref} + \frac{\lambda}{\eta_B} FE_{CO_2\,ref}}\right) \cdot 100 \tag{2}$$

where λ is the heat-to-power ratio, f_{CG} is the fuel utilization factor of CHP unit, $FE_{CO_2\,ref}$ and FE_{CO_2} are the carbon dioxide equivalent emission factor from the conventional power production and from the fuel used by the cogeneration unit, respectively. The terms η_c and η_B are, respectively, the harmonized efficiency reference values for separate production of electricity and heat, both based on net calorific value and standard ISO conditions (EUROPEAN COMMISSION, 2011; Roselli et al., 2011). Calculating this index may assess the potential diffusion of cogeneration units in a geographic area. However, for its calculation, the adopted mix of energy for that region/country must be considered. The technologies suitable to be applied to fulfil the energy requirements of residential buildings available in the market are those based on Internal Combustion Engines (ICE), Micro Gas Turbine (MGT), Micro Rankine Cycle (MRC) and Stirling Engine (SE). Several models and prototypes of each one of these technologies are being tested in order to compare their performance. The electrical and thermal performance of these CHP technologies is summarized in Figures 1 and 2 based on available data from literature (Roselli et al., 2011; Angrisani et al., 2012; Barbieri et al., 2012).

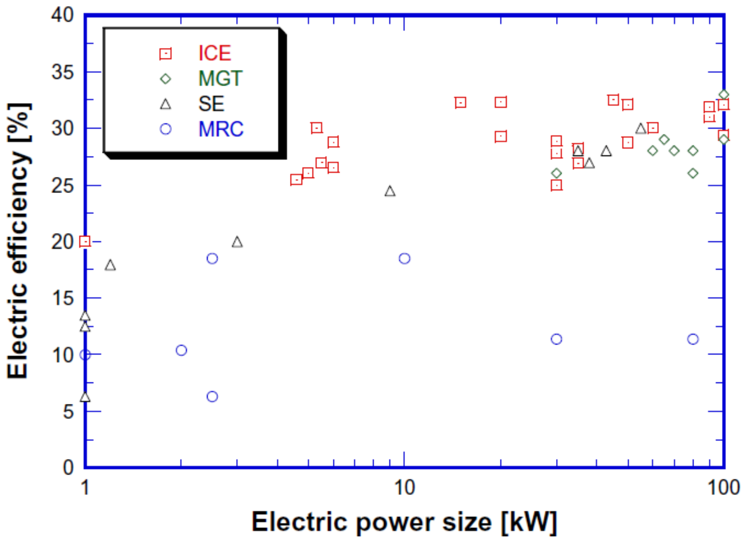

Figure 1. *Comparison of electrical efficiency for different technologies applied to CHP.*

These Figures report, for the various CHP units, the rated electric and thermal efficiency respectively, as a function of the electric power. The data shows that the technologies present performance considering the electrical or the thermal efficiency. For instance, the MRC and the SE are the technologies that present higher values for the thermal efficiency and MGT and ICE are the technologies which models can achieve a higher electric efficiency, near 33%. So, accordingly to this data, it can be said that some technologies are more suitable for some applications than other, taking into account what is more important: the heat or the electricity production.

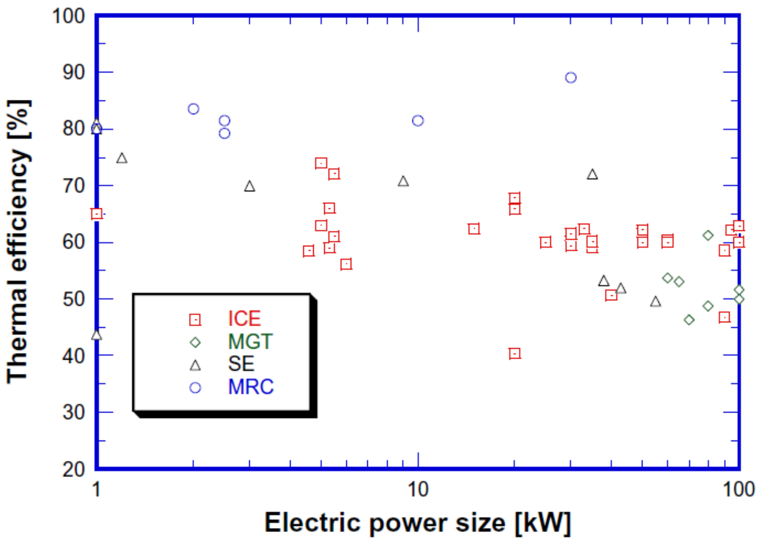

Figure 2. *Comparison of thermal efficiency for different technologies applied to CHP.*

3. DEVELOPMENT OF TECHNO-ECONOMIC OPTIMIZATION MODEL

The development of mathematical models for techno-economic evaluation is an effective way to analyse a thermal system from the techno-economical point of view. In this section, the mathematical formulation for the numerical optimization model is presented. The physical system for which this mathematical model is formulated is fully described in (Ferreira et al., 2012).

3.1 Mathematical Model Formulation

The optimization involves the definition of the objective function, the decision variables and the constraints. In this study, the objective function was defined as the maximization of the Annual Worth (AW) of the system operation, as expressed by Equation (3):

$$Max \quad AW_{CHP} \tag{3}$$

The *AW* value results from the balance between the revenues and the costs from the CHP system operation. In terms of revenues, one of the main advantages of CHP systems is the possibility of selling the energy to the power distribution network appropriate to the "producer-consumer" profile considered by the legal framework. In this study, it is considered that the client sells all the produced electricity (E_{prod}) to the grid, being the income (R_{sell}) from selling power to the net grid by the CHP system can be expressed by the Equation (4):

$$R_{sell} = E_{prod} \cdot p_{el} \tag{4}$$

where p_{el} represents the electricity price. Accordingly to the current legal framework in Portugal, the selling price of electricity to the grid of the micro-cogeneration energy systems (with the exception of biomass cogeneration systems) is equal to the purchase prices of the tariff applicable to the consumer.

When the combined production by the CHP systems is compared with the conventional power generation, it is clear that a full separate system (typically a boiler) to produce heat it is not required. In fact, one of the most important economic benefits of micro-CHP systems over conventional ones is related to their capacity to use the waste heat from electrical power generation. Therefore, the avoided cost ($C_{avoided}$) to produce the same useful thermal energy by the CHP system (Q_{CHP}) to fulfil thermal needs of the building (space heating or hot water) can be considered as an economic advantage in the model, as expressed by Equation (5):

$$C_{avoided} = p_{fuel} \cdot \left(\frac{Q_{CHP}}{\eta_b} \right) \tag{5}$$

where p_{fuel} represents the fuel price for the boiler operation and η_B is the efficiency of reference for conventional boilers. The residual value of the equipment at the end of its useful lifetime (R_{res}) should be considered as revenue. From the economic point of view, the residual value of equipment is usually estimated as a percentage of the initial system investment cost. As an environmental benefit, in this model it was proposed and included the monetization of the carbon emission savings from the CHP unit. The quantification of avoided carbon emissions was calculated by Equation (6), assuming a price of pCO_2=24 € per ton of CO_2 that is saved (according to Cozijnsen, 2012). The reference values and CO_2 emission factors depend on the technology used to produce electricity and heat. So, considering that the NG is the fuel used to run the CHP system, and according to data from DGEG, the NG emission factor was assumed as FE_{CO_2} = 64.1 gCO_2/GJ.

$$R_{CO_2} = pCO_2 \cdot FE_{CO_2} \cdot t \cdot E_{prod} \tag{6}$$

In terms of costs, the following elements may be considered: the purchase cost of each component of micro-CHP system, which corresponds to the investment costs (C_{inv}), that should include the acquisition and installation of the cogeneration system; and the fuel costs for the micro-CHP unit operation (C_{fuel}). The maintenance costs ($C_{maintenance}$) should also be included in the cost accounting.

The annual system investment cost is calculated according to the annualized capital cost. Annualizing the initial investment cost corresponds to the spreading of the initial cost across the lifetime of a system, while accounting for the time value of the money. The initial capital cost is annualized as if it were being paid off a loan at a particular interest of discount rate over the lifetime of the option. The Capital Recovery Factor (CRF) is used to determine the equal amounts of n cash transactions for an investment and can be expressed as in Equation (6):

$$CRF = (P \rightarrow A, i_e, n) = \frac{i_e(1+i_e)^n}{(1+i_e)^n - 1} \tag{7}$$

where A is the annuity (a series of equal amount cash transactions); P is the present value of the initial cost; i_e is the effective rate of return, and n is the number of years of the lifetime operation. For thermal-economic optimization the effective rate of return can be approximated as: nominal rate of return (interest rate) minus inflation rate plus owners' risk factor and correction for the method of compounding. Thus, the annual system investment cost becomes as in Equation (7):

$$C_{inv} = \sum_i C_i \cdot CRF \tag{8}$$

where C_i is the purchase cost of each component of the CHP system. The mathematical expression that defines the cost of each CHP component $C_i \rightarrow (C_C; C_{CC}; C_T; C_{IPH}; C_{WH})$ accounts for the physical parameters, being based on the works from literature (Valero et al., 1994; Marechal et al., 2005) and adjusted for small-scale units. Real data from micro-turbines available in the market (Capstone® 65) was also considered. The thermodynamic relationships as well as the cost equations are described on previous work (Ferreira et al., 2012). The C_{fuel} is calculated through the cumulative fuel consumption during the micro-CHP system working period (t), considering the fuel price per energy unit and the fuel mass flow rate ($\dot{m}_{fuel}$), usually on Low Heating Value (LHV) basis. The C_{fuel} can be expressed by the Equation (8):

$$C_{fuel} = p_{fuel}\ \dot{m}_{fuel}\ LHV\ t \tag{9}$$

The maintenance costs are usually defined as a percentage (φ) of the initial investment ($C_{maintenance} = \varphi \cdot C_{inv}$). The total operational costs C_{op} result from the sum of maintenance and fuel costs as in Equation (9):

$$C_{op} = p_{fuel}\ \dot{m}_{fuel}\ LHV\ t + \phi\, C_{inv} \tag{10}$$

The optimization models appropriate to this type of application are very complex and there are many decision variables to take in to account. As a result, some assumptions have to be performed in order to make possible the computational modelling: (1) the heat provided by the cogeneration plant should never exceed the user demand with the missing thermal energy supplied by a backup conventional boiler; (2) the thermal efficiency of the boiler should be considered equal to the reference value of the conventional boilers ($\eta_B = 90\%$); (3) the plant should operate in steady state, according to the thermal load profile of the user; (4) a period of 15 years is reasonable for the plant lifetime; (5) the maintenance and operational and costs can be assumed as a percentage (15%) of the annualized investment cost ($\phi = 0.15$); (6) the residual value of the power plant at the end of its useful lifetime was assumed as 10% of the annualized investment cost of the cogeneration plant; (7) the electricity-selling price was taken as a guaranteed and fixed feed-in-tariff of 12c€/kWh and (8) the case scenario was simulated considering the NG with a LHV of 47 100 kJ/kg.

3.2 Decision Variables

Six decision variables were selected: the compressor pressure ratio (r_C); the isentropic efficiency of the air compressor (η_C); the isentropic efficiency of the gas turbine (η_T); the air temperature at the internal pre-heater (T_3); the temperature of the combustion gases at the turbine inlet (T_4) and the electrical production ($\dot{W}$). Simple upper and lower bounds were defined for each decision variables. The simulation was performed considering the following limits for the decision variables: $3.0 \le r_C \le 6.0$, $0.70 \le \eta_C = \eta_T \le 0.90$, $500 \le T_3 \le 1000$, $1000 \le T_4 \le 1500$, and $90 \le \dot{W} \le 120$.

3.3 Constraints

Eighteen inequality constraints were formulated in order to give physical significance to the mathematical model. The definition of these constraints aims bounding some of the variables according to their feasible limits in the system operation. For instance, the high-pressure air is pre-heated before entering in the combustion chamber and so, it is required that the temperatures T_2 and T_3 are lower than the temperature of exhaust gases (T_5) at the turbine exit, in order to allow an effective heat transfer in the IPH ($T_2 \leq T_3 \ \wedge \ T_3 \leq T_5$).

3.4 Numerical Solution

The problem is solved based on the Pattern Search (PS), a search method without the need of analytic derivatives, which was implemented in the MatLab® environment. Generalized Pattern Search (GPS) algorithms are derivative free methods for the minimization of smooth functions. At each step, the algorithm generates a set of points, called *mesh*. The mesh is generated by creating a set of vectors based on the pattern by multiplying each i^{th} direction vector by a scalar which corresponds to the mesh size. At each step, the algorithm polls the points in the current mesh by computing their objective function. After polling, the algorithm changes the value of the mesh size, expanding or contracting its size. The mesh expansion depends on the polling step the success. This method has the advantage of being a direct optimization method requiring a low computation time in converging to the optimal solution. The search method used was the Nealder Mead. This method requires a feasible initial point. In this study the initial approximation defined for the six decision variables were: r_C=4; $\eta_C = \eta_T$ =0.85; T3=850K; T4=1200K and $\dot{W}$ =100kWe. The simulations were performed considering the simple limits for each the decision variable.

4. RESULTS AND DISCUSSION

The results of the optimal solution are presented in this section. A base case scenario was simulated considering the natural gas with a LHV of 47100 kJ/kg, the electricity-selling price of 0.12€/kWh and the fuel price of 10€/GJ and a price of 24 €/ton CO2. In order to evaluate the economic benefit from including the carbon emissions in the optimization model, two case scenarios were studied (Table 1). The Case 1 presents the optimal annual costs and benefits considering the carbon emission savings, while Case 2 presents the optimal solution when the bonus from carbons emissions are not considered in the mathematical model. According to Table 1, it is possible to obtain positive profit for both tested cases. It's observed that the maximum annual worth is relatively higher if the income from carbon emission is considered, a significant increase of 64%. For both cases, the predominant costs are the operational costs, where the main contribution came from the fuel costs. In terms of incomes, the revenue from selling electricity to the grid largely depends on the amount of electricity (sixth decision variable) that the system will produce. This result is also influenced by the relatively high feed-in-tariff of 12€/kWh.

Table 1 *Comparison of optimal annual costs and incomes of the CHP system.*

Annual costs and revenues (€/*year*)	**Case 1**	**Case 2**
Capital Investment Cost, C_{inv}	(14 770)	(12 187)
Total operational costs C_{op}	(47 998)	(39 488)
Revenue from equipment residual value, R_{res}	1477	1219
Revenue from selling Electricity to Grid, R_{sell}	53 568	42902
Income from Carbon Emission Savings, R_{CES}	7043	-
Avoided cost of separate heat generation, $C_{avoided}$	20 000	20 000
Annual Worth of CHP System	**19 321**	**12 445**

Table 2 shows the optimal values for the six decision variables considering the case with higher annual worth. The results show a compressor pressure ratio of r_C=5.74 and a Turbine Inlet Temperature of T_4=1385 K. This two decision variables together with the regenerator effectiveness are the most important parameters in micro gas turbines cycles. Both results are higher than the expected values of the models available in the market (an r_C of 4 and a T_4 of approximately 1200 K). A possible explanation for this difference is the possible use of low cost materials in the equipment manufacturing, which impose some limitations over the technology operation. The compressor and turbine efficiencies (~84.0% and 86.9%, respectively) seem to be within the expected values for this kind of systems. According to these results for the optimal solution, the resulting CHP system is able to produce about 111.6 kW of electrical power. Considering the electricity production output, the optimal system has a heat-to-power ratio of λ=1.12. In Table 3 the results of efficiencies and the performance criteria for the optimized solution are revealed.

Table 2 *Results for the decision variables of the small CHP system.*

Decision Variables (Case 1)	
r_c	5.743
η_C	0.8399
η_T	0.8692
T_3 (K)	982.24
T_4 (K)	1385.0
$\dot{W}$ (kW)	111.60

Table 3 *Efficiencies and performance results.*

Efficiencies & Performance Criteria, in % (Case 1)	
Electrical efficiency, η_{el}	35.1
Total efficiency, η_{total}	74.4
Primary Energy Savings, PES	13.7
Carbon Emission Savings, CES	28.7

Considering the results for the various operational variables, it was obtained an electrical efficiency of 35.1% that is higher than the current values observed with the real micro-gas turbines (25-31%). The total efficiency of 74.4% is a reasonable value for the use of micro turbines on cogeneration applications. The performance of a cogeneration system can be evaluated by comparison with the separate production of heat and electricity. In this study PES and CES were calculated considering the guidelines that established harmonized efficiency reference values for separate production in application of Directive 2004/8/EC. The calculations included the correction factors relating to the average climatic situation and the correction factors for avoided grid losses. According to the calculations, the optimal configuration allows to achieve a PES of 13.7%. Considering that the cogeneration reduces the amount of primary energy used to produce the same energy output when compared with the conventional (separate) production, carbon emissions are saved and its quantification represents an environmental and economic benefit. According to the calculations, it is possible to avoid of around 29% of carbon emissions. Thus, this result confirms that the cogeneration plants are systems that improve the efficiency in the energy production and bring noteworthy environmental benefits.

5. CONCLUSIONS

A derivative free optimization method was applied to model a small-scale cogeneration system based on micro-gas turbine technology. The results exposed the best economic output and the technical configuration for which the annual profit was maximized. For both tested cases, the optimal solution disclosed a positive annual worth, being higher if the carbon emission savings are monetized. Therefore, it can be concluded that the cogeneration systems represent a more efficient way to produce energy (positive PES), allows reducing the gas emissions. Obviously the results of the optimal solution are deeply related with the constants assumed in the model definition, namely, the fuel and the electricity feed-in-tariff. As matter in fact, the optimal solution is strongly correlated with the components performance/cost assumptions considered in the model.

In conclusion, this study disclosed that the use of optimization methods is an effective tool to perform a technical-economic evaluation of the cogeneration plant.

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Energy efficiency of a city hotel – Bringing together energy savings and life cycle costs

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Abstract

In Europe the field of tourism has an economic power about 5% of gross domestic product (GDP) and the rate of growth is about 1.75%. The building boom of lodgings and hotels continues unabated. Concurrently, the lodging sector needs to act sustainable and energy efficient. Following the directive 2010/31/EU on the energy performance of buildings, measures are needed to increase the number of buildings which not only fulfill current minimum energy performance requirements, but are also more energy efficient, thereby reducing both energy consumption and carbon dioxide emissions.

This paper deals with an exemplary city hotel in Germany which is more energy efficient than needed following the directive. It is investigated how economic and how energetic different walls and different building technologies are. Therefore a characteristic timber construction and masonry construction and their combination of five different building technologies are compared with each other.

Index Terms: energy efficiency, life cycle costs, building technology, capital value.

1. Introduction

Tourism is an important economic activity in Europe. By creating concepts for the building sector the costs are most important for the owner. The integrated approach of the life cycle with its economic but also ecologic influence is often underestimated.

Because of the change of occupancy at all time and from related services such as reception, rooms cleaning, etc., hotels consume more energy and resources (e.g. water) than residential buildings. As an example: while water consumption for an office building could be 3 liter per person employed and day, in hotel business 147 liter are used [2]. However, it must be observed that in office building are incomparably more employees than staff in hotels. Energy efficiency and resource consumption depends on number of occupancy and beds, duration of stay, services offered and space requirements per guest. For example fancy hotels with the same dimension of building but different number of guest and beds have partly the same energy consumption than low budget hotels. In Germany first investigations have shown that city hotels have a heat consumption of 144 kWh/(m²a) and a electricity consumption of 76 kWh/(m²a) for specific climatic boundary conditions [1]. As a result of offering in Germany the electricity but also hot water consumption are relatively high.

This paper deals with the investigation of different building components and technologies. Therefore the primary and final energy demand is calculated. While the final energy demand only consider the amount of energy for using heating, cooling, ventilation, hot water supply and lighting, the primary energy demand take into account the upstream process chains. The final energy demand is an important indicator to assess the costs of a building – in particular for its owner. But there are no costs included like service and maintenance. Therefore it is necessary to look over the life cycle of 50 years to evaluate and to differentiate the costs.

Fig. 1. Building model of the city hotel.

2. Methodology

Based on the German standard for residential and non-residential buildings DIN V 18599 [6] the energy requirement is calculated with the software program 'Dämmwerk' of KERN Ingenieurkonzepte [4]. Therefore only the conditioned areas of the considered building are directly accounted, so that the unheated cellar and attic are not directly included in calculations. Only for calculating transmission heat (heat sink (1) and heat source (2)) it is necessary to consider the unheated cellar:

$$Q_{T,u} = H_{T,iu} \cdot (\vartheta_i - \vartheta_u) \qquad \vartheta_i < \vartheta \qquad (1)$$

$$Q_{T,u} = H_{T,iu} \cdot (\vartheta_i - \vartheta_u) \qquad \vartheta_i < \vartheta \qquad (2)$$

With $H_{T,iu}$ for thermal transfer coefficient between heated and unheated building zone, ϑ_i for balance temperature and ϑ_u for temperature of the unheated building zone.

The thermal transfer coefficient with regard to the warmth-transferring surface reflect the average heat transfer coefficient of all exterior components and is about 0.22 W/(m² K) for the exemplary city hotel.

The warmth-transferring surface of the calculation model shall be 4.957 m². The calculation model of the building is described below. The aim is to optimize this building type up to a low final energy but also a low primary energy demand following the Energy Conservation Regulations 2009 (EnEV 2009). The final energy demand shows to the owner the energy demand for heating, ventilation, warm water supply and lighting.

Following the German standard DIN V 18599-1 the final and primary energy demand is calculated shown in Equation (3) and (4) [6]:

$$Q_p = \sum \left(Q_{f,j} \cdot \frac{f_{p,j}}{f_{HS/HI,j}} \right) \quad (3)$$

and

$$Q_{f,j} = Q_{h,f,j} + Q_{h*,f,j} + Q_{c,f,j} + Q_{c*,f,j} + Q_{m*,f,j} + Q_{rv,f,j} + Q_{rc,f,j} + Q_{w,f,j} + Q_{l,f,j} + W_{f,j} + Q_{f,x,j} \quad (4)$$

With $Q_{f,j}$ for final energy demand of energy source, $f_{p,j}$ for primary energy factor, $f_{HS/HI,j}$ as a conversion factor, $Q_{h,f,j}$ for final energy for heating system, $Q_{h*,f,j}$ for final energy for ventilation with heating function, $Q_{c,f,j}$ for final energy for cooling system, $Qc*_{,f,j}$ for final energy for ventilation with cooling function, $Q_{m*,f,j}$ for final energy for ventilation with moistening function, $Q_{rv,f,j}$ for final energy for residential ventilation, $Q_{rc,f,j}$ for final energy for residential cooling, $Q_{w,f,j}$ for final energy for warm water supply, $Q_{l,f,j}$ for final energy for lighting, $W_{f,j}$ for final energy for auxiliary power and $Q_{f,x,j}$ for final energy for other processes.

3. The calculation model of the building example

3.1 Building constructions

This paper deals with the calculation model of a typical city hotel with five floors and with a net floor space of 2.508 m². Using for gap development in the center of Berlin the building has polygonal compact structure and combined the typical characteristics. The east side of the building is about 30 m und the north/ south side 8 m each. The building technology of the hotel is situated in the unoccupied cellar. The lodging has 4 utility areas: cellar with storage, ground floor with reception and restaurant, first floor with conference hall for 150 persons but also small meeting rooms, 2nd, 3rd and 4th floor with lodges (100 beds) and 5th floor with administration and office.

The wall constructions are calculated with two different variants (a and b): masonry constructions with an external thermal insulation composite system (a) and curtain walls in wooden rack design (b). Both constructions have a heat transfer coefficient about 0.11 W/(m²K). Other constructions have the following heat transfer coefficient: cellar ceiling 0.16 W/(m²K), the roof 0.14 W/(m²K) and the windows 0.75 W/(m²K) with a portion of windows about 10 %. The building technology is also varied and is explained in chapter 3.3.

3.2 Building tightness test

Based on the standard for new buildings the hotel should automatically airproof. Therefore it is practical and reasonable to arrange an air leakage test (Blower Door test) according to DIN EN 13829. By demonstrating an air change rate of $n_{50} = 2.0\ h^{-1}$, a more favorable approach is taken into account in calculation and the ventilation heat losses are kept to a minimum.

3.3 Building technology

The desired standards following the directive 2010/31/EU and the Renewable Energy Heat Act (EEWärmeG) mentioned above can often only be reached by heat pumps or photovoltaic systems. Normally, combinations of all arrangements with each other or as an addition to the conventional heating system make sense.

As building technology for heating and hot water supply 5 different variants are investigated: gas condensing boiler, district heating, combined heat and power unit (CHP), CHP in combination with gas condensing boiler and heat pump in combination with gas condensing boiler. It is more economically to combine a heat pump or a CHP with a second heating system for the peak loads.

Other main details for technical equipment are: an underfloor heating system, insulated pipes, ventilation system with heat recovery of 75% and central warm water supply.

TABLE I: Variants of heating systems and wall constructions

Variant	Wall construction	Building technology	Energy source	Primary energy factor
1a	Thermal insulation composite system	Condensing Boiler	natural gas	1.1
1b	Wooden rack design	Condensing Boiler	natural gas	1.1
2a	Thermal insulation composite system	District heating	district heating electricity	0.56
2b	Wooden rack design	District heating	district heating electricity	0.56
3a	Thermal insulation composite system	combined heat and power unit (CHP)	natural gas electricity electricity credit	1.1 2.6 2.6
3b	Wooden rack design	combined heat and power unit (CHP)	natural gas electricity electricity credit	1.1 2.6 2.6
4a	Thermal insulation composite system	combined heat and power unit (CHP) and gas condensing boiler	natural gas electricity electricity credit	1.1 2.6 2.6
4b	Wooden rack design	combined heat and power unit (CHP) and gas condensing boiler	natural gas electricity electricity credit	1.1 2.6 2.6
5a	Thermal insulation composite system	heat pump and gas condensing boiler	natural gas electricity	1.1 2.6
5b	Wooden rack design	heat pump and gas condensing boiler	natural gas electricity	1.1 2.6

The building technology is situated in the unheated cellar. Step by step this paper investigates the different variants for both wall constructions (shown in Table I).

Different building technologies need different fuels for heating, warm water supply, ventilation and lighting.

4. Analysis of energy balance

Figure 2 illustrates the comparison between primary and final energy demand. It is obvious that the oversized combined heat and power unit (CHP) has the best primary energy demand by producing an electricity credit. The combined CHP gets better results for the final energy demand and also its primary energy demand does not poorly. For the combined heat pump the final energy demand is about the same like the combined CHP solution but the primary energy is worse. District heating and the combined heat pump have about the same primary energy demand but the final energy demand of using district heating is worse than using the combined heat pump solution. The final energy demand of using district heating and condensing boiler is about the same but the primary energy demand of using condensing boiler does poorly.

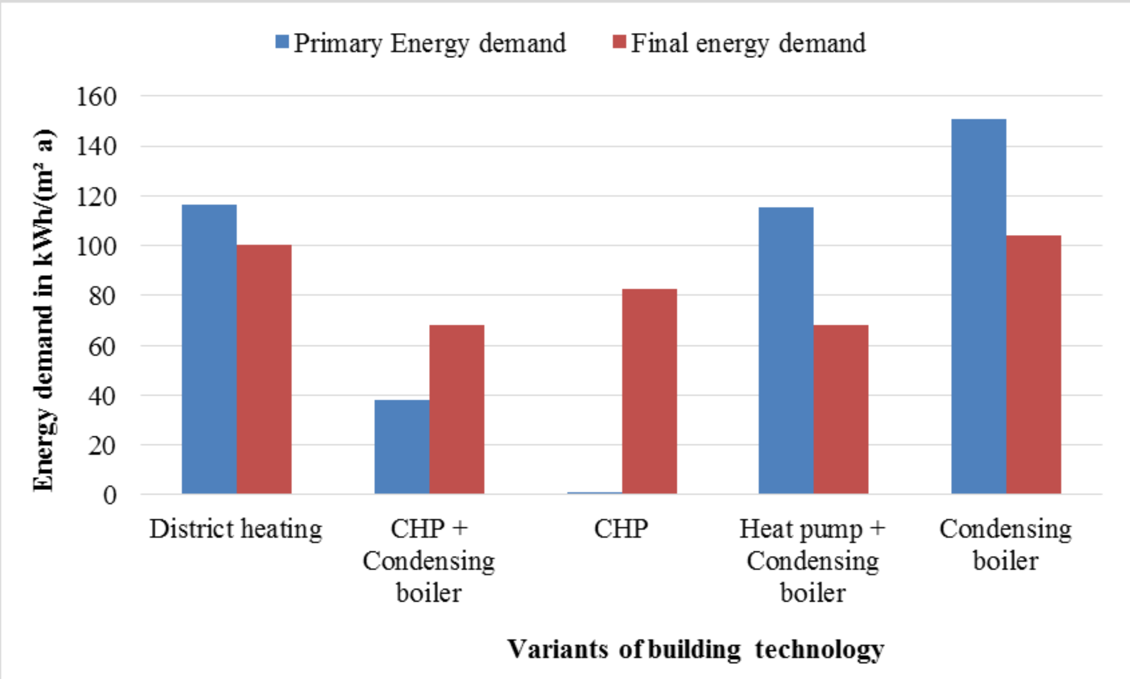

Fig. 2. Primary and final energy demand.

5. Analysis of economy

The energy balances of all variants are used to analyze the economic efficiency. Therefore capital values are calculated using the software LEGEP [8]. Finally results of all varieties are compared and discussed. As basis for life cycle calculation the characteristics of rating system for sustainable building profile number 2.1.1 [7] is used. It is assumed that the annual rate of price inflation is about 2 % in general and about 4 % for heating and electric energy. The imputed interest rate is 5.5 %. The period under review of life cycle is 50 years.

Figure 3 shows the capital value of the building variants with their different technical equipment. The capital value is a time-adjusted cash amount of any costs within life cycle – discounted to the start time. As a consequence the economic efficiency might be seen as a measure of using financial resources.

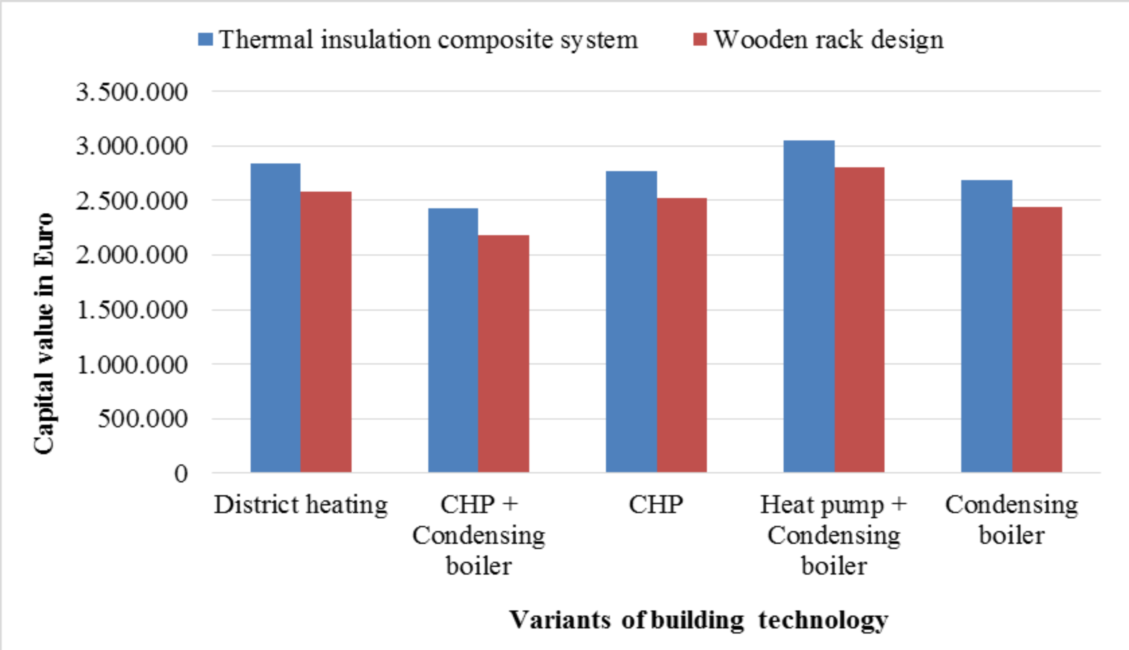

Fig. 3. Capital value.

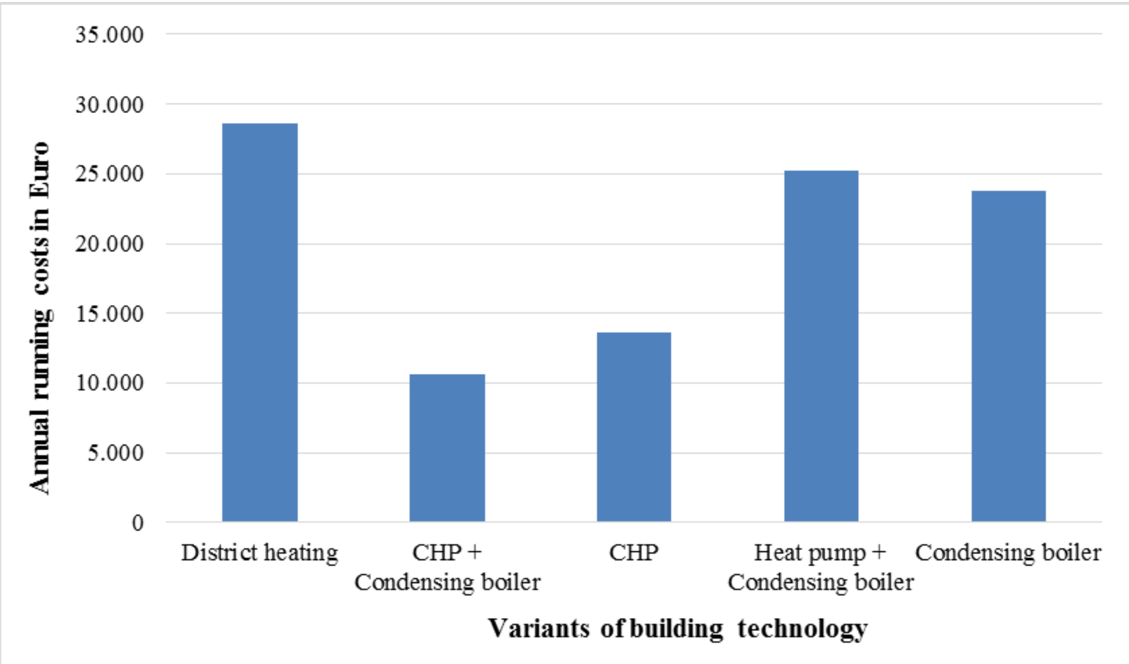

Fig. 4. Annual running costs.

It is obvious that choosing the wooden rack design the lowest capital values arises for the period under review about 50 years. This calculated result depends on the assumption of replacing the expanded polystyrene (EPS) of the whole thermal insulation composite system after 40 years and the mineral wool of the wooden rack design after 50 years.

A closer look into the building technology shows that using a combined CHP reaches the best capital value. The worst capital value gets using a combined heat pump systems. In Figure 4 the annual running costs are illustrated. Because of the production of electricity the CHP (combined or not) gets the best results. In fact for both CHP the annual running costs depend on how the current supply is remunerated. In this paper the price of electricity is calculated with 0.05 €/kWh. District heating comes off worst.

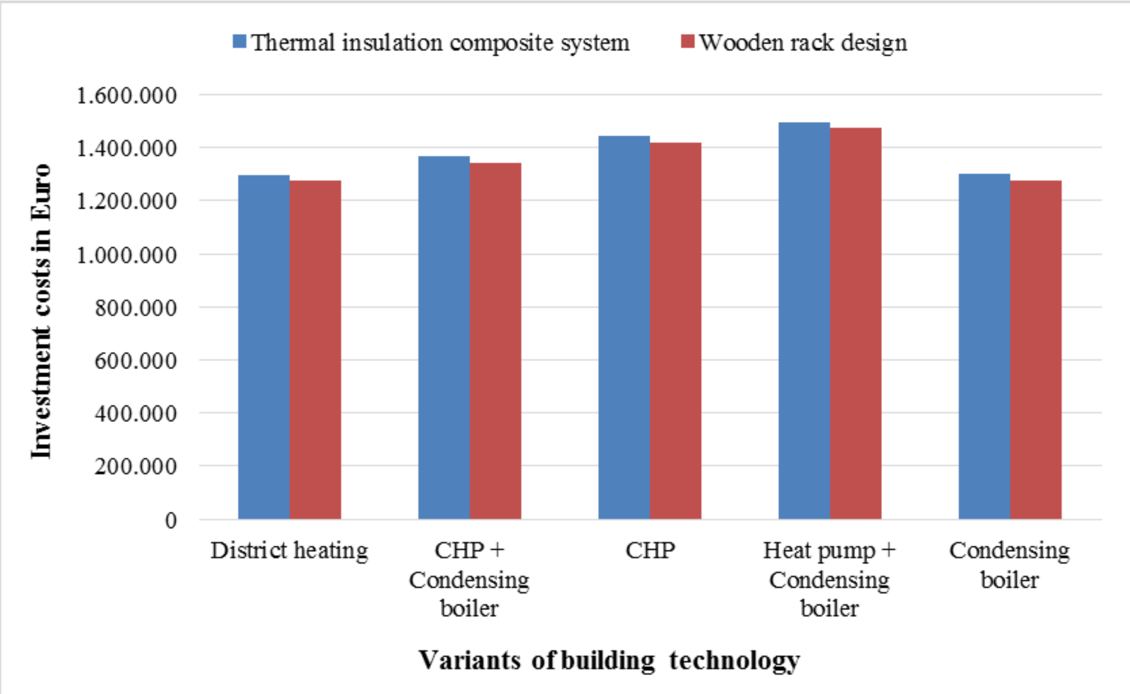

Fig. 5. Investment costs.

A closer look into the investment costs shown in Figure 5 suggests that there is no big difference between the masonry construction variant and the construction variant of wooden rack design. Considering the building technology the best results have the heating and warm water solutions of using district heating or condensing boiler. The worst result gets the combined heat pump followed by the oversized CHP.

Figure 6 shows the costs of serving and maintenance. Consistently, the costs with the walls of wooden rack design are much lower compared to the masonry construction. Here it is the same cause occurred in calculating the capital value. With both constructions district heating is the best solution for the costs of service and maintenance, closely followed by the condensing boiler. The oversized CHP gets the worst results of costs.

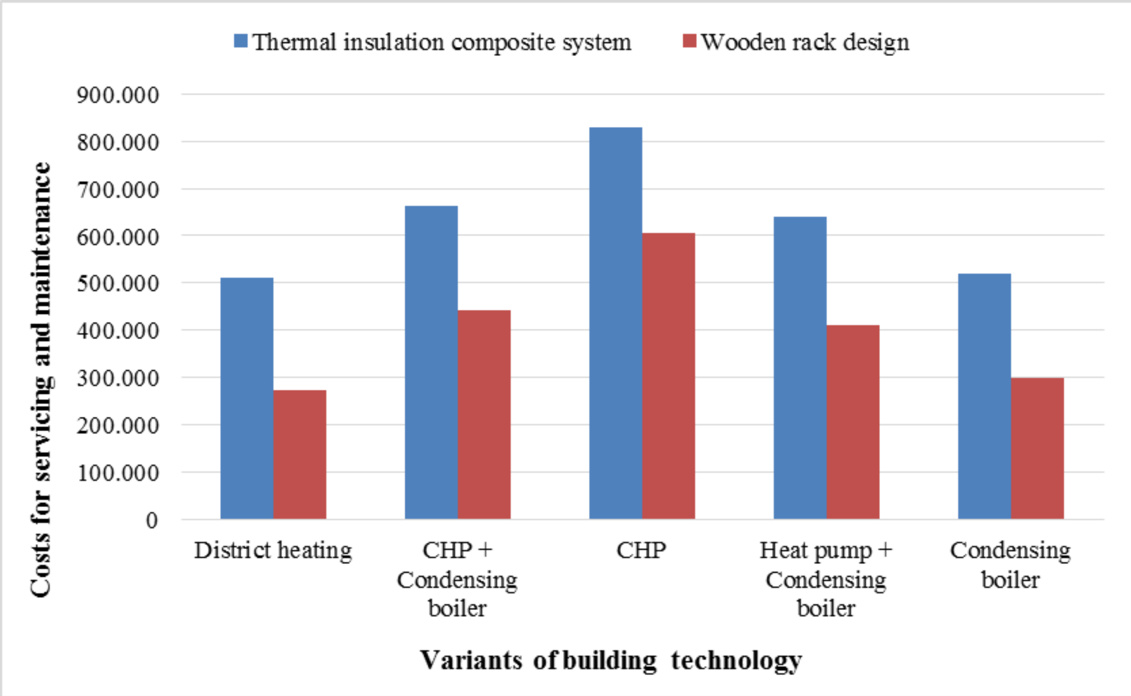

Fig. 6. Costs of serving and maintenance.

6. Results and Conclusions

If the owner only look at the final energy demand of the building, CHP and heat pump both combined with condensing boiler get the best results. In similar studies [5] for building technology the combination with heat pump has shown similar results.

The life cycle analysis of costs represents that not for all aspects there are the same results. For example the combined heat pump gets the worst results for the capital value and the investment costs. Also, the same is shown into results of the annual running costs.

For calculating the primary and final energy demand the construction with its components plays a secondary role. Only the heat transfer coefficient is used for the calculation. In our case both constructions have the same value.

But for the life cycle analysis different aspects are considered: investment costs, replacement time etc. As explained and shown above the time of replacement of materials could be different. In our case the mineral wool has a replacement time of 50 years and the expanded polystyrene (EPS) a replacement time of 40 years.

In general the calculations show that in most investigated cases the building technology of CHP is the best solution. This results in the possibility to generate electricity. Only in the costs of serving and maintenance CHP comes off poorly.

Looking to other publications [3] there are often only represented the construction costs and not for service and maintenance of a defined observation period.

This paper shows that it is not being enough to calculate and consider the energy demand of buildings. In point of fact it makes sense to analyze the life cycle costs about a defined observation period. What is missing to evaluate the whole life cycle is to analyze the life cycle assessment.

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Energetic efficiency analysis of the agricultural biogas plant in 250 kW_e experimental installation

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Abstract

European direction of energy development has been already set few years ago. Proper waste management is not just a fashion trend of the wealthy European countries – it has become a legal requirement. Processing of the biowaste into the biogas is one of the most effective technologies providing to obtain a "green" energy and improvement of the environment. Construction of small and cheap agricultural biogas plants, like in case of Poznan University of Life Sciences (PULS) experimental station Przybroda, is one of the best directions of dissemination of this biowaste valorization technology. The aim of this paper was to investigate the biogas efficiency of the substrates available in PULS experimental farm Przybroda (cattle manure, maize silage). Comprehensive laboratory analysis has shown not only a positive economic balance but also very favorable effect of the studied technology of substrates management on the environment.

1. Introduction

Penetration of fluctuating energy sources for electricity generation, heating, cooling and transportation increases the need for flexibility of the energy system to accommodate the fluctuations of these energy sources [Østergaard 2012]. The potential of the biogas market in Poland is huge. An obligation imposed by the European Commission to produce 15% of energy from renewable energy sources (RES) before 2020, forces the Polish authorities to take strong, decisive steps in this direction. It is also foreseen that the production of energy from RES in Poland is going to be related with use of biomass of different origin [Adamski et al. 2009, Dach 2009, Pilarski 2010]. Among other reasons, the Polish government has undertaken a plan to build over 2000 biogas plants until the year 2020 [Przybył 2011].

Alternative uses of agricultural waste for energy production become increasingly interesting when considered from two perspectives, first waste management and second the energy system perspective [Münster and Meibom 2011]. Biogas is produced in different environments like landfills, sewage sludge, manure, and biowaste digesters during anaerobic degradation of organic material [Rasi et al., 2007]. The present utilisation of biogas from anaerobic digestion process is low compared to the technical potential [Börjesson and Ahlgren 2010]. The methane potential is a crucial parameter for assessing design, economic and managing issues for the implementation of the anaerobic digestion process. This parameter mostly depends on the composition of solid waste [Zhou et al. 2012]. Presence of CO_2 and H_2S in biogas affects engine performance adversely [Tippayawong and Thanompongchart 2010]. However, it should not be forgotten that methane fermentation process is very complicated and requires a special technological supervision. Properly maintained and used can generate high profits but it has its own very specific requirements. German investors have already found out about the difficulties related with this process in the years 2007-09, when the methane yield from working biogas plants was significantly lower than expected. In many cases it caused huge liabilities and even the bankruptcy which affected almost ¼ from the nearly 5000 biogas plants working at that time.

In response to the arising problems many laboratories in Germany have undertaken the issue of optimization of methane fermentation for selected substrates. In the internet the special biogas calculators have become available in order to determine the biogas efficiency of the chosen agri-food substrates [Pilarski et al. 2012]. However it should be noted that the results obtained from the biogas web planners usually are burdened with a significant error. It is related to the content variability and chemical composition complexity of the tested substrates. Many factors have an influence on the substrate biogas efficiency: plant species, sowing method, soil fertility, climate conditions, harvest period and even quality of the agricultural harvesting machines. Therefore the most effective method of determining the biogas efficiency is to investigate the particular substrate and use the services of a specialized biogas laboratory.

The aim of this work was to analyze the real efficiency of biogas and biomethane production from the available substrates in order to estimate the economic profitability of the biogas plant planned to be constructed at one of the experimental farms of Poznan University of Life Sciences.

2. Materials and methods

In 2013 it is planned the opening of the new biogas plant (250 kW_e) in PULS experimental station Przybroda near Poznan (400 ha of arable land from which maximum 120 ha for maize production only as a biogas substrate Fig. 1). Therefore the scientists from the PULS Ecotechnologies Laboratory decided to investigate the biogas efficiency of the main substrates available in this farm. These studies were necessary and indispensable to determine the profitability of the planned biogas plant and had a crucial impact on the decision of the PULS Rector concerning the undertaking of a proposed investment.

Fig 1. Visualization of PULS biogas plant in Przybroda

2.1. Research material

PULS experimental station Przybroda research material contained the substrates available in the chosen experimental station. The substrates were: cattle manure and maize planted for energy purpose (stored as a silage). The materials were taken from the real scale stored manure windrow and from the silos fill in with the maize daily used for caw feeding. As an inoculum for fermentation process, digested pulp from working agricultural biogas plant has been used.

2.2. Laboratory research

The study of substrates biogas efficiency was carried out in PULS Ecotechnologies Laboratory on the strength of internal procedures based on the norm DIN 38 414. The tests were conducted on the 21-reactor research stations developed by the laboratory staff (Fig. 2.) The analyses of gasses emissions (CH_4; CO_2; NH_4; O_2; H_2S) were made in the so called gaseous-route, the device consisted of suction pomp and set of electrochemical sensors which let to determine the gas concentration in the examined sample. The following analyses of substrate parameters have been made: dry mass/humidity (drier method PN-75 C-04616/01), pH (potentiometric method PN-90/A-75101.06), conductivity (PN-EN 27888:1999), organic matter and ash (by incineration according to the modified PN-Z-15011-3).

2.3. Methane production set-up

The experiment of biogas production was carried out through anaerobic digestion in a multichamber biofermentor set (Fig. 2). This biofermentor is commonly used for testing biogas efficiency of a large amount of biomass samples.

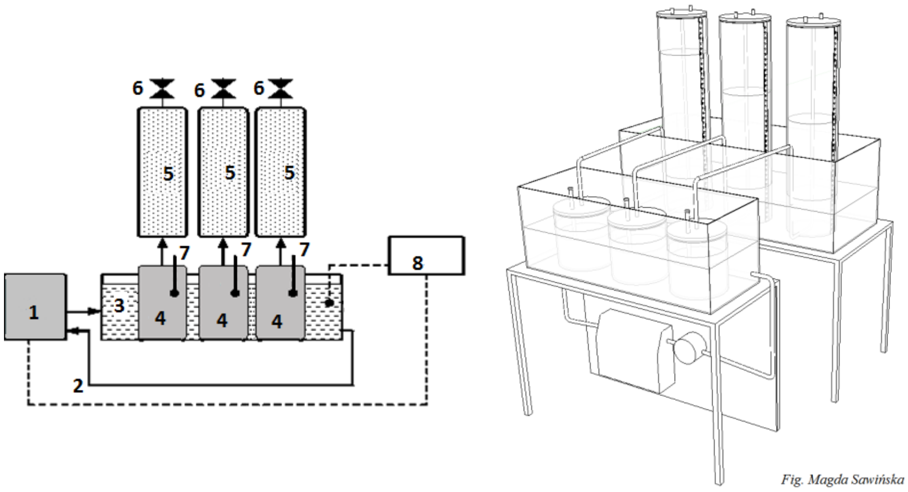

Fig. 2. Scheme of biofermentor for biogas production research (3-chamber section)

1. Water heater with temperature regulator, 2. Insulated conductors of calefaction liquid, 3. Water coat with temp. 39°C,
4. Biofermentor with charge capacity 2 dm^3,
5. Biogas reservoir,
6. Cutting off valves,
7. Sampling tubes,
8. Recording central station.

Anaerobic digestion experiments were carried out in glass constructed stirred reactors in the Laboratory of Ecotechnologies. General rules for biofermentor work were based on the fermentation of organic substrate samples which were put in the chambers with 2 dm^3 capacity. The addition of the fermentation inoculum and the absence of oxygen create the perfect conditions inside the fermentation chamber to allow the production of methane by fermentation of the analyzed substrates. Glass chambers with samples were placed in water with regulated temperature (around 39°C), which is the real condition of biogas plant. Biogas produced in each separate chamber was transferred to cylindrical store – equalizing reservoirs, filled in with neutral liquid. The samples were tested in 3 replications.

2.4 Gas samples

The volume of the produced biogas was measured every 24 hours. Gas composition was checked out from at least each 1 dm^3 of the produced gas (at the beginning of the experiment it was once a day, and after the culmination point, when the production slowed down, each three days). The concentration measurements of methane, carbn dioxide, hydrogen sulfide, ammonia and oxygen in the produced biogas were carried out with the use of absorption sensors working in an infrared and electrochemical sensor line. The type Mg-72 and MG-73 heads for gas concentration measurement were used (ALTER S.A.) [Wolna-Maruwka and Dach 2009].

The ranges of detected gaseous compounds were: 0-100% CH_4, 0-100% CO_2, 0-25% O_2, 0-2000 ppm H_2S and 0-2000 ppm NH_3, respectively. Therefore, each sample of biogas production was monitored daily for the gas compounds. The volume of biogas production and the methane content were calculated in the Excel sheet. According to the graph, it was possible to determine if the sample was working properly during the experiment. Gas-monitoring system was calibrated each week using calibration gases provided by Messer Company, using the following concentration of gas calibration: 65% of CH_4, 35% of CO_2 (in same mixture). 500 ppm of H_2S and 100 ppm of NH_3. For O_2 sensor calibration, the typical synthetic air was used.

2.5. Cumulative production calculation VDI 4630

For the batches with the mixture of the substrate or of the reference substrate, the proportion of gas production from the seeding sludge in the test is calculated by means the following equation:

$$V_{IS(korr.)} = \frac{\Sigma V_{IS}\, m_{IS}}{m_M} \qquad (1)$$

Where:

$V_{IS(korr.)}$ gas volume which was released from the seeding sludge, in m l_N

ΣV_{IS} total of the gas volumes in the test with seeding sludge for the test duration under consideration, in ml_N

m_{IS} mass of the seeding sludge used for the mixture, in g

m_M mass of the seeding sludge used in the control test, in g

The net gas normal volume of the substrate or of the reference substrate in the test is obtained for the same test times as the difference between the normal volumes of the dry gas in the test less the normal volume of the dry gas from the seeding sludge. The specific fermentation gas production Vs from the substrate or reference substrate as a function of the test duration is calculated step by step from reading to reading in accordance with the equation:

$$V_S = \frac{\Sigma V_n \, 10^4}{m \, w_T \, w_V} \qquad (2)$$

Where:

V_S the specific fermentation gas production relative to the ignition loss mass during the test period, in l_N/kgGV;

ΣV_n net gas volume of the substrate or of the reference substrate for the test duration under consideration, in $ml_{N;}$

m mass of the weighed-in substrate or of the reference substrate, in g;

w_T dry residue of the sample or of the reference sludge, in %;

w_V loss on ignition (GV) of dry mass of the sample or of the reference sludge [%].

The net methane normal volume of the substrate or of the reference substrate in the test is obtained for the same test times as the difference between the normal volumes of the methane in the test less than the normal volume of the methane from the seeding sludge. The methane normal volume is calculated by multiplying the normal volume of the dry gas by the methane content of the dry gas. If only the carbon dioxide content of the dry gas is available rather than the methane content, the methane content is calculated under the assumption that the dry gas is composed only of methane and carbon dioxide.

3. Research results

At the beginning of the research, chemical and physical parameters of substrates have been analyzed (Tab. 1.).

Tab. 1. Physical parameters of substrates

Substrate	TS [%]	VS [% of TS]	pH	Conductivity [mS]
Maize silage	37.24	87.77	4.08	1.3
Cattle manure	20.43	90.73	8.17	22.2
Inoculum	2.96	71.91	7.79	17.9

Physical parameters of substrates influenced on proportions of mixtures prepared for fermentation. Each mixture has been prepared in three repetitions.

Tab. 2. Fermentation mixtures proportion

	Substrate [g]	Inoculum [g]
Maize silage	50	950
Cattle manure	100	900
Control	-	1000

Fermentation of substrates has been shown on Fig. 3 and 4. Control reactor is omitted because biogas production from it was low. As it is shown on Fig. 3. fermentation of maize silage proceed without any complication. Initial, intensive biogas production characterized small amount of methane and large concentration of other gases (mainly carbon dioxide and traces of hydrogen sulfide).

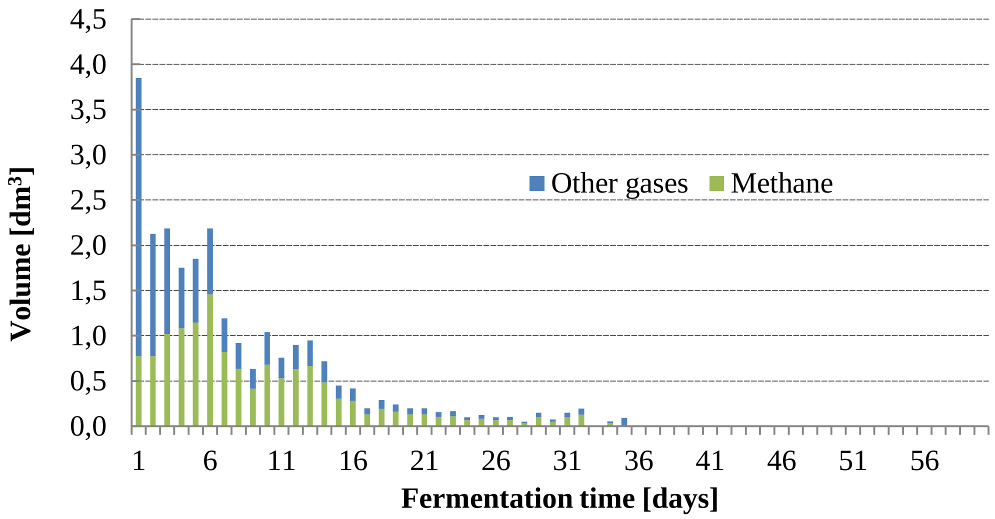

Fig. 3. Daily biogas production from maize silage

In case of cattle manure fermentation process did not causes any difficulties as well. Biogas production was stable however not so intensive. We can observe smaller daily production of biogas comparing to maize silage (Fig. 4.).

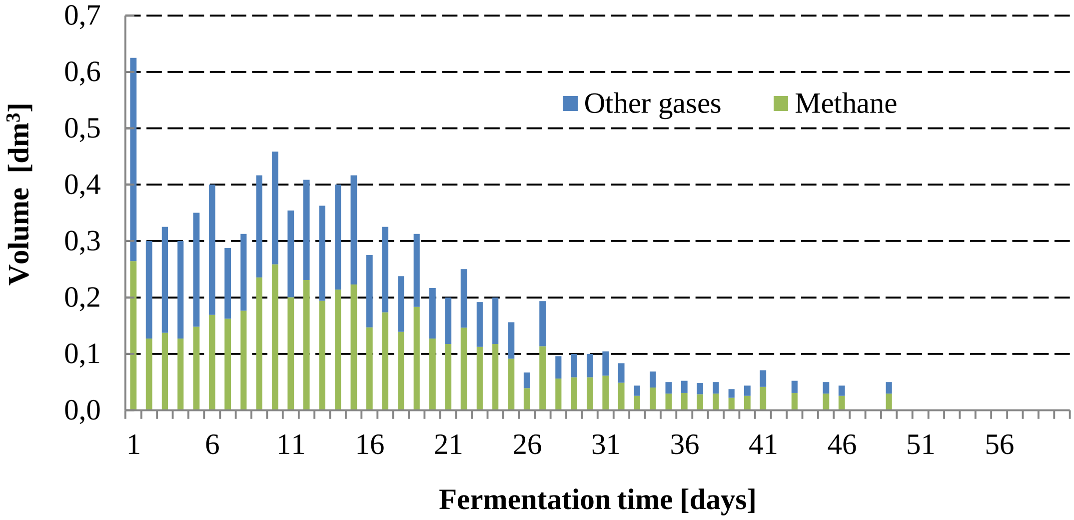

Fig. 4. Daily biogas production from cattle manure

The length of the fermentation process was dependent on the substrate. Maize silage remained in the reactors for about 35 days, while the cattle manure for about 50 days which was enough to ferment completely. In this case, the length of the process was probably correlated with the amount of hardly digested elements like lignocellulose. The graph of cumulative methane production (Fig. 5) shows that production of methane for Mg of fresh matter was more than 2.7 times higher in maize silage samples. The reason was lower content of dry mass – 20.43% and chemical composition of that substrate. However, it has to be underlined that price of manure used own biogas plant can be taken as 0 euro/Mg because the manure transformed into digested come back to the field as a fertilizer. In contrary – the maize silage cost is expensive in Western Poland conditions and can reach at least the level 24 euro/Mg of silage (sometimes over 30 euro/Mg). This makes maize silage low profitable from economic point of view.

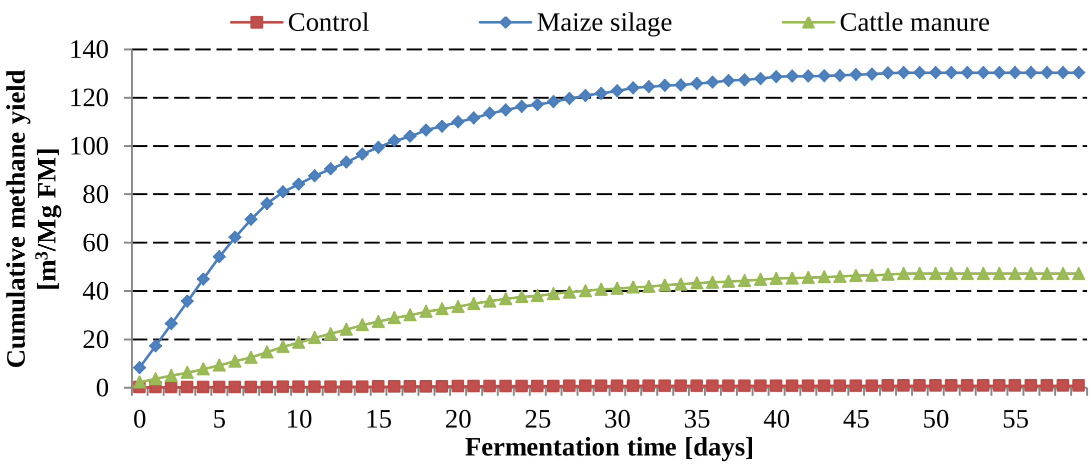

Fig. 5. Cumulative methane production

For better calculations Tab. 3 shows amount of biogas, methane and concentration of methane reached form each substrate.

	Fresh matter		
Sample	**Cumulative methane yield [m^3/Mg FM]**	**Cumulative biogas yield [m^3/Mg FM]**	**Methane concentration [%]**
Control	0.81	2.39	33.90
Maize silage	130.36	218.40	55.26
Cattle manure	47.23	80.00	53.73

Tab. 3 Cumulative methane production and concentration

The obtained results were the base for the economic calculation concerning planned installation which is present in Tab. 4.

	Maize silage	**Cattle manure**	**Units**
Amount of substrate	4000	500	Mg
Methane production	130.36	47.23	m^3/Mg FM
Amount of methane	521440	23615	m^3/year
Energetic CH_4 value	9.9	9.9	kWh/m^3
Thermal co-generator efficiency	45		%
Electric co-generator efficiency	41		%
Total amount of methane	545055		m^3/year
Thermal energy produced	5396.04		MWh/ year
Electric energy produced	5922.49		MWh/ year
Calculated electric power	0.270		MW_e
Calculated thermal power	0.296		MW_{th}

Tab. 4. Energetic calculations

The real amount of materials used as substrates is around 4000 Mg of maize silage and 500 Mg of farmyard manure. Based on the previous results (Tab. 3), this let to obtain 521,440 m^3 of CH_4 from maize and 23,615 from manure, respectively. It is clear that in the case of Przybroda farm, maize plays main role between the substrates. The growth of manure usage is not possible without increasing of caw numbers (there is not any other animal production in surroundings). Taking the standard energetic value for methane (9,9 kWh/m^3) and the energetic efficiency of co-generator planned to use (41% of electric and 45% of thermal) the yearly amount of energy produced is 5396 MWh for electricity and 5922 MWh for heat.

On the basis of obtained results, the university decided to invest in the biogas plant with basic electric power of 250 kW_e, with the possibility of increasing the power till 300 kW_e without changing the co-generator. Because of law regulations in Poland, whole produced energy will be sold to the grid. However, the thermal energy will be used for heating the tap water and the buildings. The excess of thermal energy, typically hard to use during spring-summer period, in this case will be used by big-scale freezer placed on the farm (after changing the heat into chill).

4. Conclusions

1. The research of biogas and biomethane production efficiency showed that maize is clearly more (almost 3 times) productive substrate than manure.
2. The cost of maize silage is over 24 euro/Mg which - contrary to free of charge manure - makes maize silage low profitable from economic point of view.
3. The availability of resources (120 ha of arable land and 30 caw) let to produce the substrates (maize silage and farmyard manure) which can guaranty 270 kW of electric power and 296 kW of thermal power.
4. The key-point of economic success of biogas plant investment in Polish conditions (low subsidies, more than twice times lower than in Germany) is to find the way of whole year usage of heat, mainly including spring and summer period.

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A comparative study of the evolution on energy efficiency between 1960 - 2009 across 4 European countries

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Abstract

Increasing the overall energy efficiency in the economy and understanding how to control or predict its evolution is crucial in the modern world. We analyse and compare the evolution of energy efficiency between 1960-2009 for Portugal, Spain, Denmark and Norway, four European countries with very different energetic, economic and environmental backgrounds. To explain the differences between countries we have focused on the following factors: degree of self-efficiency, distribution of total primary energy supply, differences in industrial structure, differences in discretionary personal consumption, country size and climate. Preliminary results indicate that a bond can be made between these factors and the evolution of energy efficiency.

Keywords: ENERGY EFFICIENCY; SELF-SUFFICIENCY

JEL code: Q40

1. Introduction

Energy patterns changed over the past century and continue to change very fast, as the energetic demand continues to grow. This increase in quantities of energy used and the drastic changes in energy quality that took place are linked to enormous wealth accumulation, population growth and impressive improvement in the standard of living.

The interdependence of energy is a reality (Yergin 2011) and with the world population increase from a little more than 3 billion in 1960 to more than 7 billion nowadays, a good use of energy turned out to be increasingly more and more important. Fossil fuels are becoming scarce and the renewables cannot yet replace these fuels in electricity generation and in transportation. A rigorous control of transformation and conversion efficiencies is crucial to continue to meet this energetic demand.

Most energy-related policies target energy intensities and efficiencies (Taylor, et al. 2010) The International Energy Agency (IEA) proposes an energy pyramid of indicators, with the process indicators on the base (e.g. unit energy consumption); disaggregated indicators in the middle (e.g. end-use energy intensity and sectorial energy intensity); and the aggregated indicators on the top (e.g. E/GDP). There are a lot of approaches to obtain relevant data to study past patterns of energy use.

In this study we look at the overall energetic panorama of 4 countries (primary – final – useful), comparing the evolution of their energetic efficiencies from 1960 to 2009. We will use four of the six factors proposed by Smil as a starting point to understand the energetic differences between these countries. The six key factors for energy efficiency are: degree of energy self-sufficiency; composition of TPES; differences in industrial structure; differences in personal consumption; country size and climate (Smil 2005).

According (Coccia 2010), countries can be energy-weak or energy-strong, concerning how energy dependent they are from imports. An energy-strong country has an energy production that is bigger than its energy gross inland consumption. These countries are net-exporters of energy benefiting from increases in the energy prices. Energy-weak countries are the opposite, so increase in energy prices will prejudice these countries.

Guided by the four of the six factors mentioned above we chose European countries that have different characteristics. Portugal is a small country characterized as an energy-weak (Coccia 2010). Besides Portugal, Spain is also an energy-weak country that has 4.5 times more people and is five and half times bigger than Portugal. These countries have mild winters and hot summers. On the other hand, we compare these two countries with two European energy-strong countries. Norway, a big country, the biggest exporter of oil and natural gas among the EU countries, and Denmark, a small country, that has a strong renewable policy and in a short time might be renewable self-sufficient. Norway and Denmark have severe winters.

2. Methodology and Data

We performed an energetic analysis for the four countries mention above (Portugal, Spain, Norway and Denmark) to assess the evolution of the energetic efficiency from 1960 to 2009.

Energy data was collected from International Energy Agency (IEA) Energy Balances (IEA 2011). All analyses were made only on the commercial energetic products, only those appear in the balances. These products exclude, for example: food, feed and passive solar energy.

2.1. Measuring efficiencies

Besides the study of these disaggregated indicators, we study the evolution of the efficiency between 1960 and 2009 for Portugal, Spain, Norway and Denmark. We choose three efficiencies to characterise a country: aggregated primary-to-final efficiency; electrical transformation/conversion from all the products (aggregated and by product); and efficiency of the oil refinery.

2.1.1. Primary-to-final efficiency

This efficiency gives an aggregated panorama of the evolution in the transformation and conversion technologies and processes implemented in the four countries.

$$\eta_{primary-to-final} = \frac{total\ final\ consuption}{total\ primary\ energy\ supply} \tag{1}$$

2.1.2. Electric transformation efficiency

The electricity generation is a fundamental aspect in the energy sectors of the modern economy. We focus on the thermo-electricity obtained from renewable and non-renewables sources. We take into account electricity originated from: coal products, crude, oil products, natural gas, biofuels and waste.

$$\eta_{electric\ transformation} = \frac{electric\ output}{\sum inputs\ to\ electricity\ plants} \tag{2}$$

With electricity plants as the sum of: main activity producer electricity plants, auto producer electricity plants and CHP plants. In CHP plants we remove the heat generated, as referred in the IEA Energy Balances.

2.1.3. Oil refinery efficiency

Given the importance of oil in the final energy mix of these countries we also consider the efficiency in oil refineries defined as:.

$$\eta_{oil\ refinary} = \left(\frac{oil\ products}{crude, NGL\ and\ feedstocks}\right)_{in\ oil\ refinaries} \quad (3)$$

2.2. Determinant Factors

2.2.1. Degree of energy self-sufficiency

The degree of self-sufficiency is a measure of the energy dependency of a country. It's the proportion between inland production of energetic products and the overall consumption of energetic products, admitting there are no exports (Amador 2010).

$$self\ sufficiency = \frac{production}{production + imports} \quad (4)$$

It characterizes the energy-weakness of a country and is a big influence in the competitiveness of countries, especially in a context of high energy prices. This energy weakness is measured in magnitude of energy weakness:

$$Magnitude\ of\ energy\ weakness = \log_{10}\left(\frac{Production\ of\ Primary\ Energy}{Total\ Primary\ Energy\ Supply}\right) \quad (5)$$

This $\log_{10}$ is used because it is a linear transformation that compresses the values and maintains the transitivity property. When this magnitude is lower than zero, the country is classified as energy-weak, otherwise the country is classified as energy-strong (Coccia 2010).

2.2.2. Composition of the primary energy supply

The composition of the inland gross consumption greatly influences the trend in final energy consumption of a country. In a way, this distribution is the beginning of the energy use and has to take into account not only the final use but also the transformation and conversion processes.

Starting from the World Energy Balances' products (IEA 2011), an aggregation was made to exhibit the energy carriers in a more comprehensive way:

- Coal (coal, coal products and peat);
- Oil (crude, NGL, feedstocks and oil products);
- Natural gas (natural gas);
- Electricity (nuclear and electricity);
- Renewables (hydro, geothermal, solar photovoltaic, wind, waves and tide);
- Biofuels and waste (biofuels and waste);
- Heat (heat and solar thermal).

2.2.3. Differences in the industrial structure

The industrial sector is, in the developed countries, a big consumer of energetic resources. Because of this, a well-balanced industrial structure is essential to face the economic, energetic and environmental questions a country might have.

An absolute and relative assessment of the influence of each industry was made. The industries were grouped, according World Energy Balances (IEA 2011):

- Iron and steel;
- Chemical and petrochemical;
- Non-ferrous metals;
- Non-metallic minerals;
- Transport equipment;
- Machining;
- Food and tobacco;
- Paper, pulp and printing;
- Wood and wood products;
- Construction;
- Textile and leather
- Other non-specified.

2.2.4. Country size

The country size has an impact on the overall energy use of a country. Examples that illustrate this connection include higher energy needs associated with transport in bigger countries and energy savings associated with larger electricity production sectors in bigger countries.

The country size will be evaluated using population density, surface and population. Each of these, give different results to characterize the relevance of the parameter country size in the energy efficiency of a country. We chose three indicators to measure this influence: the total primary energy supply per surface to analyse the easiness of energy distribution; the TPES per person to assess the availability of energy; and the oil products' consumption in transports to get data from the transport's dependency.

3. Results and Discussion

3.1. Efficiencies

3.1.1. Primary-to-Final Efficiency

This indicator shows an overall decrease in the efficiency of primary to final energy for all countries between 1960 and 1985 and a tendency to a more constant value in the last 20 years with the exception of Norway. The biggest overall decrease in efficiency is also for Norway, where the oil extraction is becoming more difficult, and as a result a higher amount of energy has to be used to extract oil. Denmark is the country that has a more constant overall efficiency in the last 50 years. The range of efficiency values is much narrower in 2010 that it was in 1960.

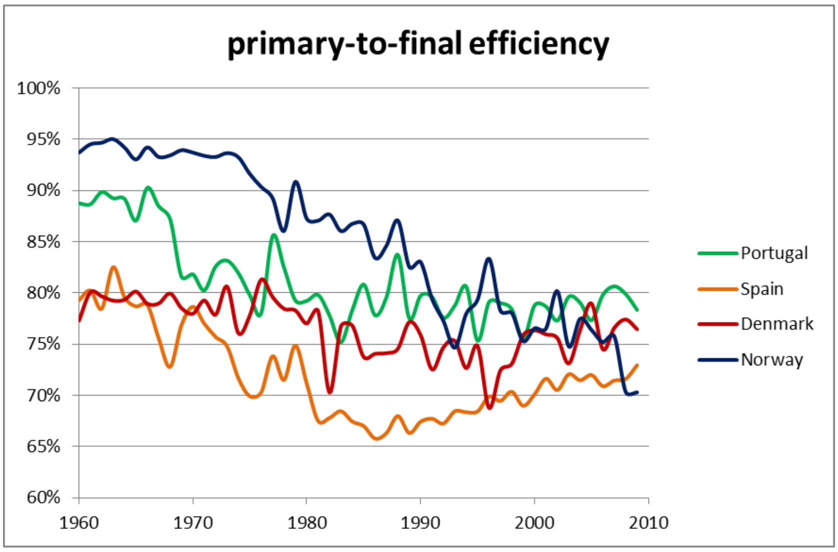

FIGURE 1 - PRIMARY-TO-FINAL EFFICIENCY

3.1.2. Thermoelectric transformation efficiency

The efficiency in the thermoelectric transformation sector has been following a slightly ascendant tendency for all 4 countries. Denmark has electricity produced by cogeneration since 1960, while the other 3 countries only implemented this measure in mid-80's. Norway due to the huge availability of fuels to produce electricity can support these big changes in this efficiency with small impact in their economy, see figure 4.

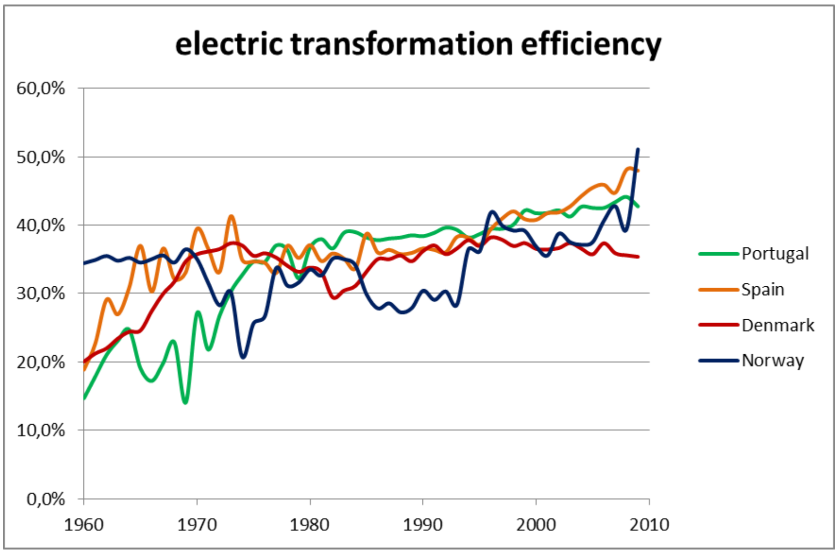

FIGURE 2 - THERMOELECTRIC TRANSFORMATION EFFICIENCY

3.1.3. Oil refinery efficiency

In the oil refinery sector, Norway could have a very high efficiency because its crude quality is very high. Portugal and Spain, with little variations, succeeded to achieve high efficiencies in the conversion process, higher than 97%. The efficiency in Denmark was the lowest in 1960, then it improved and it decreased a little in the last ten years suggesting that Denmark has been using lower quality (cheaper) oil as an input to the refinery industry.

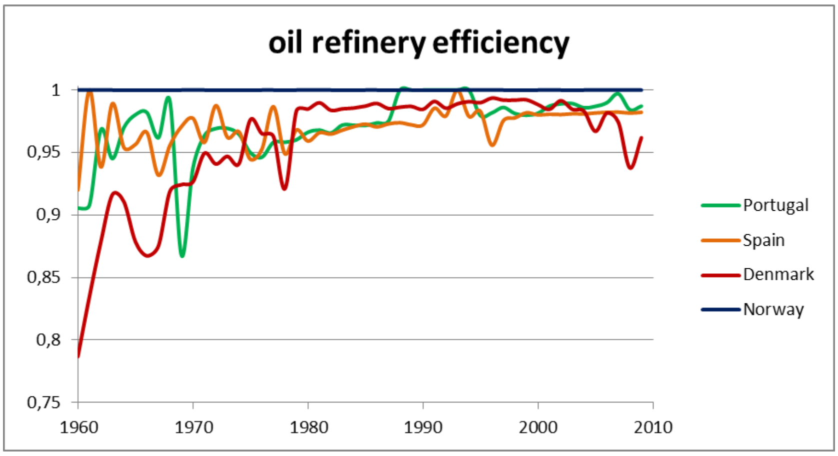

FIGURE 3 - OIL REFINERY EFFICIENCY

3.2. Determinant Factors

3.2.1. Self-sufficiency

One crucial factor in the energetic scenario of a country is the self-sufficiency. Norway and Denmark, as energetic strong countries, have a production that is higher that their Total Primary Energy Supply (TPES) and as result of this an energetic crisis and/or an increase of fuel/electricity prices would benefit these countries (Coccia 2010). On the other hand, Portugal and Spain are very dependent on imports to satisfy their energetic needs. Portugal produces only one fifth and Spain one quarter of its TPES.

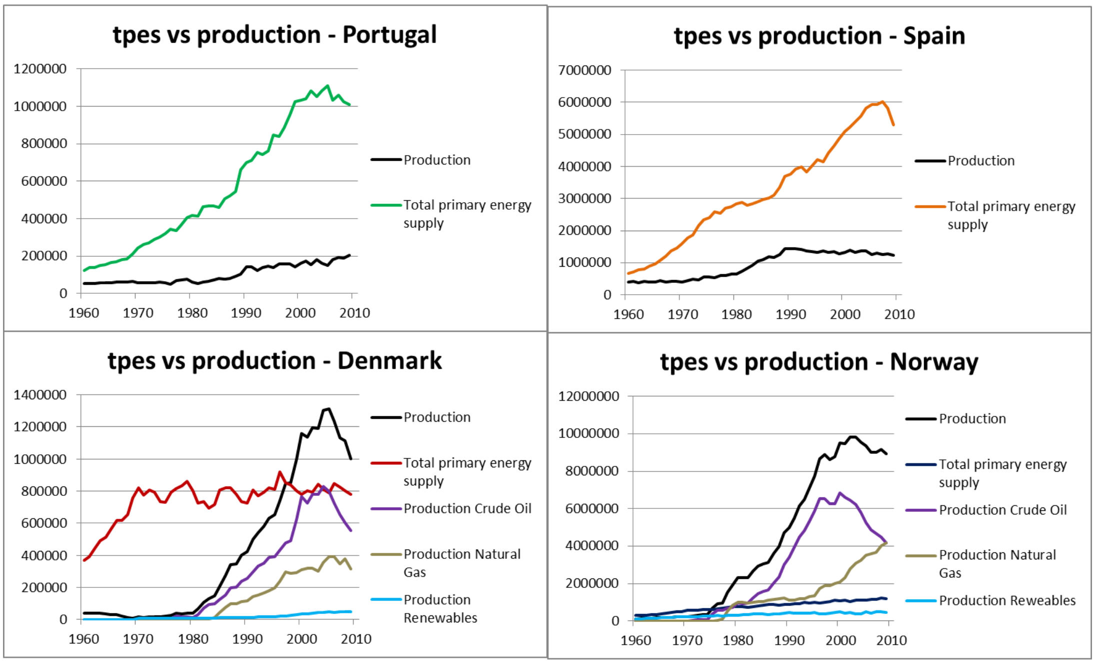

FIGURE 4 - TOTAL PRIMARY ENERGY SUPLLY AND PRODUCTION PER COUNTRY

Besides these differences in production and inland gross consumption, none of these four countries is independent concerning its energetic needs, but they have very different energetic dependences. In figure 5, we can see the increase in Norway's and Denmark's self-sufficiency due to the increase in oil and natural gas production, as well as, an investment in the renewable sector.

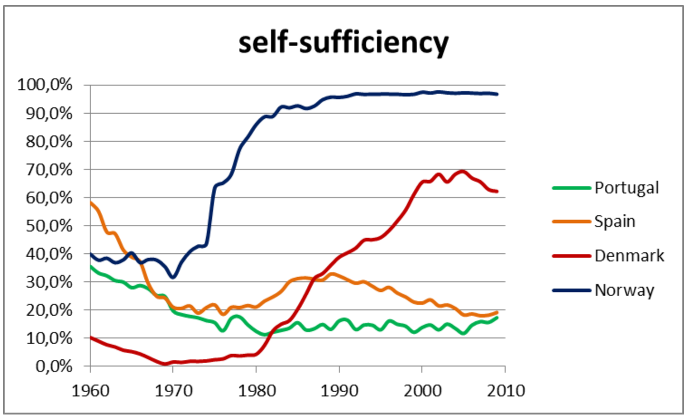

FIGURE 5 - SELF-SUFFICIECY

Magnitude of energy weakness (figure 6) gives a different perspective. It indicates how is the balance between production and inland gross consumption. In this way, we can assess that Norway has a huge importance as an exporter, and Denmark that in 2009 is an exporter, struggled around 1970 to get the energy it needed. That is why this value is lower than all Portuguese and Spanish's magnitudes, despite these have always been net-importers.

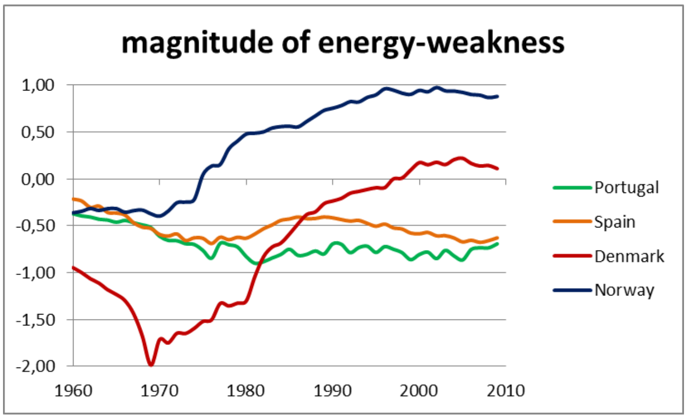

FIGURE 6 - MAGNITURE OF ENERGY WEAKNESS

Self-sufficiency and magnitude of energy weakness give us complementary information on the energy dependence of a country.

3.2.2. Composition of total primary energy supply

Oil represents the biggest fraction of energy consumption of modern countries. But some aspects are relevant for this trend. Denmark is succeeding in decreasing the consumption of oil, by replacing it with natural gas, renewables and biofuels and waste. Norway was able to keep it constant by increasing the fraction of renewables and the exploration of natural gas. Portugal and Spain have difficulties in replacing oil, but since 2008 they have been succeeding in slightly decreasing the consumption of oil due to the economic crisis. Portugal has the higher gross consumption of biofuels and waste, and Norway as a renewable policy that provides almost 50% of its TPES.

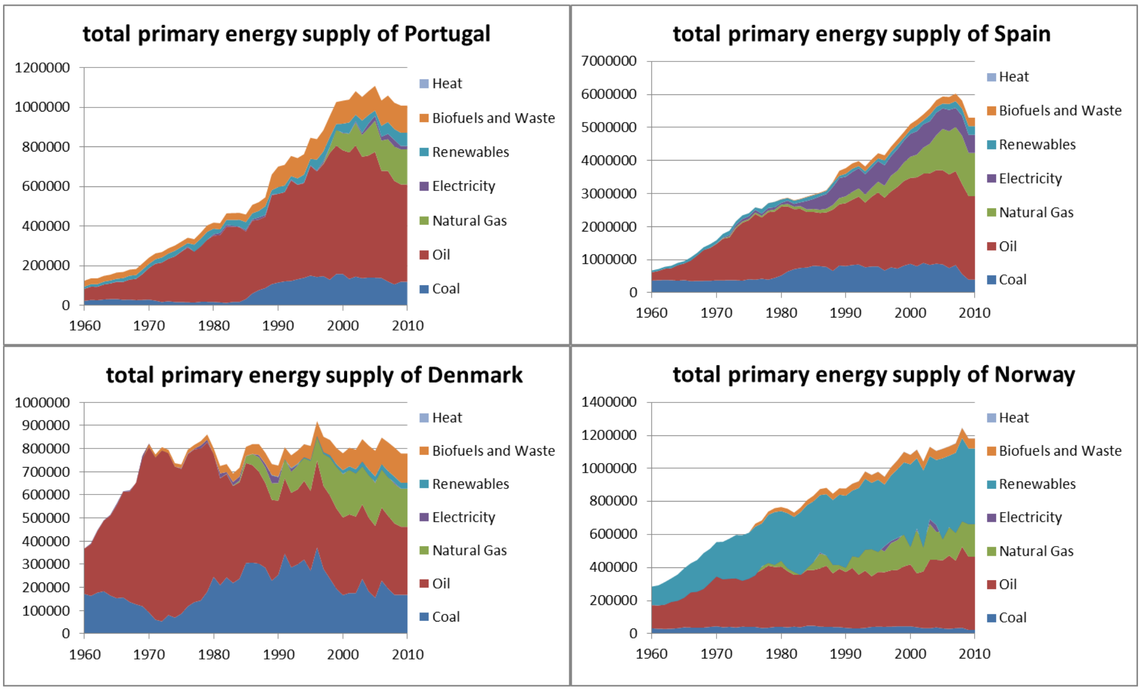

FIGURE 7 - TOTAL PRIMARY ENERGY SUPPLY PER COUNTRY AND PRODUCT

3.2.3. Differences in industrial structure

We will only consider data regarding industrial structure after 1970 due to the low quality of the prior data, as the biggest percentage of energy used is non-specified. Non-metallic minerals are the industrial sector that consumes more energy in Portugal, Spain and Denmark. Norway uses its energy in industry for non-ferrous metals. The industry of iron and steel only has relevant influence in Spain and Norway, where it's decreasing. In Portugal, paper, pulp and printing industry have a relevant influence consuming a fifth of the energy used by the industry.

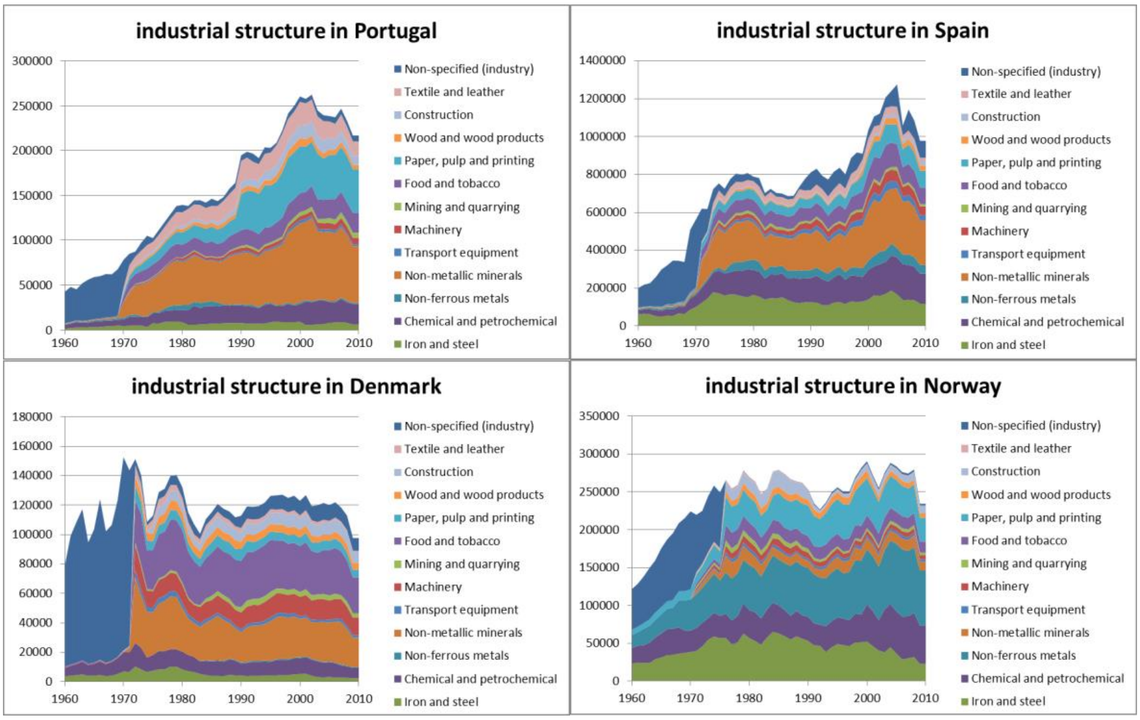

FIGURE 8 - ENERGY CONSUMPTION PER INDUSTRY

3.2.4. Country Size

Gross energy consumption, is dependent on the distance between the production, transformation and consumption. When weighted by surface, we get the easiness for energy to get to every part of a country. Norway is the one with more difficulties in this distribution. While, when weighted by person, we get the global availability of energy. Norway is the one with more energy available.

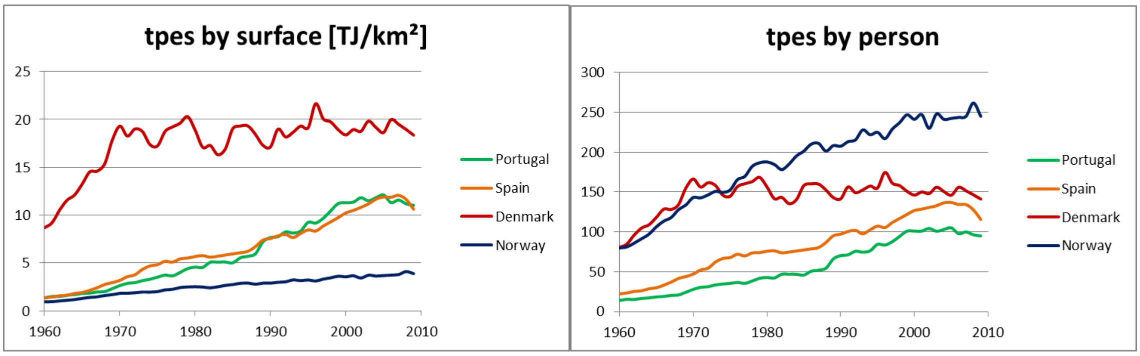

FIGURE 9 - TOTAL PRIMARY ENERGY SUPPLY BY SURFACE AND BY PERSON

The indicator presented in figure 10 is a measure of personal mobility in a country. It gives the impact of oil products based vehicles on the way of living. This has the contribution of all transports: road, rail, maritime and aerial.

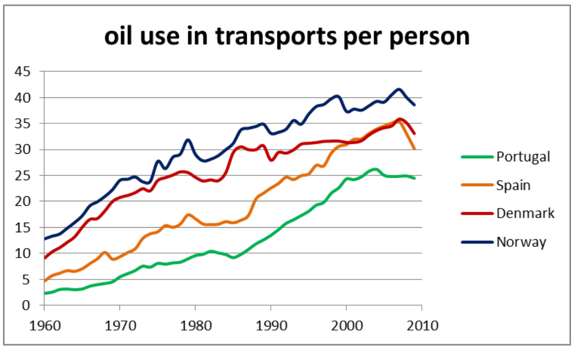

FIGURE 10 - OIL USE IN TRANSPORTS PER PERSON

4. Conclusions

Energy interdependence is very present in modern countries. Understanding this bond between factors and efficiency is crucial to explain the evolution on efficiency. Despite that, we can select individual indicators to analyse a determined influence on energy trends or efficiencies.

Some of these six factors have a clearer link to efficiency, like the degree of self-sufficiency, which explains the decrease in Norway's primary-to-final efficiency. However, some of them look more difficult to connect with energy efficiencies. For those that a direct link hasn't been made, further studies will be carried out to better understand and quantify their influence of efficiencies' variation.

Building aggregated efficiencies from individual indicators, such as self-sufficiency, sectorial data, or discretionary personal consumption are a powerful tool to assess new challenging energy scenarios. Therefore, a country would be able to adjust its energetic demand according to very different indicators, encompassing different fields of knowledge.

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DAY 10 - 16:30		
Room 613 - Energy Projects Analysis		
Evaluation of wind energy potential in Davutpasa campus	Mustafa Tahir Akkoyunlu[1]; Saban Pusat[1]	[1]Yildiz Technical University
Why shareholders of wind energy plant have a high profitability in Galicia?	Dra. Irene Clara Pisón Fernández[1]; Dr.Francisco Rodríguez de Prado[1]; Dr.Félix Puime Guillén[1]	[1]Universidad de Vigo
A risk analysis of small-hydro power (SHP) plants investment	Jorge Cunha, Paula Ferreira	Center for Industrial and Technology Management, Universidade do Minho
Domestic photovoltaic systems: a finance-based MCDA approach	Dulce Coelho[1]; Carla Oliveira Henriques[2]; Patrícia Pereira Silva[3]	[1]ISEC, Polytechnic Institute of Coimbra; [2]ISCAC, Polytechnic Institute of Coimbra; [3]Faculty of Economics, University of Coimbra
Deploying a Renewable Energy Project: An Equilibrium Analysis	Luciana Barbosa[1]; Alberto Sardinha[2]	[1]Instituto Superior Técnico, UTL; [2]INESC-ID and Instituto Superior Técnico, UTL

EVALUATION OF WIND ENERGY POTENTIAL IN DAVUTPAŞA CAMPUS

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Abstract

In the current study, wind characteristics and wind energy potential of Davupaşa Campus of Yıldız Technical University are investigated. In the analyses, data measured at the Campus are used. The results showed that the reliability of the data is not enough for wind energy potential assessment. Therefore, a new meteorological station should be planned and installed with higher capabilities.

Keywords: Wind Energy Potential Assessment, Davutpaşa Campus, Yildiz Technical University, Wind Energy Prediction

1. Introduction

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to produce electricity. However, due to the intermittent nature of wind, it has some problems to think it as a classical energy supply method [1, 2]. Therefore the assessment of wind energy potential highly depends on the wind data measurements. Wind speed is mostly measured with a cup anemometer but there are some other technologies like SODAR and LIDAR which are not common yet.

There are some international standards for wind speed measurement: using calibrated instruments, correct mast installation, size of mast parts etc. And also there are international standards for wind energy potential assessment: minimum one year data measurement, maximum %10 missing data etc. These are the some examples of minimum requirements for wind energy analysis.

There are numerous studies in the literature about wind energy potential assessment. Eskin et al. evaluated the wind energy potential of Gökçeada Island by using the data measured at four different locations [3]. In the study of Ozgener, she used the measured data in Muradiye Campus and evaluated the wind energy potential of the Campus [4]. Al-Abbadi carried out a study to assess the wind energy resource of five locations in Saudi Arabia [5]. Himri et al. studied to assess the wind energy potential of three locations in Algeria [6].

In this study, evaluation of wind energy potential in Davutpaşa Campus was done. In the analyses, data measured in Davutpaşa Campus were used. In energy production estimations, a 330 kW Enercon turbine was used.

WIND DATA COLLECTION IN DAVUTPAŞA CAMPUS

Yildiz Technical University has three campuses: Yıldız, Ayazağa and Davutpaşa. Davutpaşa Campus is located in Esenler district of İstanbul. The wind data is measured and collected over a few years in Davutpaşa Campus. The location of the wind measurement station is shown in Figure 1. The measurements are made 10 m above ground level and recorded in every one minute interval. Additionally, elevation of the station is 62 m. The data used in the analyses are 10-minute average.

Figure 1 Location of the Davutpaşa wind measurement station

The provided data have lots of gaps and problems. Therefore, almost one year data is produced from the data of 2009, 2010 and 2011. The rate of missing data in generated data set is approximately 5% which is lower than 10% (maximum rate for missing data).

2. Results

Wind Data

In this section, the wind speed and the wind direction data are statistically analyzed. Availability of wind during the day is an important issue in evaluation of the wind energy potential. The diurnal hourly change in wind speed is presented in Figure 2. The maximum wind speed occurs at 13:00 h while the minimum wind speed occurs at 00:00 h. The higher wind speed values are seen between 07:00 and 19:00 h.

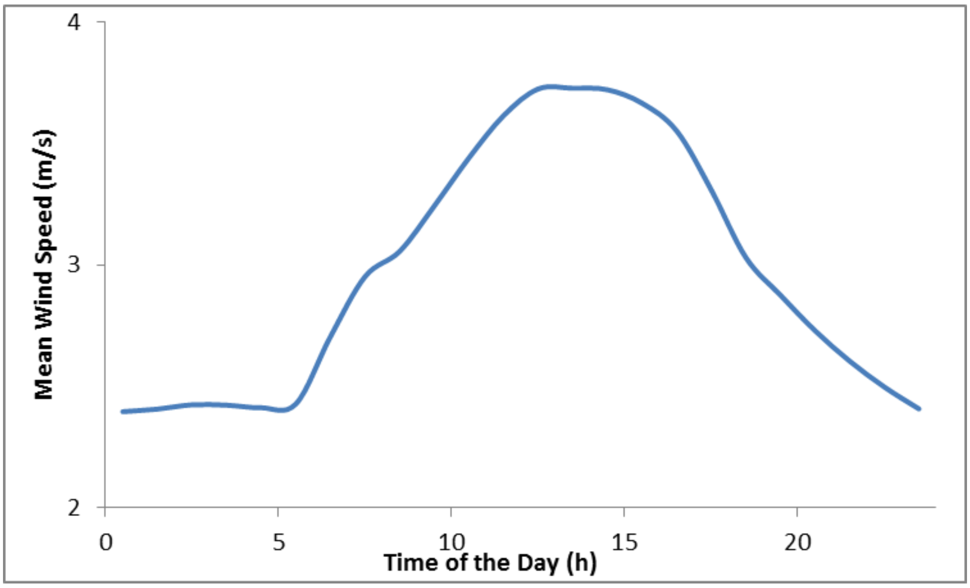

Figure 2 Hourly variation of the mean wind speed

The monthly variation of mean wind speed provides information about the availability of wind during the different months of the year. The monthly change in wind speed is presented in Figure 3. The highest wind speed occurs in December while the lowest in June.

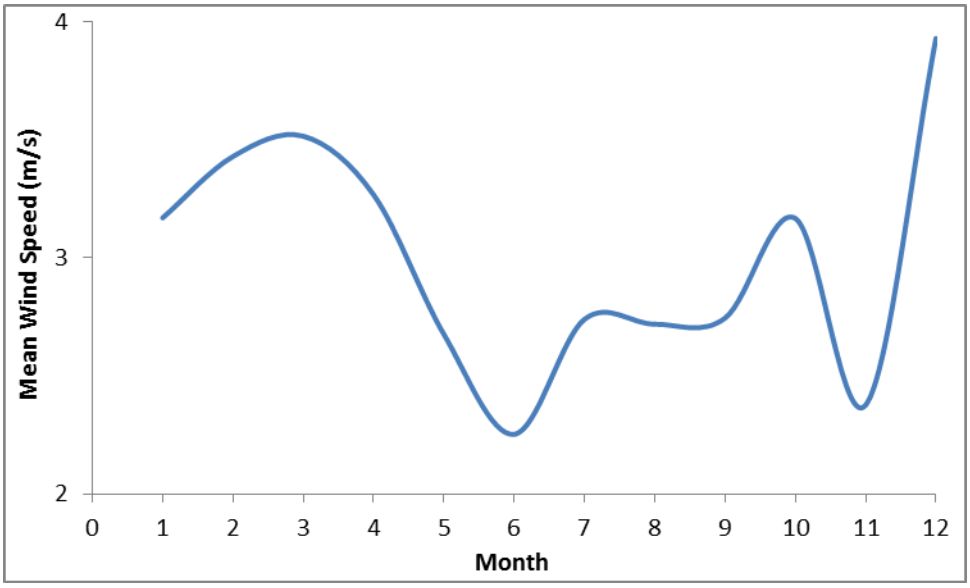

Figure 3 Monthly variation of the mean wind speed

Figure 4 presents the annual wind speed frequency distribution at Davutpaşa. This frequency distribution is based on the measured data. The shape of the distribution curve gives useful information about the amount of energy that is available for the wind turbines.

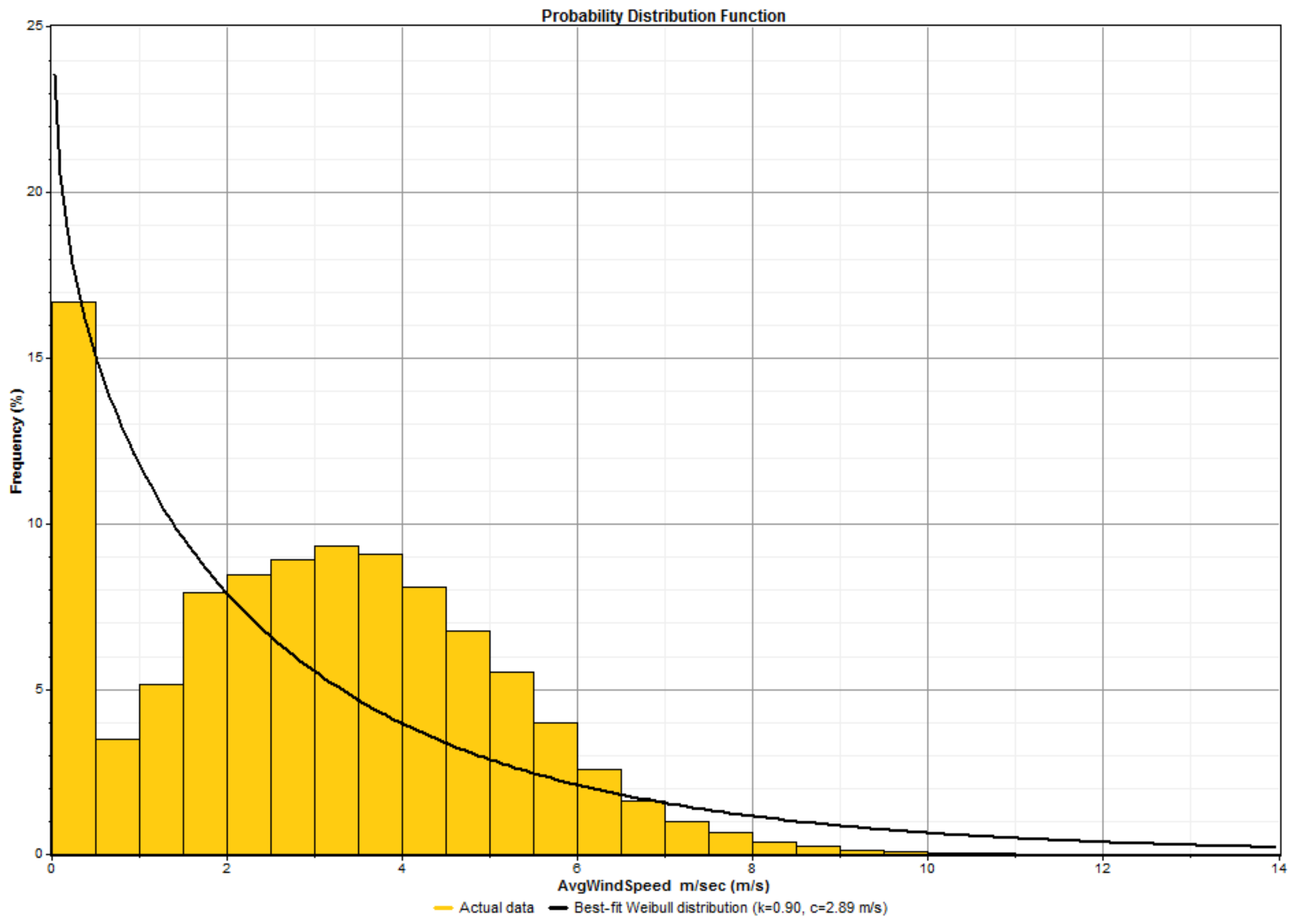

Figure 4 Wind speed frequency distribution

Wind Energy Yield Estimation

In this section, the energy yield of different wind turbines is obtained by using Windographer software [7]. Wind speed at different heights should be determined to calculate the energy produced by the wind turbines. There are only the measurements at 10 m. Therefore, the wind power law is used to determine the hub height wind speed. The value of 0.18 is used as the power law coefficient.

A 330 kW Enercon wind turbine is used in energy yield estimation. Rotor diameter is 33.4 m and hub height is selected as 75 m. In turbine output calculations, an overall energy loss rate is accepted as 2%. Monthly turbine outputs are presented in Figure 5. Annual energy production is estimated as about 407 MWh/year. Capacity factor is calculated as 14.1%.

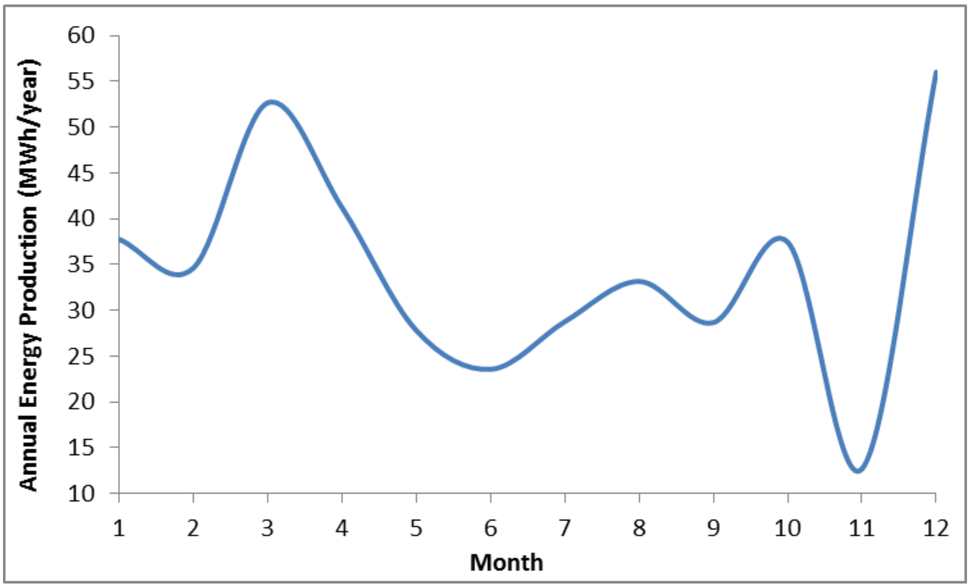

Figure 5 Monthly energy productions

3. Conclusions

In this study, evaluation of wind energy potential in Davutpaşa Campus was done. Results showed that annual wind energy production is 407 MWh and capacity factor is 14.1% for one Enercon turbine with a power of 330 kW and hub height of 75 m. The data used in the analyses have many gaps and invalid parts. Therefore, the reliability of the data is low. Therefore, measurement station in Davutpaşa Campus should be improved. Number of anemometers at different heights should be increased for accurate wind energy analyses. Quality and calibration of the sensors should be investigated. Rate of periods with no measurements should be decreased.

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WHY SHAREHOLDERS OF WIND ENERGY PLANT HAVE A HIGH PROFITABILITY IN GALICIA?

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Abstract

This paper presents an analysis of wind power in Galicia from the perspective of profitability. In this work it will be elaborated a predictive model that allows us to explain two variables “external financing” and “loan term”, that explain why shareholders of wind energy plant have a high profitability.

Keywords: Alternative Energy Sources, environment, Natural Resources.

Code JEL: O13, Q42

1. Introduction

This paper presents an analysis of wind power in Galicia from the perspective of profitability. Therefore an empirical study of wind farms will be operated in the autonomous community of Galicia taking into account the profitability of shareholders that participate in these investment projects.

It has been noted that in recent years there has been an important development of wind energy industry in the region of Galicia which has created richness and employment and according to EGA (Galician Wind Association) “Galicia is considered to be the fourth wind power in Europe, bettered only by Germany, Spain and Denmark and the sixth in the world after the United States and India”.

However, there is a problem for continuing with the development of the wind energy sector, achieving adequate finance for these types of projects and at the same time, being attractive for investors.

This study has been organized in four parts. First presented is an overview of the development of project feasibility for a wind energy plant, then the methodology of the study, the methodology of statistical analysis, variables studied in the survey, bivariate associations and estimated logistic regression model, reaching finally to the main conclusions.

2. Development of project feasibility for a wind energy plant

For the development of a generic business plan for a wind energy plant we will build a balance sheet, an income statement and a state of sources and uses of funds (EOAF), with a particular structure, of which we get the cash flow generated for a time horizon that coincides with the life of the main investment (Cibrán et all, 2008).

The formulation of these financial statements, results from a research focused on finding out what are the key variables in estimating each of the elements of each financial statement which has allowed us to conclude those variables:

a. The costs of incorporation.
b. The installed power.
c. Price paid for each kW installed.
d. Fixtures.
e. The useful life of the elements.
f. Percentage of borrowed funds on the liabilities.
g. Percentage of equity on the liabilities.
h. The Kw. generated.
i. The tariff regime.
j. Interest rates.

Which, properly selected, will allow us to obtain the initial balance sheet, income statement and cash flow generated. Information needed to develop the EOAF, allowing us in turn to estimate the cash flow available to shareholders and therefore the estimated IRR for shareholders [1].

Therefore, once known the key variables we can elaborate the balance sheet, where each asset or liability is calculated as follows:

1. **Noncurrent Assets**: from KW installed capacity, the price paid per KW, the nature of the elements that are part of each installation and the participation of these as a percentage of the total cost of the installation, you can make non-current assets by item, assigning to each its amount.
2. **The Current assets**: the sum of the average balance of clients and the average balance of cash. Knowing the number of sales, as explained below estimate in determining the income statement, and the average collection period common in the industry, we can obtain the average balance of Clients (Santandreu, 2001). On the other hand, it is possible to estimate an average balance of cash. To do this, it must be taken into account the monthly financial payments, calculated from the percentage of external financing of investment, the estimated monthly payroll based on the number of workers and suppliers monthly payments calculated from the items cost estimate as explained below in determining the income statement

From the sum of non-current assets and current assets we obtain the Total Assets and, therefore, the total liabilities, assets and liabilities which we calculate as follows:

1. **Current Liabilities**: as the average balance of Suppliers, calculated from the estimate of expenditure as explained below in determining the income statement and the average payment period.
2. **Noncurrent Liabilities**: calculated from the percentage of external financing of total investment.
3. **Equity**: the difference is obtained by the above assets and liabilities Liabilities to Total Liabilities.

To estimate the pension balance sheets for the rest of the exercises we will take into account the depreciation of investments, the benefits are taken to reserves in its entirety, the amortization of debt and increases in accounts of Clients, Suppliers and Payroll.

Also from information obtained from key industry variables it is possible to build an income statement, where Revenues and Expenses are estimated as follows:

- **Income or net sales**: as the product of the KW generated per year, data obtained from the installed power and environmental conditions in terms of annual hours of wind, hours of light and wood resources available depending on whether wind, solar or biomass forest, on the selling price of KW generated by the premium recognized in the applicable rate schedule.
- **Maintenance costs:** as an estimated per KW per year generated by the facility.

[1] Understanding the cash flow available to shareholders as money that is available on the company for shareholders and the estimated IRR for shareholders as a measure of the profitability of shareholders.

- **External services:** estimated as an amount in terms of installed capacity for insurance premiums and taxes, and as an amount based on sales in the case of the canon of the council, the rent of land, the costs maintenance and commissions of the sales agent of energy.
- **Wages and salaries**: is calculated based on the agreement for the sector.
- **Taxes:** estimated amount based on the installed power.
- **Miscellaneous:** a figure is estimated on the basis of installed capacity.
- **Depreciation:** estimated from the life of each equipment and facilities that are part of the facility, and the coefficients allowed by the tax office.

We will focus the empirical analysis that will carry out in the next section on it. Therefore, we will make the calculation of the IRR for the specific case of shareholders from capital expenditures made by partners to the start of the investment, the cash flow available to shareholders generated throughout life and liquidation value of the company, understood as the value of equity in the last year of the installation less liquidation expenses of the business (Fernandez, 2,001), we will call it *estimated IRR for shareholders*.

In a previous work, an analysis of feasibility for all current working installations in Galicia has been realized. This is really complex and implies all necessary factors for the running of these plants through financial statements such as balance sheet, an income statement and a state of sources and uses of funds (EOAF) projected for the following 20 years. Each business plan results in a spreadsheet with multiple sheets for each installation. The final output is the shareholder's cash flow which allows the calculation of IRR in 20 years on the initial investment. This extensive paper exceeds the length of the paper, so we use only the final result of this previous work, which is the IRR of each installation as input for the econometric analysis.

3. Methodology of the study

a. Goals.

The objective of this paper is to know the behaviour of the profitability of wind energy companies located in Galicia. To this end, we will realize the following:

1) Delimitation of all the wind energy facilities, also called wind farms, RIPRE database (Registration of facilities special regime producers) has been used. This information has been supplemented by information obtained from EGA (Wind Energy Association of Galicia), by information obtained from INEGA (Galicia's energy Institute) and the SABI financial database. It was obtained as a result that there are 130 installations and therefore questionnaires have been sent to them asking for answers for the following features:

a) Legal form.
b) Business group membership.
c) Nature of the joint owners.
d) Its exclusive location in Galicia or in other territories.
e) The type of generation.
f) The year of installation.

g) The existence of a separate or shared management of the activity.
h) The training manager.
i) The ownership or rental of equipment.
j) The existence of a policy of corporate social responsibility.
k) Possession of an environmental certificate.
l) The sale of CO_2 emission rights.
m) The installed power.
n) The useful life of the equipment.
o) The grant rate obtained.
p) If it has own or external maintenance.
q) The tariff regime.
r) The energy produced per year.
s) Own and borrowed funds.
t) The term of the external financing.
u) The estimated cost at the beginning of the project.
v) Present profitability.

1. Developing an individual business plan for each of the companies studied, for this purpose we will focus on the methodology used in constructing the overall business plan, financial data obtained in the survey, and for the calculation of the remaining data, adjusting their values to the dimension of the facility, allowing us to get a variable created for this purpose, called *estimated IRR for shareholders*.
2. Selecting the successful implementations in terms of profitability from a discriminant analysis on the variable *estimated IRR for shareholders*. Use of this variable on the idea that shareholders measure the return on investment in terms of actual disbursements made by them and the returns generated by the facility in terms of *cash flow available for shareholders*. In this way, a plant which *estimated IRR for shareholders* is higher than the estimated average IRR for the shareholders of all facilities, is considered successful.
3. Stating a predictive model that allows us to explain what variables are relevant for justifying what causes that a wind energy plant has an above-average profitability and why.

b. Design and Data collection.

The main body of the survey was divided into two blocks: on one hand a series of questions for identification purposes of the activity and on the other hand, purely financial questions.

The data collection was performed during the first quarter of 2011, through a series of personal contacts with managers and / or owners. These contacts have taken the form of personal interviews and carrying out a survey, in person or by telephone[2], to collect certain

[2] A telephone survey may have a certain level of risk if an individual of the population has no telephone. In our case, the entire population had a telephone, as far as we know, so we would not be including any bias. However, in some cases we chose a face-to-face interview (Azorin and Sanchez Crespo, 1986).

data with a certain degree of homogeneity in all companies, which would be useful to proceed later to its statistical treatment.

4. Methodology of statistical analysis

For the study of the data we used SPSS for Windows, following the methodology that we explain below.

Logistic regression models.

Regression methods have become an integral component of any analysis that tries to describe the relationship between a response variable and one or more variables to explain that answer. What distinguishes mainly to a linear regression is that the outcome variable (dependent) is binary or dichotomous. However, the aim in both types of regression is basically the same. This is to find those variables that explain the result, and to quantify the relationship between variables using a mathematical model. The goodness of this model will be greater the more it fits to the relationships that occur in reality and therefore present a greater applicability. In the case of logistic regression what we try is, through a mathematical model, find variables that allow us to classify individuals of a sample in each of the two subpopulations established and determined by the two possible values of the dependent variable. That is, due to logistic regression we can investigate causal factors of a particular characteristic of the population and also consider what factors modify the probability of a given event.

The ultimate goal would be to use the model for prediction purposes and, therefore, have a greater applicability. That is, if we know the values of the independent variables, which in the case of logistic regression are called covariates, through the model we could try to predict which would be the value of the dependent variable to know in what subpopulation we included this particular individual, understanding that we can have a margin of error which will be smaller, the greater the goodness of fit of the model.

The mathematical model is given by the formula (Hosmer y Lemeshow, 2000):

$$\pi(X) = P(Y = 1 / x_1, x_2, ..., x_p) = \frac{e^{\beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + ... + \beta_p \cdot x_p}}{1 + e^{\beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + ... + \beta_p \cdot x_p}}$$

where Y is the dependent variable and (x_1, x_2,..., x_n) are the covariates.

Another difference between the linear and logistics regression is that in the first one we need the random disturbance ε to be a white noise, i.e., to be distributed as a normal with mean 0 and variance σ2, being:

$$\varepsilon = Y - E(Y / X)$$

However, in the logistic regression ε is a dichotomous variable that takes two values:

$$1 - \pi(X) \quad si \quad Y = 1$$

$-\pi(X) \ \ si \ \ Y = 0$

Therefore, ε behaves as a binomial distribution. In addition, logistic analysis has the advantage of not requiring the condition that the variables are allocated according to a normal, making it more robust than the discriminant (Vilarino Rodriguez, 1995).

Moreover, not just any model is valid because we have to check that the covariates are significant, or what would be the same, that the model which includes the variables explains more about the dependent variable that the model that does not include them. The latter, we will consider it when building the model and will be determined by the value of the Wald statistic.

To select the covariates it was made, prior to the estimated logistic regression model, a contrast to evaluate the association between each of the potential covariates and the independent variable, entering only in the logistic regression model those covariates that in univariate contrast have a statistical significance ($p < 0.05$).

When making the estimate of the logistic regression model is found that the variables included in the model maintained statistical significance. If all the coefficients that are at the end of the process are statistically different from zero, we get that the model actually has a statistical meaning.

Evaluation of the final model

One way to evaluate the fit of the model is through a kind of "assessment of a diagnostic test" checking how the new test classifies (the model obtained) the individuals from the test sample compared with reality (what is observed). In fact, the program SPSS automatically analyzes, after selecting the model, variables which would be the classification of individuals in the study after applying the equation obtained, and creates a 2x2 table with the values predicted and those actually observed.

Another option for assessing the fit of the model as a whole is through the so-called global measures of goodness of fit, among which are:

1. The model deviance, which corresponds to minus twice the natural logarithm of the likelihood (-2 log-likelihood,-2LL) measures how well a model fits the data.
2. The generalized R square of Cox and Snell is a coefficient of determination used to estimate the proportion of variance of the variable explained by the predictors. The R square of Cox and Snell is based on the comparison of log-likelihood (LL) for the model with respect to the log-likelihood (LL) for a baseline model. Its values range between 0 and 1.
3. The Nagelkerke R-squared is a corrected version of the R-squared of Cox and Snell. The R square of Cox and Snell has a maximum value less than 1, even for a "perfect" model. The Nagelkerke R square statistic corrects the scale to cover the full range from 0 to 1.

5. Variables studied in the survey

Through the answers obtained in the questionnaire, the following variables have been studied:

- Province.
- Legal Form.
- Group Membership.
- Partners owners.
- Only in Galicia.
- Year of installation.
- Kw Price.
- Other activities of generation.
- Training Manager.
- Corporate Social Responsibility.
- Environmental Certificate.
- Sale Co2 rights.
- Tariff regime.
- External financing (%).
- Term loan.
- Installed power (kW).
- kw produced annually.
- Previous Return (%).
- Current Profitability

6. Bivariate associations

Recoding of variables.

In logistic regression, two decisions can be taken with respect to categorical variables:

1.- Try to reduce its size by grouping the categories until converting it into dichotomous.
2.- Transform it into a number of c-1 dummy variables, where c is the number of different categories of this variable.

However, when the number of possible values of a categorical variable is very high, its transformation into dummy variables, on one hand would oversize the number of variables, a not highly recommended decision considering the small sample size with which we count (130) and, on the other hand would greatly hinder the interpretation of the model.

To this we must add that when facing some of the categorical covariates with the dichotomous variable *discrimination charter profitability*, we encounter crosses with too small sample sizes which do not allow consideration of the variables as they were originally made for inclusion in the model.

Therefore, in this analysis and taking into account the contingency tables for each of the categorical variables with the variable *discrimination on profitability*, we chose to minimize the number of categories of the variables, *Legal Form*, *Other activities of generation*, *tariff regime and installation year,* as follows:

- **Recoded legal form:** The Categories Public agency and Public limited liability companies are grouped together, being few observations. Remaining recoded as follows:

  0: Groups together the categories Public Agencies and Public limited liability companies
  1: Corporation.

- **Other activities of generation:** The one which develops activities not of generation will be grouped with the ones which do not develop other activities. Remaining recoded as follows:

  0: Groups the categories: companies without other activities and companies with other activities not of generation.
  1: Companies with other activities of generation.

  - **In the case of the tariff regime**, as it is a variable with 7 categories and taking into account that some of them had few observations, we decided to group them into three categories based on the knowledge of the researcher:

  0: Groups RD 2366/1994 and RD 2818/1998.
  1: Groups RD 1432/ 2002 and RD 436/ 2004.
  2: Groups RD 661/2007, RD 6 / 2009 and RD 1.614 / 2010.

  - **For the year of installation**, as it is a variable with 13 categories and taking into account that some of them had few observations, we decided to group them into three categories based on the knowledge of the researcher:

  0: Groups the years 1998, 1999, 2000 and 2001.
  1: Groups the years 2002, 2003, 2004, 2005 and 2006.
  2: Groups the years 2007, 2008, 2009 and 2010.

In the case of quantitative variables is obvious that its transformation into categorical variables implies a loss of information.However in this paper after analyzing the percentage distribution of frequencies of the different values of each of the quantitative variables, two of them, namely, the *percentage of external financing* and the *loan term*, it was decided to transform them into dichotomous as it was observed a change of pattern in the data with respect to *discrimination on profitability.*

- In the case of the **loan term** this change is observed after 15 years, since for all values of the continuous variable less than or equal to 15 years, there is a higher percentage of companies with below average profitability than in the rest of categories. (Table 2)

Discrimination by profitability proportionally to the loan period.

			Discrimination by profitability	
			0	1
Loan period	10	Count	2	0
		% of the loan period	100,0%	,0%
	12	Count	30	1
		% of the loan period	96,8%	3,2%
	15	Count	30	6
		% of the loan period	83,3%	16,7%
	18	Count	8	18
		% of the loan period	30,8%	69,2%
	20	Count	3	31
		% of the loan period	8,8%	91,2%
	28	Count	0	1
		% of the loan period	,0%	100,0%

Table 2

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

If we look at the 69 companies which have a loan period lower or equal to 15 years, nearly 90% have a lower profitability than the average. This percentage practically is reversed when the companies with a loan period longer than 15 years, in this case, 82% of the companies reach more than the average profitability.

- For the **percentage with external financing**: this case is observed in 90% of the cases, since for all values of the continuous variable smaller than 90%, there is a bigger percentage of companies with profitability lower than average compared to the rest of the categories. (Table 3)

Discrimination by profitability proportionally to the percentage of external financing.

			Discriminación por profitability	
			0	1
external financing (%)	80	Count	23	1
		% de external financing (%)	95,8%	4,2%
	82	Count	6	0
		% de external financing (%)	100,0%	,0%
	84	Count	5	0
		% de external financing (%)	100,0%	,0%
	85	Count	23	1
		% de external financing (%)	95,8%	4,2%
	90	Count	14	26
		% de external financing (%)	35,0%	65,0%
	92	Count	0	4
		% de external financing (%)	,0%	100,0%
	95	Count	2	25
		% de external financing (%)	7,4%	92,6%

Table 3

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

From the 59 companies that have an external financing percentage lower than 90%, 96,6% have a lower than average profitability. This fact changes if you consider the 71 companies with an external financing share equal or over 90%, in this case 75,5% of the companies have an over the average profitability.

- **Exploring bivariate associations.**

In order to analyze the relationship of the dependent variable (*discrimination by profitability*) with each single independent variable, a bivariate analysis is performed as part of the preceding analysis, which makes a preliminary selection of variables with high matching level that will be the variables will be the ideal candidates to take part in the logistic regression model.

- With the categorical variable contingency tables and chi-square test with Fisher exact test are used. (Table 4)

Summary of contingency tables and the p-value associated with each contrast for categorical variables used.

CATEGORICAL INDEPENDENT VARIABLE	DISCRIMINATION BY PROFITABILITY				p-value
	0		1		
	N	%	n	%	
Total	73	56,154	57	56,154	
PROVINCE					0,218 [a]
A Coruña	26	50	26	50	
Lugo	32	59,259	22	40,741	
Ourense	3	37,5	5	62,5	
Pontevedra	12	75	4	25	
LEGAL FORM (recoded)					1,000 [a]
Other (0)	7	58,333	5	41,667	
Corporation (1)	66	55,932	52	44,068	
BELONGS TO GROUP					1,000 [a]
No	5	55,556	4	44,444	
Yes	68	56,198	53	43,802	
OWNERS ARE PARTNERS					-
Institutional Investors	2	100	0	0	
Individual investors	71	55,906	56	44,094	
Public investors	0	0	1	100	
IN GALICIA ONLY					1,000 [a]
No	65	56,034	51	43,966	
Yes	8	57,143	6	42,857	
PRICE Kwh.					0,459 [a]
1000	44	57,895	32	42,105	
1100	11	52,381	10	47,619	

1200	13	48,148	14	51,852	
1600	5	83,333	1	16,667	
OTHER GENERATION ACTIVITIES (RECODED)					0,512 [a]
{No other activities; Other activities not generation} (0)	7	70	3	30	
{Other generation activities} (1)	66	55	54	45	
MANAGERS TRAINING					1,000 [a]
Postgraduate	67	56,303	52	43,697	
University	6	54,545	5	45,455	
CORPORATE SOCIAL RESPONSIBILITY					1,000 [a]
No	7	58,333	5	41,667	
Yes	66	55,932	52	44,068	
ENVIRONMENT CERTIFICATE					-
No	1	33,333	2	66,667	
Yes	72	56,693	55	43,307	
CO_2 RIGHTS SALE					1,000 [a]
No	6	54,545	5	45,455	
Yes	67	56,303	52	43,697	
RATE REGIME (RECODED)					0,645 [a]
{2366/1994; 2818/1998} (0)	19	51,351	18	48,649	
{1432/2002; 436/2004} (1)	38	60,317	25	39,683	
{661/2007; 6/2009; 1614/2010} (2)	16	53,333	14	46,667	
EXTERNAL FINANCING (RECODED)					0,000 [a]
< 90% (0)	71	71,717	28	28,283	
≥90% (1)	2	6,452	29	93,548	
LOAN TERM (RECODED)					0,000 [a]
≤ 15 years (0)	62	89,855	7	10,145	
> 15 years (1)	11	18,033	50	81,967	
INSTALLATION YEAR (RECODED)					0,825 [a]
{1998; 1999; 2000; 2001} (0)	20	54,054	17	45,946	
{2002; 2003; 2004; 2005; 2006} (1)	37	58,730	26	41,270	
{2007; 2008; 2009; 2010} (2)	16	53,333	14	46,667	

[a]Chi-square with Fisher exact test.

Table 4

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

Table 4 shows that the only categorical variables that have a significant association (p<0,05) with the resulted variable *discrimination by profitability are external financing* (recoded) and *loan term* (recoded).

- As for the continous variables a check is completed to see if there is a difference in the midpoint of each continuous variable comparing the two groups assembled by the categories of the dependent variable *discrimination by profitability*. The statistic proof used in this case was the non-parametric Mann-Whitney test, as the necessary normality assumption was not confirmed to apply a Student t.

This approach is applied for the variables: *Installed power (kw)*, *Kw produced per year*, *previous profitability* and *current profitability.*

In charts 1, 2, 3 and 4 the distribution of each one of the previous variables is shown in the two groups established by the *discrimination by profitability*.

Distribution of the installed power according to the discrimination by profitability.

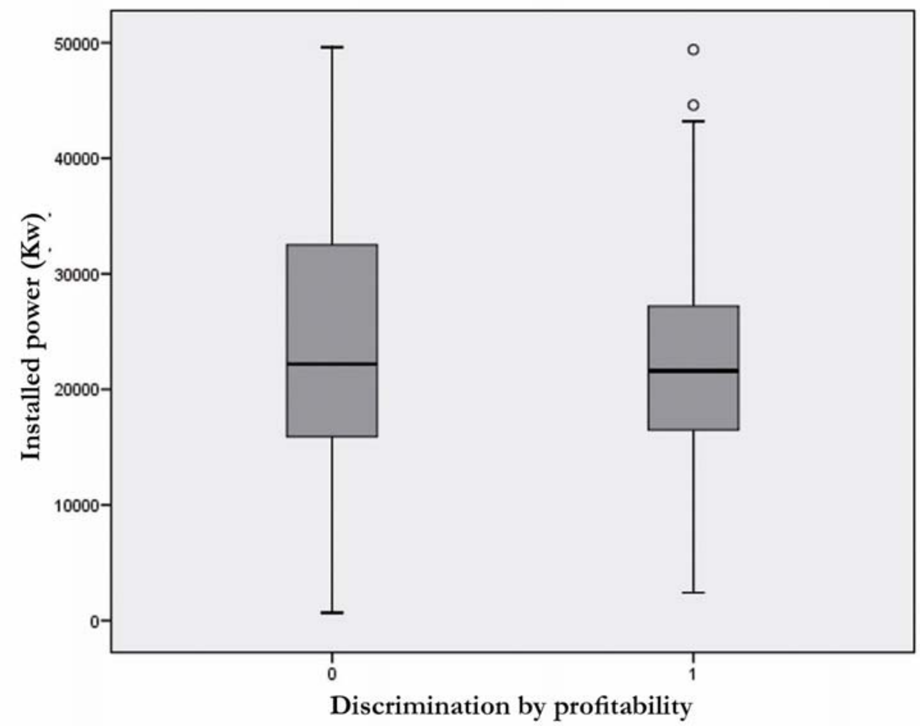

Chart 1

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

In the box-plot the distribution of the *installed power* is shown graphically in the two groups established by the *discrimination by profitability*. As you can see on chart 1 we cannot reject the equality of means of the variable installed power in the two profitability groups. Nevertheless we should consider the bigger dispersion in the values of this variable in the group where the variable *discrimination by profitability* is equal to zero.

Distribution of the kilowatts produced per year according to the discrimination by profitability.

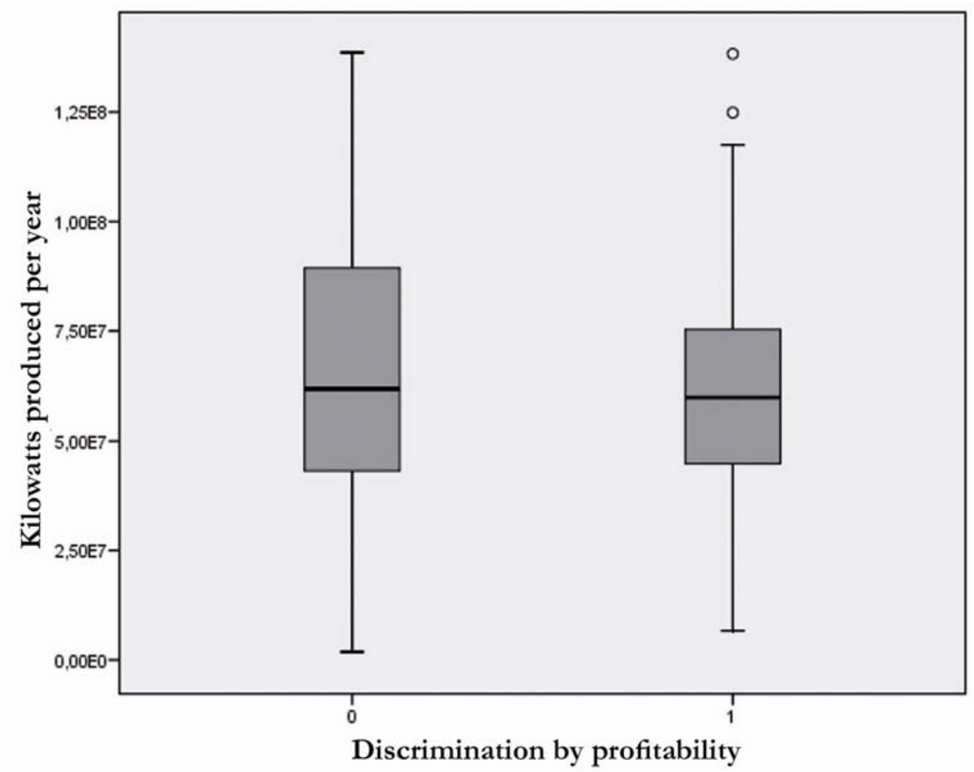

Chart 2

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

As already seen in the case of the installed power, the box-plot representing graphically the distribution of *Kws produced per year,* in both groups established by *discrimination by profitability,* no significant differences are seen in the behaviour of the variable in each one of the profitability groups. We should consider that like in the previous case the greater dispersion in the numbers of variable *Kw produced per year* takes place in the group where the *discrimination by profitability* is equal to zero.

Distribution of the previous profitability according to the discrimination by profitability.

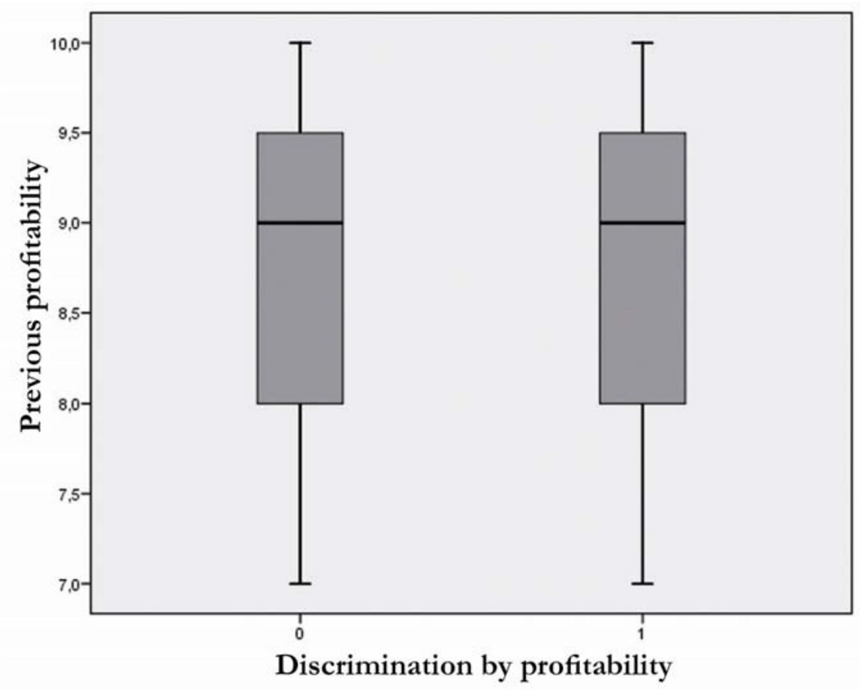

Chart 3

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

In the box-plot you can see graphically the distribution of the *previous profitability i*n the two groups established by the *discrimination by profitability*.

In the first place we should highlight the similarity of the distribution in the previous profitability looking at the two profitability groups.

As you can see in Chart 3, companies with lower profitability than the average, as well as enterprises with more than the average profitability, the median of the distribution of the variable *previous profitability* has the value 9%, this means that 50% of the companies have a *previous profitability* lower that 9%, no matter the value taken by the variable *discrimination by profitability*.

Distribution of the current profitability according to the discrimination by profitability.

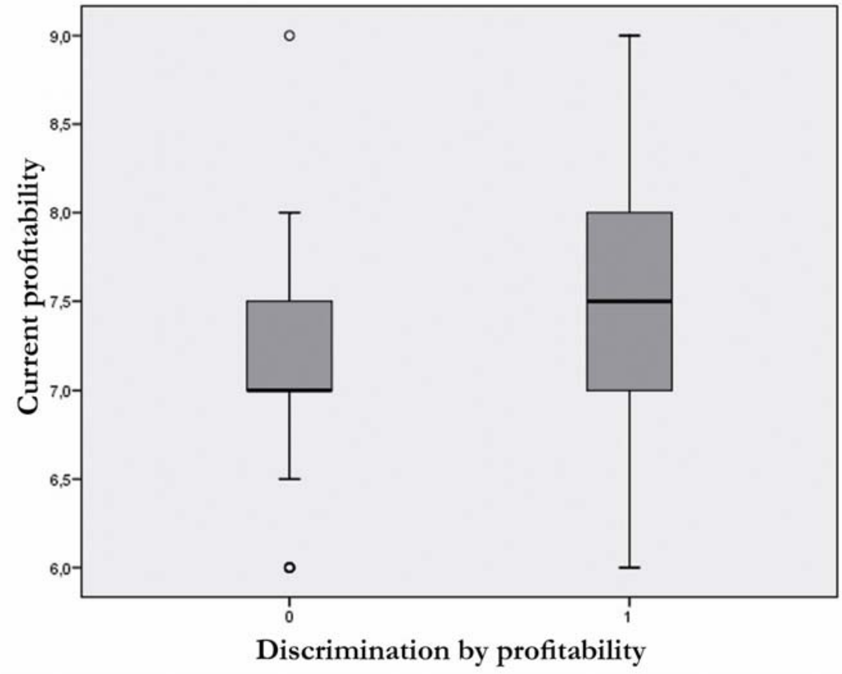

Chart 4

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

In the box-plot you can see graphically the distribution of the *current profitability* in the two groups established by the *discrimination by profitability*.

As visible in chart 4, the variable shows a much greater dispersion in the company group with the *discrimination by profitability* equal 1.

On the other hand, 50% of the companies that exceed the average profitability have a *current profitability* bigger than 7,5%. In case of the companies with profitability lower than the average, this percentage descends to 25%.

The following table 5 shows the non-parametric Mann-Whitney test for the variables: *Installed Power (kw)*, *Kws produced per year*, *previous profitability* and *current profitability.*

Contrast statistics[a] for variables Installed power, Kw. Produced per year, previous profitability and current profitability.

	U de Mann-Whitney	Sig. Asintót. (bilateral)
Installed power	1971,000	,607
Kw produced per year	1978,500	,632

Previous profitability	1964,000	,576
Current profitability	1944,000	,510

[A]Cluster variable: Discrimination by profitability

Table 5

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

The critical values obtained in the contrast for all four considered variables ($p>0,05$) do not permit refusing the null hypothesis and therefore we cannot postulate for an association between each one of the continous variables and the discrimination by profitability. This fact confirms what we had already observed before visually through the box-plots of the four variables.

Reached this point and after having analyzed the dependent variable (*discrimination by profitability*) with each one of the independent variables, we found out that the only variables that show a significant association level with the dependent variable are: *Loan Term (recoded) and Percentage of external financing (recoded).* Therefore we will estimate a logistic regression model including as dependent variable the *Discrimination by profitability* and as independent variables the two mentioned before.

7. Estimated logistic regression model.

We have chosen a logistic regression model where as covariables we include those ones which have shown to be statistical relevant in univariate association with the result variable *discrimination by profitability,* they are:

- *External financing* (recoded): dummy variable takes the value 0 if the percentage of external financing on investment is less than 90% and 1 otherwise.
- *Loan Term* (recoded): dichotomous variable that takes the value 0 if the loan term is less than or equal to 15 and 1 otherwise.

The result obtained by the SPSS statistical application to logistic regression is:

Variables in the equation of the logistic regression model.

		B	E.T.	Wald	Gl	Sig.	Exp(B)	I.C. 95,0% para EXP(B)	
								Inferior	Superior
Step 1(a)	External Financing(1)	4,461	1,055	17,873	1	,000	86,542	10,942	684,456
	Loan Term (1)	4,337	,795	29,766	1	,000	76,514	16,107	363,469
	Constant	-3,462	,719	23,160	1	,000	,031		

a Variable(s) introducided in Step 1: External Financing, Loan Term.

Table 6

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

The above table presents the parameters' estimates (B), together with its standard error (SE), their statistical significance with the Wald test, a statistic that follows a Chi-square rule, and the estimate of the OR (Exp (B)) with their confidence intervals.

The covariates included in the model maintain the statistical significance ($p < 0.05$) that relates them to the dependent variable:

Discrimination by profitability.

The model has the following functional form :

$$P(Y = 1) = \frac{1}{1 + \exp(3{,}462 - 4{,}461X_1 - 4{,}337X_2)}$$

Where:

Y=Discrimination by profitability

X_1= External Financing (recoded)

X_2= Plazo de préstamo (recoded)

The interpretation of these results will lead to the following conclusions:

- The ***external financing*** (recoded) variable acts as a positive sign, because an increase in the percentage of external financing increases the likelihood that the company has an over the average profitability. Specifically, firms with a percentage of external financing equal or greater than 90% are 86.542 times more likely to have an above average profitability than those with a lower than 90% percentage of external financing.

- Similarly, the variable ***Loan Term*** (recoded) is also involved with a positive sign, therefore, an increase of the loan term increases the probability that the company has an above average profitability. More precisely, firms with a loan term greater than 15 are 76.514 times more likely to have an above average profitability in comparison with those with a loan term less than or equal to 15 years.

Validation of the logistic regression model.

As you can see in Table 7, the model taken to analyze these two variables is able to classify correctly 88,5% of the observed cases, although it classifies better higher profitabilities than the lower ones.

In fact, the model classified 55 out of the 57 companies with "above average profitability" (Y = 1), so that the sensitivity of the model is 96.5% and classified correctly 60 out of the 73 companies with "Profitability below average," so that the specificity of the model is of 82.2%.

Classification table for the logistic regression model .

	Observed		Pronosticado		
			Discrimination by profitability		Correct percentage
			0	1	
Step 1	Discrimination by profitability	0	60	13	82,2
		1	2	55	96,5
	Global percentage				88,5

a The cutoff value is, 500

Table 7

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

As seen in Table 8, the proportion of variability of discrimination by profitability explained by this model is acceptable, between 56.1% (R square of Cox and Snell) and 75.1% (R square Nagelkerke). Therefore we can say that an important percentage of the fact that a wind energy company has an over the average profitability depends on the analyzed variables.

Overall fit statistics of the logistic regression model.

Step	-2 plausibility log	R Cox and Snell square	R Nagelkerke square
1	71,329(a)	,561	,751

a Estimation terminated at iteration number 6 because parameter estimates changed in less than, 001.

Table 8

Source: Particular composition obtained from the survey data and the analisis done with the statistical application SPSS.

8. Conclusions

In the obtained model, the relationship between the external financing of the investment and the loan term used to finance the project becomes very clear for the wind energy companies profitability. So the factors that did lead to a bigger company profitability in this type of enterprises have been: having an external financing percentage equal or over 90% and a loan term over 15 years.

Nowadays this has changed thanks to the improvement of the technology. Using the obtained logistic regression model in this paper, it can be estimated the obtained profitability for lower financing percentages and for loan term lower than 15 years.

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A risk analysis of small-hydro power (SHP) plants investments

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Abstract

The increase in electricity consumption has led to a sharp increase in energy demand which rose environmental and sustainability concerns. To address this issue, there has been an incentive to resource to renewable energy sources for electricity production. Departing from a real case study, the investment appraisal of a SHP project under the present market conditions is described, followed by a sensitivity analysis in order to identify the main sources of risk. The main results obtained showed that in the context of a regulated tariff the project is worthwhile due to a positive NPV. However, if electricity had to be sold at market prices, the project becomes unprofitable. This is an important issue because the perspectives for the future are a reduction of incentives and increased difficulties of network access for producers of electricity from renewable sources. The results put also in evidence the vulnerability of an investment of this kind to an adverse change in interest rates. Therefore, future SHP plant investments should take into account the need to operate in a free market, without special rates for renewable energy and that will have to compete with technologies based on fossil fuels or large hydro.

Keywords: Renewable energy; Small-hydropower plants; Investment risk; Sensitivity analysis

JEL classification codes: G31 - Capital Budgeting; Investment Policy; O22 - Project Analysis; Q01 - Sustainable Development; Q42 - Alternative Energy Sources

1. Introduction

With industrial development and population and economic growth, there has been a huge increase in energy demand, which has to be met with an increase in energy production. However, given the raise of sustainable development concerns, there is the need to think about alternative sources of energy production, with a particular emphasis on renewable energy sources (RES). Apart from the need to meet the increased energy consumption, there are several reasons for the growth of RES interest (Ribeiro et al., 2011), namely: the increase in fuel prices; the concern about protecting the environment of the impact of nefarious power generation through non-renewable sources (e.g., coal and oil); and the desire to reduce dependence on traditional energy sources (e.g. thermal). It is, therefore, imperative to develop new solutions for sustainable energy production combining economic development with environmental sustainability (REN, 2006). As a manner of fact, reducing dependence on thermal energy can be achieved either by decreasing energy consumption by implementing saving programs and energy efficiency measures (both at industrial and household levels), or increasing the use of RES.

In this context, and despite the existence of some geographic and environmental restrictions, promoting the exploitation of water resources can be a viable solution for energy production. According to REN (2006), the use of thermal energy and hydropower has been implemented in the last decade and has been shown to be a viable alternative comparing with a system entirely dependent on fossil energy, since it provides greater flexibility in power management in addition to the decreased emissions of CO_2.

Water has been used for electricity production since the mid-nineteenth century as a response to the needs of factories and other human activities. In the late 1980s, small hydropower (SHP) production emerged with the publication of legislation on the establishment of the special arrangements for the production of electricity in SHP plants with installed power up to 10 MW (REN, 2006).

Notwithstanding the share of renewable energy production achieved, Portugal remains heavily dependent on imported energy sources (e.g. oil, coal and natural gas). In the particular case of hydroelectric production, it can represent almost 30% of the total electricity consumption but in dry years its contribution is even weaker (DGEG, 2012). Therefore, the continued use of renewable energy emerges as fundamental goal of the energy policy, and is a way to improve the trade balance and to contribute to energy independence. Moreover, the hydropower technology, and particularly where it is possible reservoir capacity regularization, has value added to the national grid operation, given its high availability, reliability and flexibility of operation (REN, 2006).

However, as a result of the financial, economic and political climate of the country, the risk of the investment in renewable energy has increased (Leach et al., 2011). At the same time, tends to decrease the potential interest from investors in such projects. Moreover, in addition to the factors that influence the general economic activity, investments in renewable energy are affected by many other sources of risk. Thus, there is the need to identify which factors influence those investments and understand which are perceived as risk and uncertainty drivers in these projects in order to develop strategies that help mitigate those risks and to make this type of investment as safe as possible (Agrawal, 2012).

The aim of this paper is to assess the viability of projects for electricity production in SHP plants in Portugal, analyzing, in particular, the risk factors of these investments. Given the current situation, it is of great interest to evaluate the risks inherent in the renewables sector and, in particular, investment in projects that produce electricity in SHP plants. For this, a qualitative and quantitative analysis was undertaken in order to examine how the risk and uncertainty affect the interest of the project and its expected profitability.

The remainder of the paper is organized as follows. Section 2 presents a brief description of the Portuguese electricity sector, with a particular emphasis on RES. Section 3 describes the investment project evaluation in the case based scenario. Section 4 identifies the main sources of risk underlying the type of investment under analysis. In section 5 the results of the sensitivity analysis are presented. Finally, section 6 drawn the main conclusions of the paper and highlights future avenues of research.

2. Portuguese Electricity Sector

The Portuguese electricity generating system presents a diversified structure including a different set of technologies. The role of the RES has been increasing over the years strongly supported by the government objectives of reducing energy importations and reducing CO_2 emissions. The Special Regime Producers (SRP) includes the small hydro generation, the production from other renewable sources and the cogeneration. These producers have priority access to the grid system under the established feed-in tariffs for the licence period. Their integration in the grid is however, dependent on the energy policy decision makers calls and on tender procedure with specific criteria.

The total installed power reached in 2011 about 18894MW, distributed between thermal power plants (coal, fuel oil, natural gas and gas oil), hydro power plants and SRP, as detailed in Figure 1. In 2011, the total electricity consumption reached 52211 GWh (DGEG, 2012).

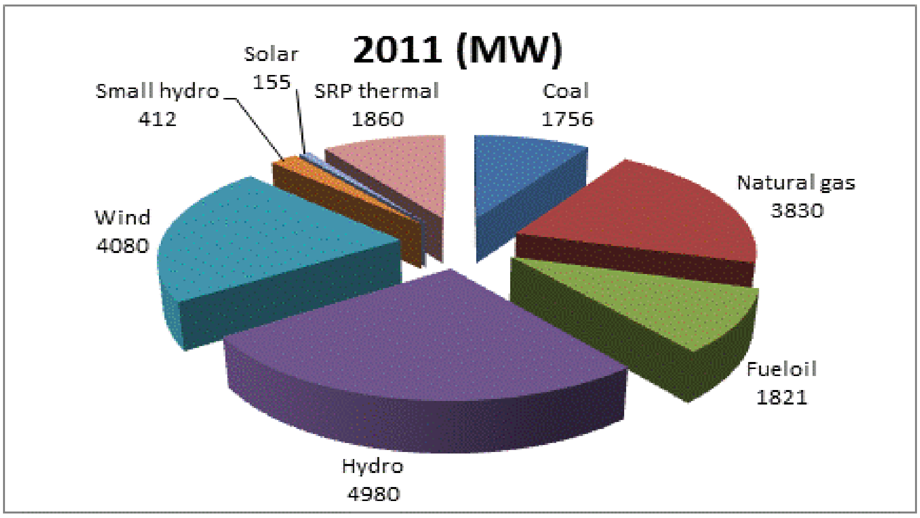

Figure 1- Distribution of the total installed power in Portugal, 2011 (Source: REN, 2012)

The future of the electricity power systems is strongly constrained by international environmental agreements, namely the Kyoto protocol and RES Directive. The Portuguese strategy for the electricity system, based on RES and natural gas growth, is fundamental to the accomplishment of these goals. The evolution of the hydroelectric sector along with the SRP is part of this strategy for the electricity system, representing a clear effort for the promotion of endogenous resources, reduction of external energy dependency and diversification of supply. The combined growth of natural gas and coal allows for a mixed thermal system and contributes to the reduction of Portugal's strong dependence on oil, although the transportation sector still plays a major role in this matter. Figure 2 presents the evolution of electricity production from RES in Portugal (excluding islands).

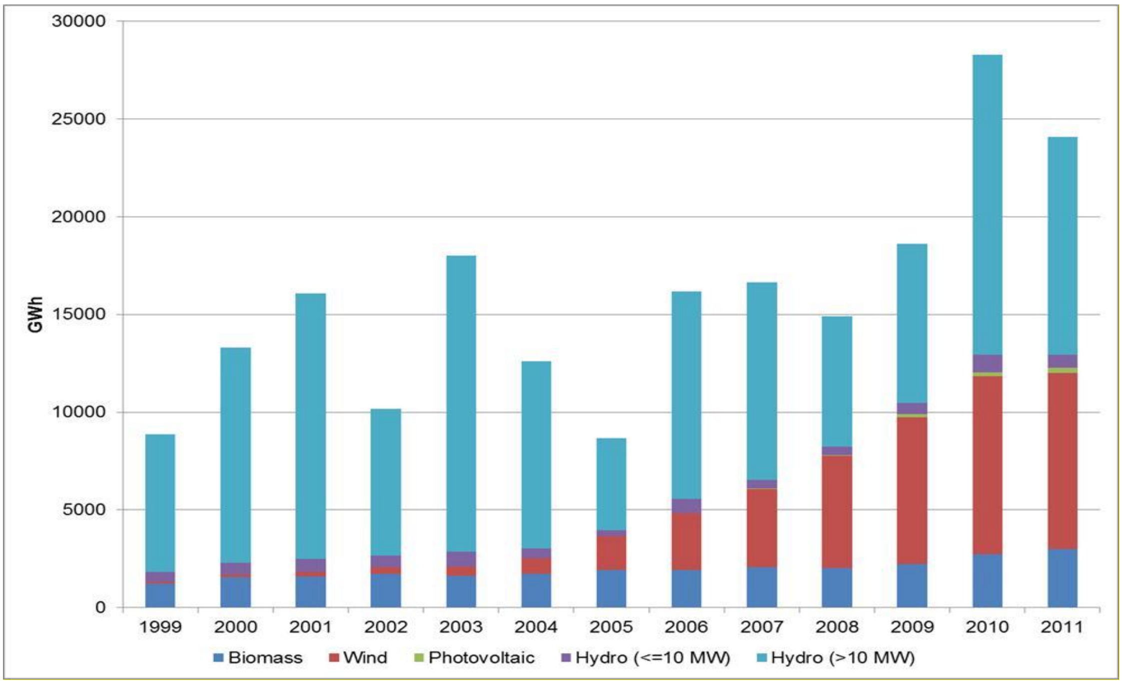

Figure 2- Electricity production from RES in Portugal (excluding islands), 1999-2011. Source: Own elaboration of DGGE (2012) data.

It has become apparent that large hydro generated electricity is the most important RES, with a contribution of 46% of the total RES production in 2011. This is closely followed by wind power production with a 37% share, biomass with 12% and small-scale hydro with less than 3%. However, the total RES production is extremely vulnerable to the rainfall conditions and in rainy years such as 2010 it becomes evident that both large and small hydro play a major role on the electricity system as a whole.

3. Investment Evaluation

This section provides the characteristics of the project under analysis regarding the forecasted production, capital and operational expenditures. It is also shown the results of the investment appraisal.

3.1 Production and revenues

The investment refers to a project of a SHP plant and is based in a real case, although some adjustments and simplifications have been made. Given the characteristics of the location, the best alternative was a small weir with an adjacent central that has the advantage of allowing some regularization capacity. Energy production is ensured by a single generator of 1.90 MW.

To support the analysis of production and their economic valuation a study was conducted based on hydrological series of daily average flows recorded at several hydrological stations in the region, which allowed to estimate the average daily flow of the tributaries to the SHP Bayou.

Table 1 - Forecasted annual production (average hydrological regime)

Description	**Value (MWh/year)**
Annual production	6124

Table 2 – Estimated revenues

Description	**Value**	**Observations**
Feed-in- tariff	91 €/MWh	Determined in accordance with the currently average values.

3.2 Capital expenditures

Investment in the development and construction of a SHP power plant is conditioned by its characteristics, opportunity, choice of equipment, and ability to negotiate with suppliers. The forecasted capital expenditures are detailed in table 3. The values were obtained specifically for this project and were provided by manufacturers and installers of major equipment and construction prices were based on average market prices.

Table 3- Estimated capital expenditures

Description	**Value (k€)**	**Amortisation**
Infra-structures Building	1350	30 years
Hydromechanical equipment	544	16 years
Electromechanical equipment	1120	16 years
General electrical installations	365	16 years
Auxiliary equipment	60,5	16 years
Interconnection line	62,5	20 years
Acquisition of land	169	-
Studies and projects	127,1	3 years
Audit and consulting	161,5	3 years
Licensing	10	3 years

3.3 Operational expenditures

The operational expenditures of a SHP plant involve a limited number of factors, some of which are characteristic of the plant itself and others that are conditioned by the potential for exploiting the investor's synergies. Although, they represent a small portion of the total costs, these expenditures should be properly identified and taken into account in the economic study for a correct investment evaluation. Those costs were identified and estimated by comparing the known costs of similar facilities and some examples are: general and administrative expenses; monitoring and first level surveillance; technical support; scheduled maintenance or maintenance on failure; supplies, communications and energy; administrative charges (e. g. water and energy); insurance; and major maintenance or replacement needs. Tables 4 and 5 show these costs grouped in main categories.

Table 4- Estimate of annual Operation and Maintenance (O&M) costs

Description	**Value (k€/year)**
General and administrative	11
Operation and maintenance	21,5
Insurance	10
Contingencies	1,5

Table 5- Major maintenance costs forecasted

Description	**Value (k€)**
Revision turbine and alternator (after 15 years)	25
Review and partial replacement of equipment (after 15 years)	60

3.5 Investment appraisal

The analysis of the project was undertaken considering an investment horizon of 25 years, current prices, a discount rate of 10.3%, and an income tax rate of 25%. For simplicity it was assumed that investments values were paid completely at time zero. Moreover, the analysis was conducted in the context of a regulated tariff (feed-in), which means that the energy produced is received in full by the grip operator and there is a fixed payment per MWh, as set in Table 2. A conservative approach was assumed regarding revenues and expenditures' growth over the investment horizon. Through the consumer price index (excluding housing) of the last five years, it was possible to calculate an estimate for the tariff's value growth rate of 1.92%. On the other hand, given that in the last two years the average rate of inflation was a little more than 3%, it was assumed that operational expenditures increased at this rate. To assess the economic viability of the project the following indicators were computed: net present value (NPV); internal rate of return (IRR); simple payback period (PBP) and the discounted payback period (DPBP). Table 6 presents the main results.

Table 6- Investment appraisal indicators

NPV	984.240,25 €
IRR	13,17%
PBP (years)	7,8
DPBP (years)	15,2

As can be seen in the table, the investment is recovered in 15 years, with a positive NPV of € 948,240 and an IRR of 13.2% (higher than the discount rate of 10.3%). Therefore, one may conclude that this is an economically viable investment project under the assumed conditions.

While in this baseline scenario, the investment is attractive, this type of investment is subject to a number of risks that may restrict its profitability. Project risks involve the likelihood and degree of unacceptable deviations from predicted characteristics that are the basis for the investment decision (Kurowski and Sussman, 2011). In this sense, it is important to identify the main sources of uncertainty and risk associated with such investments. In fact, as emphasized by Kurowski and Sussman (2011), risk analysis is an essential part of project development.

4. Identification of Risks

In this section the major potential risks associated with investments in these SHP plants were identified according to a literature review (Carneiro and Ferreira, 2012, Agrawal 2012, Cucchiella et al. 2012, Leach et al. 2011, Nikolic et al. 2011, Rangel 2008, and Cleijne and Ruijgroks 2004). Thus, the following types of risks were considered to be relevant for the project: construction/completion, technological, geological, hydrological, economic, financial, political, environmental, nature, and sociocultural. These risks are briefly described in what follows.

4.1 Construction/Completion Risk

The possibility of construction delays, increased costs relative to expected, and the overall quality of the project should be analyzed together with their respective impacts. Thus, this type of risk corresponds to the possibility of the project is not concluded, and this can be due to monetary or technical reasons. The monetary reasons include the underestimation of construction costs, unexpected rise in inflation, unexpected delays in the schedule, among others. With regard to the technical reasons they are related to inaccuracies in the initial project design, failure in supplies (e.g. materials), and contractual problems.

The impact underlying this type of risk can vary from moderate to high depending on the extent of the consequences of delays or cancellation of the project itself. The delay of construction may increase the risk of the project, the cost can increase significantly and the project economic viability can be strongly affected.

4.2 Technological Risk

This risk occurs when the technology becomes obsolete very soon or performs below their specifications throughout the project life. In fact, this risk can be a major threat in the design of a hydroelectric plant, given that even a small percentage reduction in yield of a turbine may represent a large capital loss over the life of the project. Moreover, although the hydro technology is well established in Portugal, in recent years there has been a significant development of other renewable technologies for energy production, which may represent a risk for this type of investment competing in the same market segment.

4.3 Geological risk

The geological risk will depend on the construction site of the dam. This must be able to accommodate a reservoir and a power station generation. A detailed study is vital to know the geological conditions of the site. Flaws in the underlying rock structure may cause problems in construction, leading to an increase of the estimated costs if not previously identified. The risk of seismic activity should also be considered.

4.4 Hydrological risk

The hydrological risk must also be considered because the energy production will depend on the river water supplied, which will be unpredictable as well as environmental conditions and precipitation. Problems of water loss by evaporation or leakage from the reservoir must also be considered. Therefore, a detailed study about their existence and of the water availability is essential, in order to estimate the amount of energy produced, and take into account, also, other parameters that will influence the viability of the project (e.g. the rate of precipitation and evaporation in the region and the flow of water from tributaries).

4.5 Economic Risk

This type of risk arises from the possibility of a poor economic performance of the project, even if the project is underpinned in good technology and operating at normal load. In this case, the revenue generated, while being able to cover operating costs, may not be sufficient to cover the initial investment cost, preventing the recovery of the investment and achieving the required rate of return. In the case of a SHP investment, this risk derives from the uncertainty about the price of electricity in a liberalized market, mismanagement of the project, increasing operating costs, among other factors.

4.6 Financial Risk

Financial risk arises from external factors to the project and can significantly affect its financial condition. This risk may be related to difficulties in obtaining financing, uncertainty regarding interest rates and exchange rates.

4.7 Political or Legal Risk

The political and/or legal risk arises from unexpected changes in current legislation, particularly in the energy sector, which might favor investments in other than hydro technologies. Thus, due to possible changes in government regulations (or policies), the economic viability of a project, initially profitable, might be compromised. Although the new legislation usually applies to projects that have not yet been submitted, if this does not occur, these changes can have a major impact on the initial investment and revenue. On the other hand, if there are frequent changes in legislation, this can cause uncertainty among possible investors.

4.8 Environmental Risk

This risk occurs when the effects of the project on the environment cause delays in their development or even a change in the initial design. Since an investment in hydroelectricity means that the production of electricity uses a natural resource, the existence of environmental risk is inevitable. Some problems that can arise are related to the deterioration of water quality; impact on flora and fauna; emission of greenhouse gases; relocation of inhabitants of their areas of residence and occupation of agricultural land by the water.

Environmental risk may be enhanced by the action of groups of people (e.g. residents of the affected area, environmentalists, etc.), which might have slight consequences, such as making a small change in the project, or severe consequences, such as the cancellation of the project. In order to mitigate this risk and allow the implementation of the project is necessary to develop studies of environmental impact assessment in order to comply with the regulations.

4.9 Risk of other external events

The risk of external events is characterized by the occurrence of a particular event that prevents the normal operation of the project. In the case of hydroelectric plant this risk may be associated with technical failures, fires, and strikes or even due to external causes such as earthquakes or other natural disasters.

4.10 Socio-cultural Risk

This type of risks arises from social and cultural differences between the promoters of the project, local authorities and workers. This type of risk is generally considered very important by the promoters and funders of the investment, as they can be translated into a large increase in costs as a result of complaints and grievances of the populations concerned. Some of the most common effects of this type of risk relates to abandonment of projects, reputation damage of promoters and investors, loss of revenue, consumer boycotts, among others.

5. Sensitivity Analysis

From the risks discussed in the previous section, a sensitivity analysis was developed. This procedure is a way of analyzing the effects of changes in selected project variables that might have major implications for project profitability and associated risk (Kurowski and Sussman, 2011). Therefore and taking into account the availability of data, a sensitivity analysis was undertake, regarding the following types of risks: political risk (value of the tariff); completion risk (a delay in the starting of electricity production); economic risk (an increase in the initial investment amount); and financial risk (the cost of capital).

5.1 Political risk

This risk was proxied by the change in the value of the tariff charged. Although, the investment in a SHP as in this case is protected by a fixed feed-in tariff, the liberalization trend of the electricity market can open way in the future to fully competitive RES market. It is then interesting to see what would happen in terms of the economic viability of the project if the electricity produced was sold at market prices. Since these prices are below the regulated tariff, it was simulated the effect of a tariff decrease on the project's NPV, and the results are shown in Figure 3

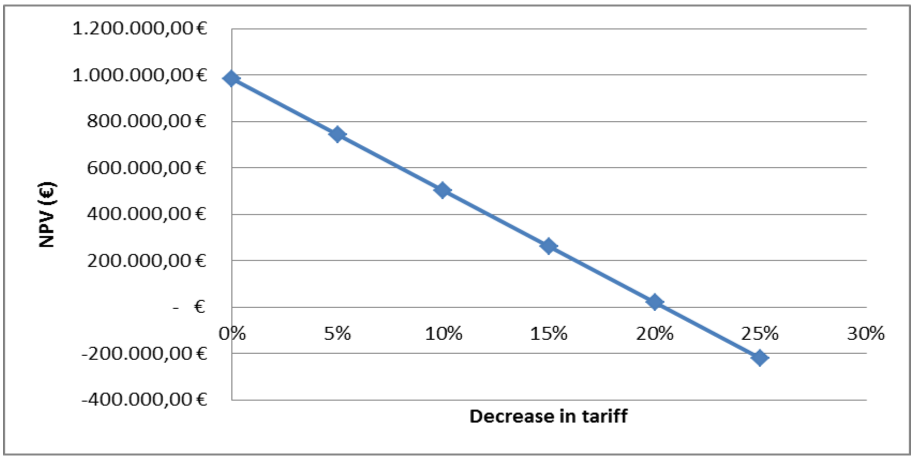

Figure 3- Electricity tariff change impact on NPV

One concludes that the NPV reaches a value of zero for a price decrease of 20.43%, which means a tariff of 72.41 euros. Given that the average market price of electricity is around fifty euros, this means that an investment with these characteristics outside the Special Regime Production (SRP) would not be economically viable.

5.2 Completion risk

To assess the impact of this risk, it was undertaken a sensitivity analysis regarding what happen if there is a delay in starting electricity production. From the analysis of and Figure 4 it is seen that the project presents some robustness in this context, for only after three years of delay in the start of production the project would become unviable. However, one must take into account either that the regulatory/legal framework in which the project takes place or the market conditions can change and could undermine its profitability.

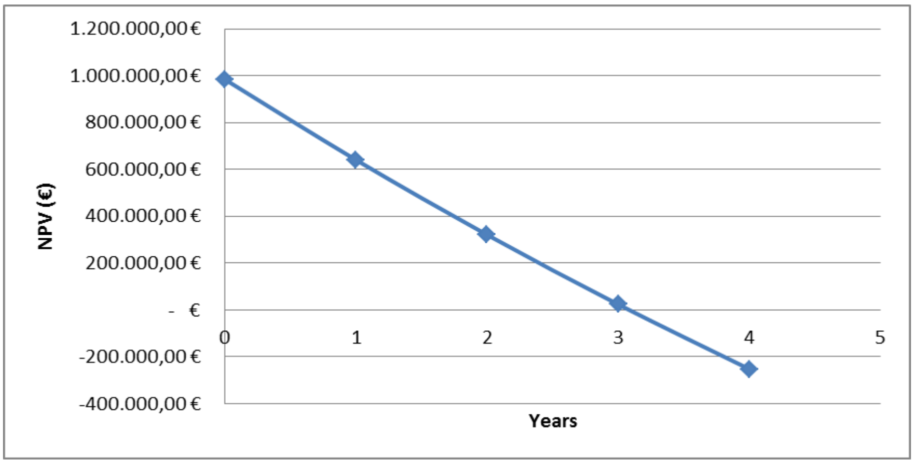

Figure 4- Impact of project delay on NPV

5.3 Economic risk

Although, the economic risk could be measure in several ways, in this study it was proxied by an increase in the initial investment amount, given that in this type of project, the major component of total investment is capital expenditures. Therefore, it is reasonable to think that an unexpected increase in these expenditures would have an effect on the investment's profitability. The impact of changes in this variable can be seen in figure 5.

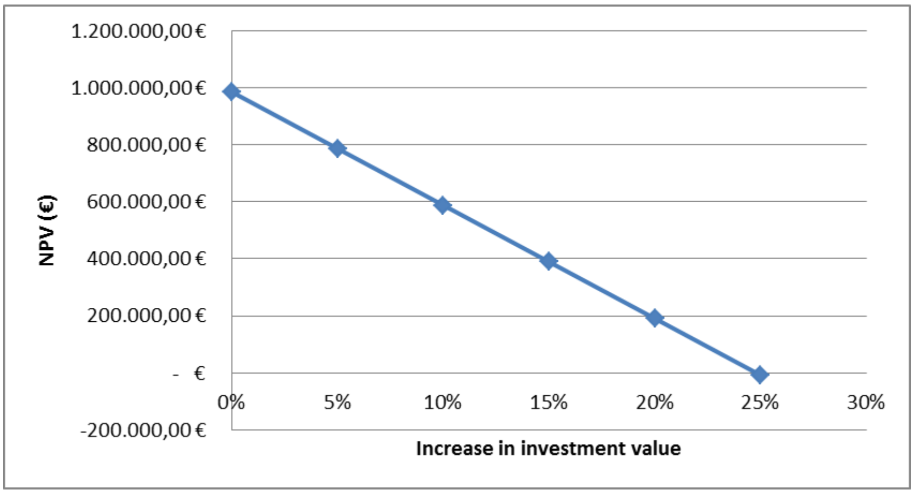

Figure 5- Impact of investment increase on NPV

As can be seen, it would be required an increase of almost 25% in the initial investment amount to reach a zero NPV for the project. The initial value of the investment would have to grow from 3,969,600 euros to 4,962,000 euros, i.e. an increase of about one million euros, which seems to be very implausible.

5.4 Financial risk

This risk can be measure by the cost of capital used to calculate NPV. In fact, capital intensive projects are very sensitive to a change in the discount rate. This change can be due, for example, to an increase in the country risk premium component of the cost of capital, as has been the case for Portugal in the last years as a result of the profound economic crisis and the difficulties in obtaining finance either by the government, financial institutions or private investors. Therefore, it should be recognized the importance of changes in the cost of capital and its impact over the project´s NVP is shown in figure 6.

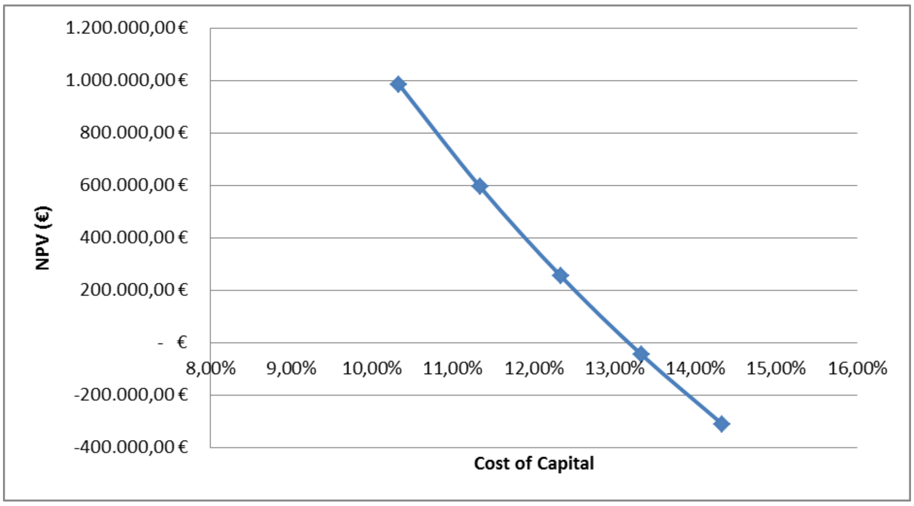

Figure 6- Cost of capital impact on NPV

As expected, given the nature of the investment, the project´s NVP decreases sharply for each percentage point increase in the cost of capital.

6. Conclusions

Given the growing concerns with sustainable electricity production, small hydroelectric power plants emerge as an interesting alternative, especially as it refers to renewable energy sources. However, it is advisable to develop a thorough identification of the risks associated with this investment, since they range from completion to technological risk, from hydrologic to environmental impact, and from political to sociocultural risk.

In this paper, departing from a real case study, the investment appraisal of a SHP project was described under the present market conditions followed by a sensitivity analysis in order to identify the main sources of risk.

The results obtained showed that in the context of a regulated tariff, as was the case-base scenario, the project is worthwhile due to a positive NPV. However, if electricity had to be sold at market prices, the project becomes unprofitable. This is an important issue because the perspectives for the future is a reduction of incentives (especially feed-in tariffs) and increased difficulties of network access for producers of electricity from renewable sources. In fact, the possibility of reducing these rates or being replaced by other incentive systems seems to be an increasingly likely possibility. Countries such as Belgium, Sweden and Italy have opted for implementing quota systems for green certificates at the expense of special fixed tariffs. In the limit, the need to operate in a free market, without special rates for renewable energy and that will have to compete with technologies based on fossil fuels or large hydro, should also be considered.

The sensitivity analysis put also in evidence the vulnerability of an investment of this kind to an adverse change in interest rates. This is not an unexpected outcome given the nature of RES projects, characterized by large investment values and reduced O&M costs. In fact the present market conditions giving rise to high capital costs along with the liberalization trend of the tariffs represent important risk elements that can easily lead to a reduction of the investors' interest on these projects.

Evidently, this was an exploratory study that aimed to provide the necessary inputs for an in-depth risk analysis of the SHP investments. Future research is expected to address the use of different tools able to incorporate a formal risk analysis procedure on project evaluation, namely the application of real options approach, multi-criteria decision methods in order to take into account different perspectives on the decision-making process and a probabilistic assessment of the risk factor impacts.

Acknowledgements

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Domestic photovoltaic systems: a finance-based MCDA approach

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Abstract

The purpose of this paper is to provide an integrated analysis of a particular form of renewable energy, relying on a two-step approach, combing financial methods with Multicriteria Decision Analysis (MCDA). A case study on the Portuguese domestic photovoltaic systems based on MCDA is provided in order to assess how these systems perform either from the producer's or from the decision policy authorities' stances. Several alternatives according to the year of photovoltaic systems implementation have been analysed according to five different criteria: real net present value, avoided energy imports, avoided CO_2 emissions, employment benefits and tariff deficit. A financial analysis was also performed on different real installations in the centre of Portugal to determine the impact of the proposed cuts of the feed-in-tariffs to typical domestic photovoltaic systems.

keywords: Photovoltaic systems, Microgeneration, Minigeneration, Multicriteria Decision Analysis.

JEL Codes: Q42, Q48, C49

1. Introduction

Increasing the share of renewable energy sources for electricity generation (RES-E) has been a high priority in the energy strategies of many countries worldwide. The European Union (EU) has been setting ambitious targets for RES-E since the early 2000s (Directive, 2001, Directive 2003 and Directive 2009).

Nevertheless, to facilitate a breakthrough for RES-E, several economic, institutional, political, legislative, social and environmental barriers have to be overcome (Lior, 2010). RES-E market is limited owing to its two main characteristics: the high production cost and the low energy return on investment compared with conventional fossil energy. Therefore, Feed-in-tariffs (FITs) scheme are the most common market driven instruments that governments, namely the Portuguese Government, have been taking to facilitate RES-E market development (Liao et al., 2011, Haas et al., 2011, Amorim et. al, 2013). The central principle of FITs policies is to offer guaranteed prices for fixed periods to enable greater number of investors (Cherrington et al, 2013). The FITs scheme has rapidly increased the deployment of PV technologies at small scale since its introduction in 2008 (Ministerial Order 201/2008).

As of October 2010, Decree Law 118-A/2010 modifies some aspects of the Microgeneration Law (Decree Law 363/2007). This amendment intended to support the generation of electricity from renewable sources in Low voltage (LV) systems by simplifying the application procedure. The new regulation increased the annual ceiling for installation to 25 MW per year and streamlined the access to the microgeneration regime for public, social, education, defence and local institutions. Moreover, the beneficed regime was adjusted to the cost of equipment used in the microgeneration and could only be accessed under certain conditions, namely the compliance with energy efficiency measures and the use of solar thermal collectors or biomass boilers.

Decree Law 34/2011 establishes the minigeneration regime and complements the microgeneration regime. This new regulation simplifies the licensing regime through the new System of Registration of Minigeneration electronic platform managed by DGEG.

According to the Letter of Intent of the Economic and Financial Policies, and Technical Memorandum of Understanding (Portuguese Government, 2011) the regulated electricity tariffs will be phased out by January 1st, 2013 at the latest. For the existing contracts in renewables, a renegotiation of the contracts in view of lower FITs is also currently under way. For the new contracts in renewables, the FITs are being revised downward, ensuring that the tariffs do not over-compensate producers for their costs and they continue to provide an incentive to reduce costs further, through digressive tariffs. As far as more mature technologies are concerned, the development of alternative mechanisms is also being considered (through the use of feed-in premiums). As a result of all the measures considered in (Portuguese Government, 2011), the VAT tax rate in the electricity sector has suffered an increase from 6% to 23%, during 2011. Since the 1st of January of 2012 the renewable technologies have suffered an increase of the corresponding VAT from 13% to 23% (see Table 1 and Table 2). The Portuguese Government has also eliminated in 2012 any kind of fiscal deductions regarding the investment on RES-E. Finally, on 5 January 2012, Portugal's Council of

Ministers voted to suspend the awarding of licenses for new generation capacity for renewables with immediate effect. The Portuguese government has been tasked with a commitment to eradicate the FITs deficit by 2020 which currently stands at €3 billion.

Table 1. Evolution of PV microgeneration support measures

	2010*	2011	2012
Value Added Taxes	13%	13%	23%
Feed-in tariffs (€/kWh) during 1st years	0,65 (a)	0,38 (b)	0,326 (b)
Feed-in tariffs during de following time (€/kWh)	(c)	0,22 (d)	0,185 (d)
Fiscal incentives (€)	796	803	0
Legislation	DL 363/2007 MO 201/2008	DL 118A/2010, Dispatch DGEG 2010 MO 1185/2010	MO 284/2011
Registration Fees (€) - without VAT	250	500	500

* Until November

(a) 1st 5 years
(b) 1st 8 years, decreasing 0,020€ per year
(c) The same value for new contracts
(d) Next 7 years

Table 2. Evolution of PV minigeneration support measures

	2011	2012
Value Added Taxes	13%	23%
Feed-in tariffs 1st year (decreasing 7% each year) - Level I	0,25 €	0,2325€
Tariffs Level II and III	Depends on the market	Depends on the market
Fiscal incentives (€)	803,00	0
Legislation	DL 34/2011, MO 178/2011	
Registration Fees - Level I (<20kW) (€)	500	
Registration Fees - Level II (>=20kW and <100kW) (€)	1000	
Registration Fees - Level III (>=100kW and <=250 kW) (€)	2000	

The aim of this paper is to provide an integrated analysis of domestic PV, embedding avoided CO_2 emissions, the reduction of primary energy imports, the direct and indirect employment generation potentials through the use of Input-Output multipliers, the financial impact of the PV units and the expected tariff deficit impacts according to the Portuguese legislation available and according to the availability of solar energy. In the next sections a brief a description of the modelling approach will be provided, some illustrative results will be presented and conclusions are drawn with future developments in this field of research.

2. The modelling approach

A methodological framework based on multi-criteria analysis (MCDA) has been developed to facilitate the analysis of different photovoltaic systems: microgeneration and minigeneration. MCDA can assist an integrated analysis towards photovoltaic energy systems since it is able to deal with a complex process inherently involving multiple issues, multiple and conflicting evaluation criteria: economic, technical, environmental and social. MCDA also offers the opportunity to deal with mixed sets of data: quantitative and qualitative.

The methodology starts with the selection of the different alternatives, that are then scrutinised with the purpose of choosing the representative criteria which will be used in the framework of the multicriteria assessment herein suggested in order to obtain the performance of each alternative against each criteria, taking into account the market available technologies, the local availability of solar irradiation and the FITs schemes. With this analysis we highlight the producers' expectations regarding the FITs schemes in force at the year of the PV systems implementation.

2.1. Selection of alternatives

The selection of the alternatives provided in Table 3 was based on data availability obtained from several sources (Rodrigues et al. 2013, Silva et al. 2012, Oliveira et al, 2012).

Table 3. Alternatives for PV systems

Alternative	Description
a1	Microgeneration fixed PV System (4,56 kWp) – 2010
a2	Microgeneration fixed PV System (4,56 kWp) – 2011
a3	Microgeneration fixed PV System (4,56 kWp) – 2012
a4	Mono-Axis (4,56kWp) – 2010
a5	Mono-Axis (4,56kWp) – 2011
a6	Mono-Axis (4,56kWp) – 2012
a7	Bi-Axis (4,56kWp) – 2010
a8	Bi-Axis (4,56kWp) – 2011
a9	Bi-Axis (4,56kWp) – 2012
a10	Minigeration fixed (21,66 kWp) – 2011
a11	Minigeration fixed (21,66 kWp) – 2012
a12	Minigeration Mono-Axis (21,66 kWp) – 2011
a13	Minigeration Mono-Axis (21,66 kWp) – 2012

In the microgeneration case (see Figure 1) it is possible to conclude that the reduction of the FITs had severe impacts on the Net Present Value (NPV) attained for each PV system, considering a discount rate of 6% and an annual average increase of the market electricity price of 5% after the end of the FITs, particularly in 2010 (see the difference between the Expected NPV and the real NPV value obtained according to the current FITs legislation – Table 4).

Another interesting conclusion regards the decrease on the investment cost for each PV system, following the same trends of the FITs and indicating the distortive effect of these subsidies on the technology prices. In fact, even with the lowest values for the FITs in 2012 it is better to invest on renewable microgeneration systems in this last year (see Table 4) than in 2011, except for the Bi-Axis system. In the case of minigeneration, there is a significant increase in 2012 of the NPV for both systems considered, with a discount rate of 6%, in spite of the FITs reduction (see Figure 2 and Table 4).

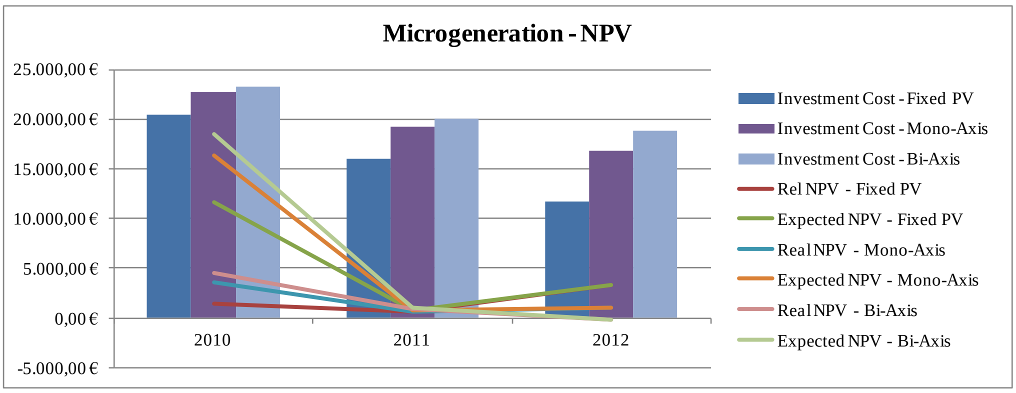


Figure 1. NPV for different microgeneration systems

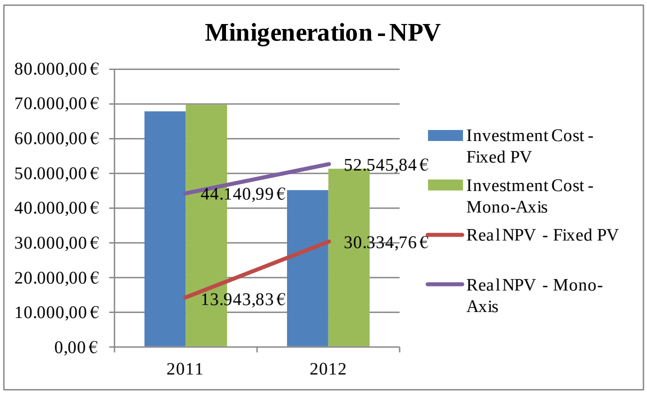


Figure 2. NPV for different minigeneration systems

Since the assumptions of discount rates for low-carbon generation projects is not worldwide consensual, we perform our analysis in the 6% to 10% range to reflect issues such as technological or market risks as in Mott (2010), ARUP (2011), Oxera (2011), and Rogers and Duffy (2012).

Thus, after performing the analysis of the impact of different discount rates on the NPV of each alternative, it is possible to conclude that the investment on different microgeneration systems is only appealing from the producer's point of view in 2010 and 2011 in the set of alternatives herein considered for a discount rate of 6%. In 2012 only the Bi-Axis system is no longer interesting with the same discount rate (see Figure 3). For higher discount rates the different microgeneration systems become less competitive, namely for the year of 2011. With a discount rate of 10% none of the alternatives becomes interesting from the investor's stance.

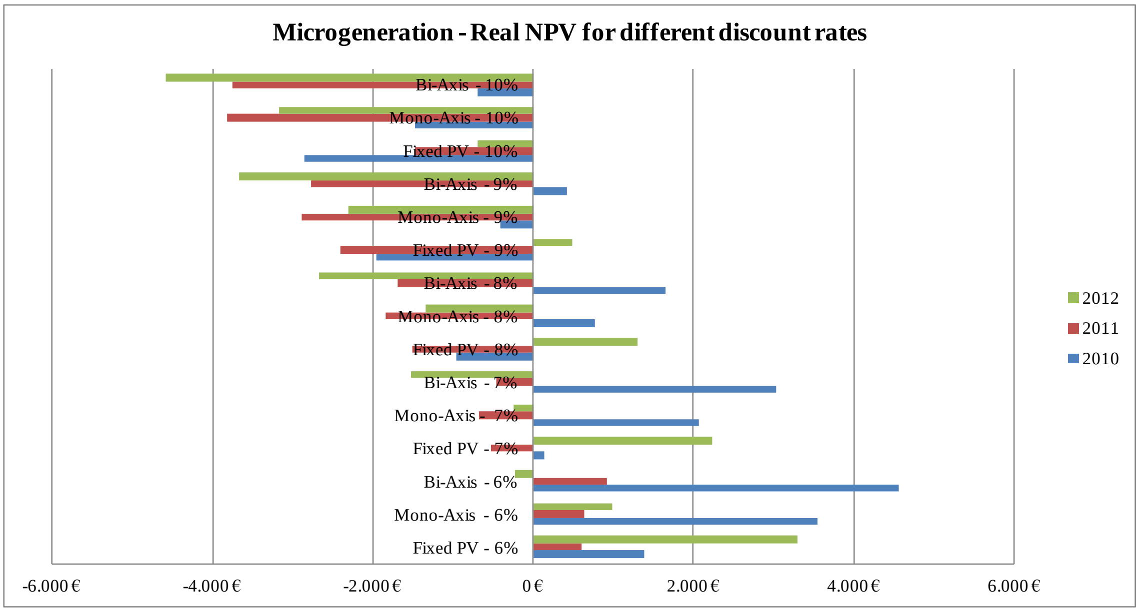


Figure 3. NPV with different discount rates for Microgeneration

From the investor's point of view the minigeneration systems are always interesting except for the Fixed PV systems in 2011 with a discount rate ranging from 9% to 10% (see Figure 4).

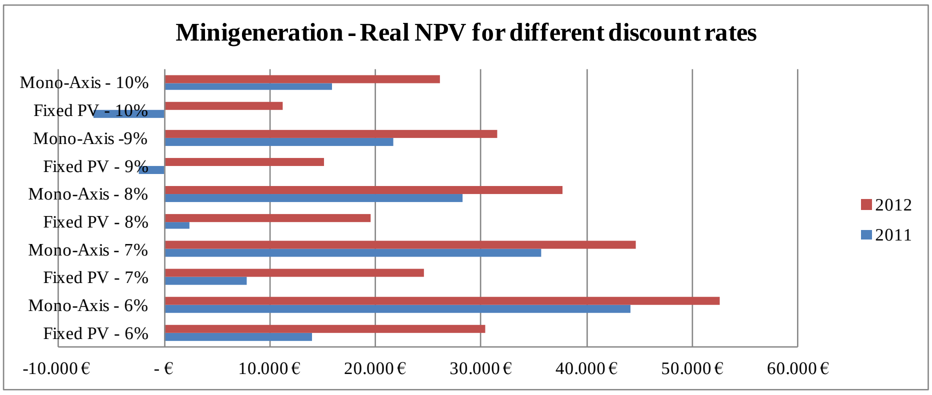


Figure 4. NPV with different discount rates for Minigeneration

Table 4. Assessment data for each technology in different years with a discount rate of 6% (authors' computation)

Data		Technical		Economical								Environmental	Social		Social/Economical
		O&M (€/year)	Average Production (kWh/year)	Investment costs (€)	Expected Payback period	Real Payback period	Energy Imports reduction (kWh/year)	Expected Internal Rate of	Real Internal Rate of	Real NPV	Expected NPV	CO2 reduction (CO2 kg eq/year)	Direct Jobs (Job/kW)	Indirect Jobs (Job/kW)	Tariff Deficit (annual average contribution)
Microgeneration 2010	Microgeneration fixed PV System (4,56 kWp)	20,00 €	4.624,12	20.406,0 €	6,37	7,6	2.775,13	13,40%	7,13%	1.387,3 €	11.669,0 €	1.710,92	0,01	0,32	1.127,7 €
	Mono-Axis (4,56 kWp)	100,00 €	5.780,12	22.741,0 €	5,78	6,6	3.468,90	15,25%	8,64%	3.542,2 €	16.394,5 €	2.138,64	0,01	0,32	1.409,7 €
	Bi-Axis (4,56kWp)	150,00 €	6.242,56	23.282,0 €	5,53	6,09	3.746,43	16,13%	9,37%	4.566,7 €	18.447,2 €	2.309,75	0,01	0,32	1.522,4 €
Microgeneration 2011	Microgeneration fixed PV System (4,56 kWp)	20,00 €	4.624,12	16.046,0 €	9,2	9,43	2.775,13	6,64%	6,52%	602,7 €	723,8 €	1.710,92	0,01	0,32	731,9 €
	Mono-Axis (4,56 kWp)	100,00 €	5.780,12	19.209,8 €	9,06	9,29	3.468,90	6,60%	6,47%	642,6 €	793,9 €	2.138,64	0,01	0,32	914,9 €
	Bi-Axis (4,56kWp)	150,00 €	6.242,56	19.989,0 €	8,77	8,94	3.746,43	6,79%	6,65%	914,5 €	1.077,9 €	2.309,75	0,01	0,32	988,1€
Minigeneration 2011	Minigeration fixed (21,66 kWp)	200,00 €	28.586,00	67.800,0 €	9,07		17.155,69	8,48%		13.943,8 €		10.576,82	0,03	1,50	4.181,4 €
	Minigeration Mono-Axis (21,66 kWp)	300,00 €	38.825,83	69.490,0 €	6,56		23.301,06	13,44%		44.141,0 €		14.365,56	0,03	1,50	5.679,2 €
Microgeneration 2012	Microgeneration fixed PV System (4,56 kWp)	20,00 €	4.624,12	11.690,0 €	6,85		2.775,13	9,64%		3.303,6 €		1.710,92	0,01	0,32	590,1€
	Mono-Axis (4,56 kWp)	100,00 €	5.780,12	16.790,0 €	9,53		3.468,90	6,79%		993,5€		2.138,64	0,01	0,32	737,6 €
	Bi-Axis (4,56kWp)	150,00 €	6.242,56	18.900,0 €	10,67		3.746,43	5,83%		-230,9 €		2.309,75	0,01	0,32	796,6 €
Minigeneration 2012	Minigeration fixed (21,66 kWp)	200,00 €	28.586,00	45.005,0 €	6,51		17.155,69	13,62%		30.334,8 €		10.576,82	0,03	1,50	3.658,7 €
	Minigeration Mono-Axis (21,66 kWp)	300,00 €	38.825,83	51.155,0 €	5,35		23.301,06	17,26%		52.545,8 €		14.365,56	0,03	1,50	4.969,3 €

2.2. Selection of criteria

Based on the previous analysis five criteria have been selected for assessing the merit of the alternatives:

- Tariff deficit (criterion to minimize) – involves the difference between the FITs and the electricity market price. It is expressed in thousands of Euro;

- Avoided energy imports (criterion to maximize) – represents the impact of a specific alternative in the reduction of the amount of energy imports and it is expressed in kWh/year;

- Avoided CO_2 emissions (criterion to maximize) – represents the impact of a specific alternative in the reduction of the amount of CO_2 emissions and it is expressed in CO_2 kg eq/year;

- Employment benefits (criterion to maximize) – involves the contribution of a specific alternative to direct plus indirect employment generation potential and it is expressed in full time jobs/kW.

- Real NPV (criterion to maximize) – expresses net present value attainable for each alternative considering the most updated legislation and conditions available, taking also into account the investment costs. It is expressed in thousands of Euro.

2.3. Application of ELECTRE TRI

Out of the various multcriteria decision-aid methods available, the ELECTRE TRI method (Yu, 1992, Mousseau et al. 1999) was chosen because it allows the evaluation of each action in absolute terms and not in comparison with others. Moreover, the independence towards scales allows the inclusion of evaluation aspects expressed in different units and even measured in qualitative terms.

The ELECTRE TRI method belongs to the ELECTRE (*ÉLimination Et Choix Traduisant la REalité*) family of methods, based on the construction and exploitation of outranking relations, with respect to the problem to be tackled (Roy, 1991 and 1996) ELECTRE TRI is devoted to the sorting (or classification) problem, which consists in assigning each alternative from a set of alternatives $A = \{a_1, \cdots, a_m\}$, evaluated according to n criteria, $g_1, \cdots, g_n$, to one of a set of pre-defined ordered categories (class of merit) $C = \{C^1, \cdots, C^h\}$, where C^1, C^h are the worst and the best category, respectively. Each category is C^l, $l = 1, \ldots, h$ is limited by two reference profiles (reference alternatives): b_l^j (the upper bound) and b_{l-1}^j (lower bound), defined for each criteria g_j, $j = 1, \cdots, n$, as shown in Figure 5.

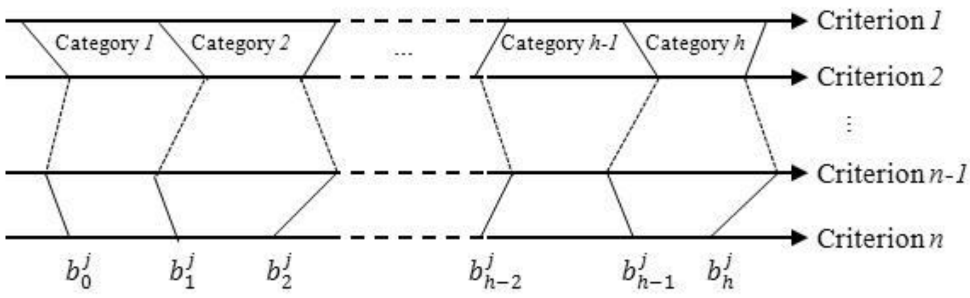


Figure 5. Definition of categories $\boldsymbol{C^l}$ with reference actions $\boldsymbol{b_l^j}$.

The assignment of each action $a_i \epsilon A$ to a category C^l is done by comparing its value in each criterion to the performances of the reference actions. The procedure assigns each action to the highest category such that its lower bound is outranked by a_i. The outranking relation is verified by comparing a credibility index, computed using the differences in performance and the criterion weights k_j, with a cutting level (ϵ [0.5,1]) which defines the "majority requirement", hence the exigency of the classification. For further details about ELECTRE TRI see for instance (Dias et al., 2002).

In our experiments the software package IRIS 2.0 (Interactive Robustness analysis and parameters' Inference for multiple criteria Sorting problems) Demo freely available online has been used (IRIS 2.0). IRIS implements a methodology developed by Dias and Mousseau, 2003) that is based on the ELECTRE TRI method, but which accepts uncertainty in the input parameters. The main characteristics of this software package are: (1) acceptance of imprecision regarding the criterion weights and the cutting level through the definition of intervals for each parameter, or the definition of linear constraints; (2) acceptance of classification examples, with the input of the better and worse category that each action can be assigned to. This is translated into constraints on the parameters that guarantee that those example results are reproduced; (3) inference of a combination of parameters that limits the violation of the constraints in the case of inconsistency. It is also possible to find the constraint subsets, which must be removed to restore consistency (4) inference of a central combination of parameters when the constraints are consistent. For each alternative, it is shown which category represents this central combination, and the other possible classifications that respect the imposed constraints.

The ELECTRE TRI method requires from the user the definition of the categories in which actions will be classified, the specification of the reference profiles associated with the categories ($b_0^j, \dots b_h^j$), the criterion weights ($k_j,\ j = 1, \cdots, n$), and the cutting level (λ). Also, a set of indifference (q_j), preference (p_j) and optional veto (v_j) thresholds for each criterion and reference profile can be defined. Indifference and preference thresholds characterize the acceptance of imprecision in the judgement by considering as indifferent two actions when their performances in each criterion j differ less than a specified amount q_j. Moreover, the transition from indifference to preference is made gradually, changing linearly from q_j, to p_j.

Four categories were defined to classify actions according to their efficiency: C^1 = "Poor"; C^2 = "Fair"; C^3 = "Good" and C^4 = "Very Good". The aim is to assign each action to one of these ordered categories according to the multiple evaluation criteria. Indifference and preference thresholds were fixed as percentages of the value ranges in each category, 1% and 10%, respectively. A veto threshold was not applied in the case study.

The IRIS software allows for the consideration of uncertainty in the weights (as well as in the cutting level). This feature contributes to reducing the data requirements and increasing the confidence in the results.

3. Illustrative results

The starting point of the evaluation process is the introduction in the IRIS software of the performance data for the actions according to the different criteria (left area of the window in Figure 6). The aggregate reference profiles and associated thresholds and the criterion weights are supplied to the software in a similar manner.

Each alternative has a lower and a higher category where it may be assigned (columns ELow and EHigh, respectively). In Figure 6 the column ELow contains the lowest category C^1 and the column EHigh contains the highest category C^4, meaning that no additional constraints regarding the category in which a given alternative may be sorted have been imposed in this study. Any change in these values would constrain an alternative assignment.

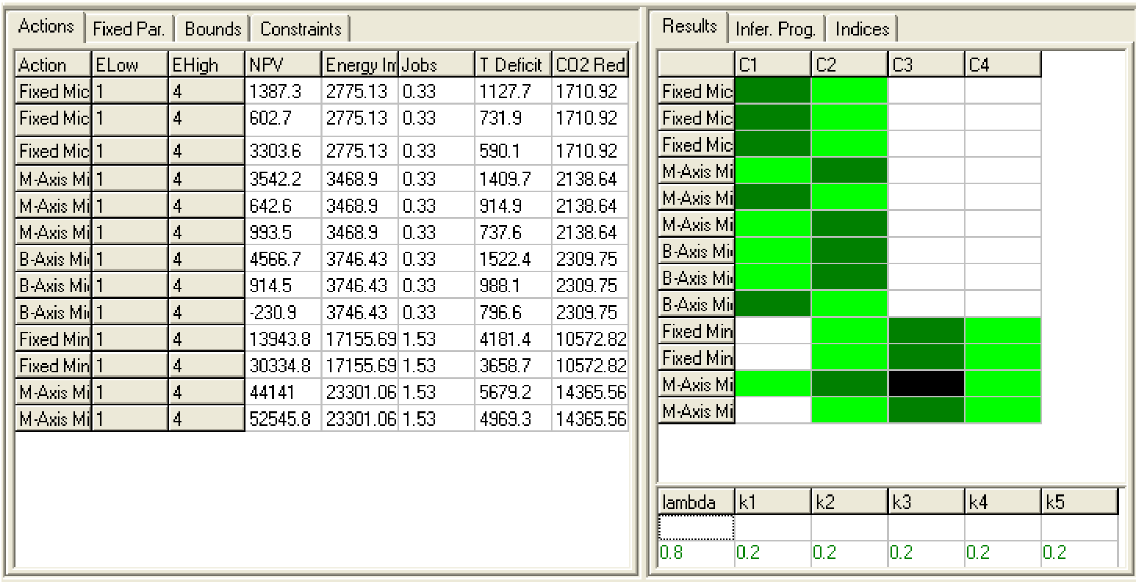


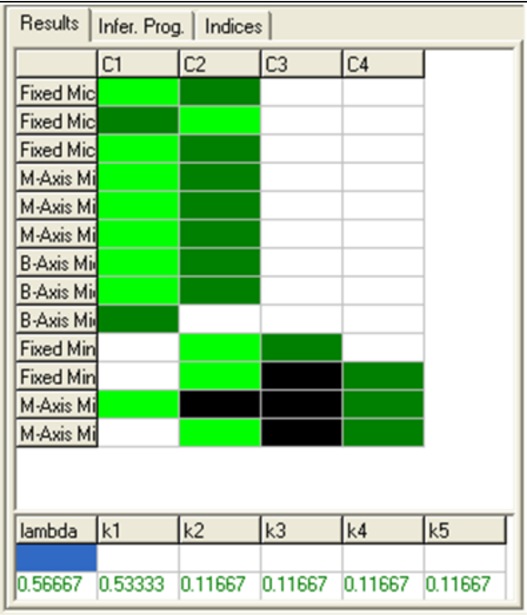
Figure 6. Performances for the alternatives and initial results sorted by input order.

The results are presented using different colours to indicate the range of possible assignments for each action, i.e. the categories where it may be assigned without violating constraint bounds and assignment examples. These ranges appear in different green colours. In each range, one of the cells has a darker shade of green, meaning it is the assignment recommended by IRIS software, based on the inferred combination of parameters values.

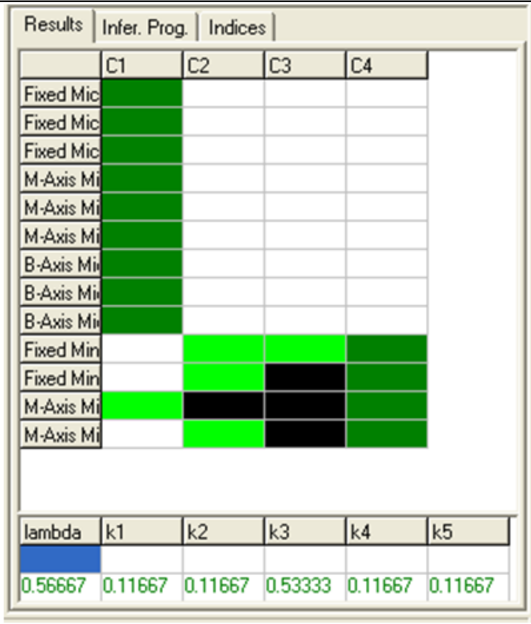
In some situations, there are some intermediate categories where an action cannot be assigned, as for instance the last four actions in the Figure 7, regarding options a) and b) (black shade). When these actions are good enough to be better than C^1, reaching C^4 without being assigned to C^2 and C^3.

According to Figure 6 it might be concluded that with the IRIS results considering the same weights for each criterion, the cluster of fixed microgeneration systems is classified in the worst class as well as the investment on Mono-Axis in 2011 and Bi-Axis in 2012 and the remaining alternatives regarding microgeneration and minigeneration are generally classified in C^2 ("Fair") and C^3 ("Good"), respectively. IRIS does not classify any of the alternatives herein considered in the best class. Thus, from this point of view IRIS does not classify as "Very Good" any of the actions.

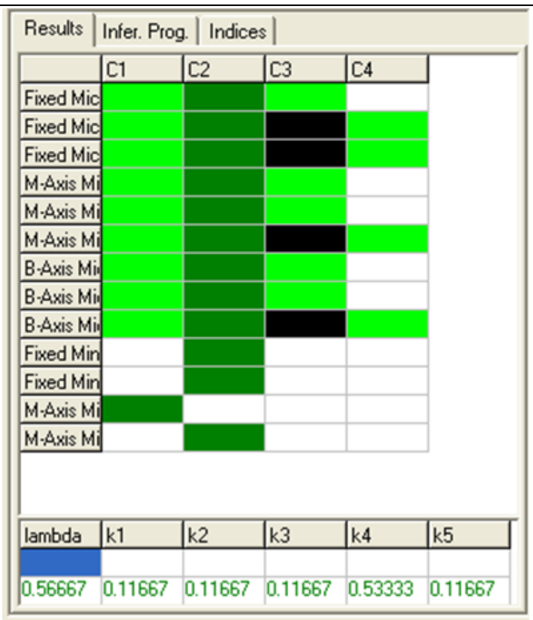
Figure 7 outlays some of the results that might be obtained with the IRIS software according to different assumptions. In the upper left hand side of Figure 7 a) we have considered the assignment of a higher criterion weight on NPV, thus considering the economic criterion as the most important one. In this situation, only two microgeneration systems (Fixed microgeneration in 2011 and Bi-Axis in 2012) remain in the worst class. Three of the minigeneration systems appear now with the highest classification, indicating that according to the economic criterion these are the best options. In the upper right hand side of Figure 7 b) we have considered the assignment of a higher criterion weight on employment, thus considering the social criterion as the most important one. In this situation, the variability of the possible classification of all the microgeneration systems is reduced and all of them are classified in the worst class. The minigeneration cluster maintains the highest classification. The results herein obtained were expected due to the higher number of jobs directly and indirectly generated with these last alternatives.



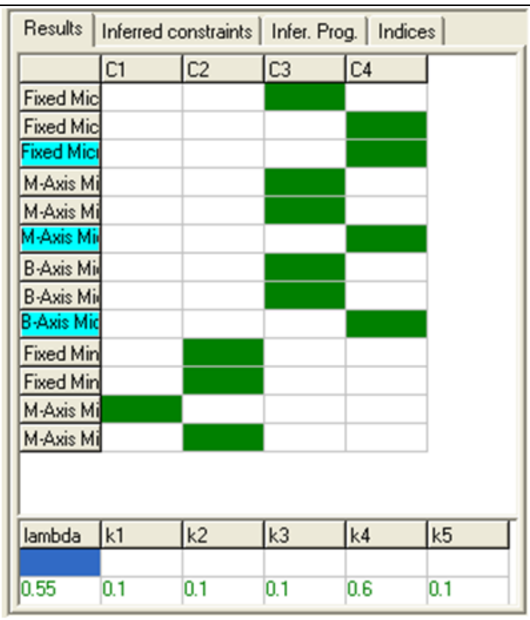
a) Assignment of a higher criterion weight on NPV



b) Assignment of a higher criterion weight on employment



c) Assignment of a higher criterion weight on tariff deficit



d) Imposing a lower bound on the minimum classification (C3 – “Good”) of microgeneration installations in 2012

Figure 7. Results obtained with different assumptions sorted by input order.

In the lower left hand side of Figure 7 c) we have considered the assignment of a higher criterion weight on the tariff deficit, thus considering the social/economical criterion as the most important one. In this case, except for the investment on Mono-Axis minigeneration in 2011, all the remaining alternatives are classified as “Fair” (C^2). The variability of the minigeneration cluster is limited to one class only.

With the purpose of analysing possible policy measures to support the cluster of microgeneration in 2012 aimed at achieving the targets imposed to Portugal we have tested the impact of considering the actions regarding this cluster at least classified as “Good” (C^3) - lower right hand side of Figure 7 d) (identified by the blue colour of their label). IRIS allowed us to conclude that this condition is only possible by imposing a higher weight in the tariff deficit. Therefore, the minigeneration cluster becomes penalized in its classification, because of the expected higher tariff deficit. Another important conclusion obtained with this analysis regards the attractiveness of the different actions throughout the years. Finally, it might be seen that the Economic results regarding microgeneration investments in 2010 are less attractive than in 2012, even with lower FITs. This reflects the effects of the trade-offs of the maturity of technology and the FITs (see also Table 4).

4. Conclusions

We have presented an integrated financed-based MCDA approach for the evaluation of PV systems, in particular microgeneration (fixed, mono-axis and bi-axis systems) and minigeneration (fixed and mono-axis systems) in the central region of Portugal according to local renewable resources potentials, namely monthly average solar radiation.

The analysis highlights the financial impact of this technology from the producer’s point of view according to the evolution of the Portuguese support measures of these alternative technologies, taking particularly into account the different FITs available throughout the years of 2010, 2011 and 2012. Furthermore, due to the current economic and financial crisis Portugal is facing, it is evident an increasing cost of capital, so a set of discount rates was accounted for. A wide range of factors can be expected to affect discount rates, some of which are outside the control of a particular developer (e.g., wholesale electricity prices and government policy); others appertain to a specific type of technology (e.g., load factor, cost structure or technology maturity). Additionally, the PV systems, as well as other low-carbon generation technologies, are exposed to policy risk leading investors to properly rank all the risk factors due to the uncertainty surrounding future energy policy.

Although the support measures of these technologies have been negatively affected (FITs and fiscal incentives), according to the results herein attained by using the IRIS software it was possible to conclude that the decrease of these support measures was compensated by the reduction of the investment costs of the PV systems herein assessed, reflected on the NPV. In fact, the attractiveness of the investment on these technologies is higher in 2012 than in 2010 (with higher supports). Future work is currently under way in order to assess the appraisal of these and other technologies (e.g. wind) in different country regions, with different climate conditions, and incorporating other financial costs not taken into account. Learning by doing impacts and the increasing maturity of these technological processes are assumed to have played an important role in the period used in this work, although not specifically dealt with in this study. Policy interventions aimed at increasing the competitiveness of entrant technologies by increasing their installed capacity, assume that costs will continue to decrease as accumulated production increases, leading to the technology being increasingly cost competitive in the marketplace. Likewise, additional work is being performed to also tackle those features.

Acknowledgments

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Deploying a Renewable Energy Project: An Equilibrium Analysis

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Abstract

Deploying a renewable energy project is an important decision that can facilitate sustainability. In addition, these projects can mitigate many environmental and health issues that arise with the excessive generation from depletable resources, such as gas and coal. This paper analyzes the impact of increasing the probability of deploying a renewable energy project in a Cournot oligopoly energy market, where two generation firms are in equilibrium. The results show that supply rises and prices fall, when the probability of deploying an energy project increases.

JEL Classification: L94, Q42, C72

Keywords: Cournot Equilibrium, Real Options, Renewable Resourses, Depletable Resourses

1. Introduction

The consumption of depletable resources, such as gas or coal, for generating energy is a problem from a sustainability perspective, since supplies used now are not available for future generations. These carbon-based energy sources are also directly related to many environmental and health issues; due to this fact, there are many policies in place to mitigate theses energy generation problems (Grubb 2004), thus reducing environmental pollution, global warming and public health issues.

As the number of people living in cities increases, the demand for energy in urban areas also increases. Madlener and Sunak (2011) state that the process of urbanization is increasing energy consumption, especially in less developed countries; hence, energy planning in urbanization management is a key issue that has to be addressed. In addition, energy generation from depletable resources is not a sustainable solution for this issue and this is why renewable energy technologies are an important part of the portfolio mix of generation companies. Policies for promoting renewable energy, such as the Renewable Portfolio Standards (Wiser, Namovicz, Gielecki, and Smith 2007) in the US and the RES Directive (Klessmann, Lamers, Ragwitz, and Resch 2010) in the EU, are playing an increasingly important role in the decision-making process of generation companies. Hence, planning the allocation of depletable and renewable sources over time is an issue that has to be addressed.

One might think that it is a reasonable strategy to extract less depletable resources today in order to save the reserves for future generations. However, restricting the supply makes the price increase above the competitive level. Renewable resources are becoming an important alternative for generation companies; in addition, price-based systems (e.g., feed-in tariffs) are becoming an effective policy for incentivizing the deployment of renewable energy (Burer and Wustenhagen (2009); Couture and Gagnon (2010)). Hence, it is important to analyze how the probability of deploying a renewable energy project might change the energy prices and profits of generation companies.

This paper aims to analyze energy prices, allocation of depletable and renewable resources, and profits of generation companies in a two stage Cournot oligopoly, where generation companies have the option to deploy a renewable energy project in the future. The key contributions of this paper are twofold. First, we analyze the impact of these decisions on important economic variables. Second, we calculate the value added by the option of deploying a renewable energy project.

In literature, many papers have utilized the Cournot oligopoly to predict interesting properties of energy markets and propose policies to resolve some of the economic and sustainability issues. For instance, Wolfram (1999) analyzes the market power of generation companies in the British electricity market, and show that prices are lower than estimates due to many reasons, such as entry deterrence and actions from the regulator. Chuang, Wu, and Varaiya (2001) formulate a Cournot oligopoly market for generation expansion planning, and present numerical results to analyze industry expansion, generation investment and trends. Murphy and Smeers (2005) present an open-loop and closed-loop Cournot model, in which investment and power dispatch decisions occur simultaneously in the former model and in two stages in the latter model; in addition, this work compares both models with a perfect competition. Nanduri, Das, and Rocha (2009) utilize a similar single stage Cournot model as (Murphy and Smeers 2005) taking into consideration the network transmission constraints. Twomey and Neuhoff (2010) examine the case of intermittent generation return under perfect competition, monopoly and oligopoly; the results show that, when different technologies are used, the market participants benefit differently from the increased price. Moreover, intermittent technologies benefit less from the market power effect than conventional technologies. Despite the numerous papers with Cournot oligopoly models for energy markets, none of these works have analyzed the economic aspects of the energy market, when generation companies have the option to deploy a renewable energy project in the future; in addition, we also analyze these aspects when the probability of deploying the project increases and calculate the value added by the option.

This paper is organized as follows. Section 2 introduces the model and some economic implications of important variables, such as the price and the probability of deploying a renewable energy project. Section 3 presents a numerical example and an analysis from an economic and social welfare perspective. Conclusion and future research close the paper in Section 4.

2. The model

Twomey and Neuhoff (2010) state that electricity markets are neither a monopoly nor a perfect competition; in fact, modeling the market as an oligopoly is the most appropriate assumption. Hence, we assume that our market has two established generation companies, which have to choose simultaneously on how much energy to produce from a depletable resource, such as gas and coal, or a renewable resource.

Our model is a Cournot oligopoly with 2 periods, where the amount of energy produced from a depletable resource at time 0 depends on the total amount each generation company has of this resource; hence, the more they use this resource at time 0, the less it will be available in the future. The amount of energy produced at time 0 also depends on the probability of the generation companies deciding to deploy a renewable energy project at time *t*.

2.1 Assumptions of the Model

The generation companies (or simply firms) must decide simultaneously a quantity to be produced at time 0 and at time *t* in the future. At time 0, the firms can only produce energy from a depletable resource, and at time *t*, the firms can produce energy from both depletable and renewable resources (if it decides to deploy a renewable energy project). In order to create an incentive for deploying a renewable energy project, we use a price-based system (i.e. feed-in-tariff) based on a market-dependent model (Couture and Gagnon 2010).

The following table summarizes all the symbols that will be used in our model:

Q_i	energy produced from a depletable resource owned by firm i, with $i \in \{1,2\}$
q_i^0	quantity of energy generated by firm i at time 0
q_i^t	quantity of energy generated by firm i at time t
λ_i	probability of firm i deploying a renewable energy project
β	expected rate of increase in energy production, as a percentage of Q_i, from the deployment of a renewable energy project from firm i, where $\beta \in [0,\infty)$
ε	deviation from expected energy generated from a renewable resource, where $\varepsilon \sim (0, \sigma^2)$
r	discount rate (opportunity cost)
Q_i^*	expected quantity of energy generated from firm i after deploying a renewable energy project
c_D	marginal cost for generating energy from depletable resources
c_R	marginal cost for generating energy from renewable resources
x	percentage of energy generated from renewable resources in the firm's portfolio, with $x \in [0,1]$
ω	constant premium or bonus over the price (due to a feed-in-tariff)
Π_i	expected profit from firm i
I	investment cost of deploying renewable energy project

We consider a market where the price is a linear function of the total quantity of energy generated. Hence, the inverse demand function of firm *i* for each period is described as:

$$p^0 = a - \theta(q_1^0 + q_2^0) \tag{1}$$

$$p^t = a - \theta(q_1^t + q_2^t) \tag{2}$$

where ϑ is the demand slope, a is a constant, and $\vartheta(q_1^0 + q_2^0) \leq a$. If firm *i* decides to not deploy the renewable energy project, then the total energy generated is Q_i; otherwise, we assume that the energy generated with the addition of a renewable resource has a fixed and a stochastic component $Q_i + (\beta Q_i + \varepsilon_i)$; the stochastic component has been utilized in previous models of renewable energy generators, such as the model proposed by Twomey and Neuhoff (2010). Hence, the following equation is the expected quantity of energy generated by firm *i* after deploying a renewable energy project:

$$Q_i^* = Q_i(1 - \lambda_i) + ((1+\beta)Q_i + \varepsilon)\lambda_i \tag{3}$$

$$Q_i^* = (1 + \beta\lambda_i)Q_i + \varepsilon\lambda_i \tag{4}$$

We also assume that q_i^0 and q_i^t must be equal to the expected quantity of energy generated (Q^*_i), hence:

$$Q_i^* = q_i^0 + q_i^t \tag{5}$$

We utilize a market-dependent model (Couture and Gagnon 2010), also known as feed-in-tariff, for the price of the energy generated from a renewable resource, i.e. $p^t + \omega$. Hence, the expected profit function of firm *i* for producing energy with depletable and renewable resources is:

$$\Pi_i = \left(p^0 - c_D\right) q_i^0 + (p^t - c_D)(Q_i^* - q_i^0)(1-x)e^{-rt} + (p^t + \omega - c_R)(Q_i^* - q_i^0)x.e^{-rt} - I\lambda_i e^{-rt} \tag{6}$$

Substituting Equations 1, 2 and 4 into Equation 6 will yield:

$$\begin{aligned}\Pi_i = &\left(a - \theta(q_i^0 + q_{3-i}^0) - c_D\right) q_i^0 + \\ &(a - \theta((1+\beta\lambda_i)Q_i + \varepsilon\lambda_i - q_i^0 + (1+\beta\lambda_{3-i})Q_{3-i} + \varepsilon\lambda_{3-i} - q_{3-i}^0) - c_D)((1+\beta\lambda_i)Q_i + \varepsilon\lambda_i - q_i^0)e^{-rt}(1-x) + \\ &(a - \theta((1+\beta\lambda_i)Q_i + \varepsilon\lambda_i - q_i^0 + (1+\beta\lambda_{3-i})Q_{3-i} + \varepsilon\lambda_{3-i} - q_{3-i}^0) + \omega - c_R)((1+\beta\lambda_i)Q_i + \varepsilon\lambda_i - q_i^0)e^{-rt}x - I\lambda_i e^{-rt}\end{aligned} \tag{7}$$

2.2 First Order Conditions, Reaction Functions and Equilibrium

At time 0, the profit maximization assumption states that firm *i* generates energy q_i^0 in order to maximize the firm's profit. Thus, the first order maximization conditions for q_i^0 are:

$$\begin{aligned}\frac{\partial \Pi_i}{\partial q_i^0} = &a - 2\theta q_i^0 - \theta q_{3-i}^0 - c_D - ae^{-rt}(1-x) + 2\theta((1+\beta\lambda_i)Q_i + \varepsilon\lambda_i)e^{-rt}(1-x) - 2\theta q_i^0 e^{-rt}(1-x) + \\ &\theta((1+\beta\lambda_{3-i})Q_{3-i} + \varepsilon\lambda_{3-i})e^{-rt}(1-x) - \theta q_{3-1}^0 e^{-rt}(1-x) + c_D e^{-rt}(1-x) - ae^{-rt}x + 2\theta((1+\beta\lambda_i)Q_i + \varepsilon\lambda_i)e^{-rt}x - \\ &2\theta q_i^0 e^{-rt}x + \theta((1+\beta\lambda_{3-i})Q_{3-i} + \varepsilon\lambda_{3-i})e^{-rt}x - \theta q_{3-1}^0 e^{-rt}x - we^{-rt}x + c_R e^{-rt}x = 0\end{aligned} \tag{8}$$

Solving Equation 8, we find the reaction functions:

$$\begin{aligned}q_1^0 = &-\frac{q_2^0}{2} + \frac{a(1-e^{-rt})}{2\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{2\theta(1+e^{-rt})} + \frac{(c_R - c_D)xe^{-rt}}{2\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_1)Q_1 + \varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} + \\ &\frac{((1+\beta\lambda_2)Q_2 + \varepsilon\lambda_2)e^{-rt}}{2(1+e^{-rt})} - \frac{\omega xe^{-rt}}{2\theta(1+e^{-rt})}\end{aligned} \tag{9}$$

$$\begin{aligned}q_2^0 = &-\frac{q_1^0}{2} + \frac{a(1-e^{-rt})}{2\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{2\theta(1+e^{-rt})} + \frac{(c_R - c_D)xe^{-rt}}{2\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_2)Q_2 + \varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} + \\ &\frac{((1+\beta\lambda_1)Q_1 + \varepsilon\lambda_1)e^{-rt}}{2(1+e^{-rt})} - \frac{\omega xe^{-rt}}{2\theta(1+e^{-rt})}\end{aligned} \tag{10}$$

Substituting Equation 10 into Equation 9 yields Equation 11; in addition, substituting Equation 9 into Equation 10 yields Equation 12. Hence, we have the following equilibrium:

$$q_1^0 = \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} - \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \tag{11}$$

$$q_2^0 = \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} - \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \tag{12}$$

Substituting Equations 11 and 12 into Equation 1 yields the price in equilibrium at time 0:

$$p^0 = a - \frac{2a(1-e^{-rt})}{3(1+e^{-rt})} + \frac{2c_D(1-e^{-rt})}{3(1+e^{-rt})} + \frac{2(c_D-c_R)xe^{-rt}}{3(1+e^{-rt})} - \frac{\theta((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} - \frac{\theta((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} + \frac{2\omega x e^{-rt}}{3(1+e^{-rt})} \tag{13}$$

In addition, substituting Equations 11 and 12 into Equation 5 yields the equilibrium at time *t*:

$$q_1^t = (1+\beta\lambda_1)Q_1+\varepsilon\lambda_1 - \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} - \frac{((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} + \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \tag{14}$$

$$q_2^t = (1+\beta\lambda_2)Q_2+\varepsilon\lambda_2 - \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} - \frac{((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} + \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \tag{15}$$

And substituting Equations 14 and 15 into Equation 2 yields the price in equilibrium at time *t*:

$$p^t = a - \theta(1+\beta\lambda_1)Q_1 - \theta\varepsilon\lambda_1 - \theta(1+\beta\lambda_2)Q_2 - \theta\varepsilon\lambda_2 + \frac{2a(1-e^{-rt})}{3(1+e^{-rt})} - \frac{2c_D(1-e^{-rt})}{3(1+e^{-rt})} - \frac{2(c_D-c_R)xe^{-rt}}{3(1+e^{-rt})} + \frac{\theta((1+\beta\lambda_1)Q_1+\varepsilon\lambda_1)e^{-rt}}{(1+e^{-rt})} + \frac{\theta((1+\beta\lambda_2)Q_2+\varepsilon\lambda_2)e^{-rt}}{(1+e^{-rt})} - \frac{2\omega x e^{-rt}}{3(1+e^{-rt})} \tag{16}$$

The expected price and quantity in equilibrium, where $E[\varepsilon] = 0$, are:

$$q_1^0 = \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_1)Q_1)e^{-rt}}{(1+e^{-rt})} - \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \tag{17}$$

$$q_2^0 = \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} + \frac{((1+\beta\lambda_2)Q_2)e^{-rt}}{(1+e^{-rt})} - \frac{\omega x e^{-rt}}{3\theta(1+e^{-rt})} \tag{18}$$

$$p^0 = a - \frac{2a(1-e^{-rt})}{3(1+e^{-rt})} + \frac{2c_D(1-e^{-rt})}{3(1+e^{-rt})} + \frac{2(c_D-c_R)xe^{-rt}}{3(1+e^{-rt})} - \frac{\theta((1+\beta\lambda_1)Q_1)e^{-rt}}{(1+e^{-rt})} - \frac{\theta((1+\beta\lambda_2)Q_2)e^{-rt}}{(1+e^{-rt})} + \frac{2\omega xe^{-rt}}{3(1+e^{-rt})} \quad (19)$$

$$q_1^t = (1+\beta\lambda_1)Q_1 - \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} - \frac{((1+\beta\lambda_1)Q_1)e^{-rt}}{(1+e^{-rt})} + \frac{\omega xe^{-rt}}{3\theta(1+e^{-rt})} \quad (20)$$

$$q_2^t = (1+\beta\lambda_2)Q_2 - \frac{a(1-e^{-rt})}{3\theta(1+e^{-rt})} + \frac{c_D(1-e^{-rt})}{3\theta(1+e^{-rt})} - \frac{(c_R-c_D)e^{-rt}x}{3\theta(1+e^{-rt})} - \frac{((1+\beta\lambda_2)Q_2)e^{-rt}}{(1+e^{-rt})} + \frac{\omega xe^{-rt}}{3\theta(1+e^{-rt})} \quad (21)$$

$$p^t = a - \theta(1+\beta\lambda_1)Q_1 - \theta(1+\beta\lambda_2)Q_2 + \frac{2a(1-e^{-rt})}{3(1+e^{-rt})} - \frac{2c_D(1-e^{-rt})}{3(1+e^{-rt})} - \frac{2(c_D-c_R)xe^{-rt}}{3(1+e^{-rt})} + \frac{\theta((1+\beta\lambda_1)Q_1)e^{-rt}}{(1+e^{-rt})} + \frac{\theta((1+\beta\lambda_2)Q_2)e^{-rt}}{(1+e^{-rt})} - \frac{2\omega xe^{-rt}}{3(1+e^{-rt})} \quad (22)$$

The term ε affects both quantities and prices. Therefore, the expected profit contains the term ε^2, which is not zero in expectation but $E[\varepsilon^2] = \sigma^2$. The difference between the expected profit with ε and without the stochastic component is:

$$-\frac{\theta\varepsilon^2\lambda_i(\lambda_i+\lambda_{3-i})e^{-rt}}{(1+e^{-rt})} = -\frac{\theta\sigma^2\lambda_i(\lambda_i+\lambda_{3-i})e^{-rt}}{(1+e^{-rt})} \quad (23)$$

Hence, the stochastic component of the renewable energy generator reduces the expected profit.

2.3 Implications

This section presents some propositions of the model described above; in other words, the economic implications of important variables, such as the price and the probability of deploying a renewable energy project. Thus, we will analyze the impact that these variables can have on the energy market and how they can facilitate social welfare.

Proposition I: As the probability of firm *i* deploying a renewable energy project (λ_i) increases, the quantity generated at time 0 also increases and the price decreases. However, the probability of the other firm deploying a renewable energy project, λ_{3-i}, does not affect the decision of the firm.

Proof:

$$\frac{\partial q_i^0}{\partial \lambda_i} = \frac{(\beta Q_i + \varepsilon)e^{-rt}}{(1+e^{-rt})} > 0; \frac{\partial p^0}{\partial \lambda_i} = -\frac{\theta(\beta Q_i + \varepsilon)e^{-rt}}{(1+e^{-rt})} < 0; \frac{\partial q_i^0}{\partial \lambda_{3-i}} = 0 \tag{24}$$

Proposition II: As the probability of firm *i* deploying a renewable energy project (λ_i) increases, the energy generated at time *t* increases and the price decreases. However, the probability of the other firm deploying a renewable energy project, λ_{3-i}, does not affect the decision of the firm.

Proof:

$$\frac{\partial q_i^t}{\partial \lambda_i} = \frac{\beta Q_i + \varepsilon}{(1+e^{-rt})} > 0; \frac{\partial p^t}{\partial \lambda_i} = -\frac{\theta(\beta Q_i + \varepsilon)}{(1+e^{-rt})} < 0; \frac{\partial q_i^t}{\partial \lambda_{3-i}} = 0 \tag{25}$$

The intuition behind Preposition I and II is clear. As the probability λ_i increases, the expected energy generated also increases, and consequently the price will decrease, since the supply will be greater. Hence, Propositions I and II show that increasing the probability of deploying a renewable energy project will decrease the price in any period, regardless of the competing firm's decision, which in turn may help increase the social welfare.

Proposition III: As the expected rate of increase in renewable energy production (β) rises, the quantity produced at time 0 and *t* also increases and the prices decrease.

Proof:

$$\begin{aligned} &\frac{\partial q_i^0}{\partial \beta} = \frac{\lambda_i Q_i e^{-rt}}{(1+e^{-rt})} > 0; \frac{\partial q_i^t}{\partial \beta} = \lambda_i Q_i \left(1 - \frac{e^{-rt}}{(1+e^{-rt})}\right) > 0 \\ &\frac{\partial p^0}{\partial \beta} = -\frac{(\lambda_i Q_i + \lambda_{3-i} Q_{3-i})\theta e^{-rt}}{(1+e^{-rt})} < 0; \frac{\partial p^t}{\partial \beta} = -\theta(\lambda_i Q_i + \lambda_{3-i} Q_{3-i}) \left(1 - \frac{e^{-rt}}{(1+e^{-rt})}\right) < 0 \end{aligned} \tag{26}$$

Hence, the prepositions above show that energy prices decrease when the expected production of energy from renewable resource increases. Lower energy prices may help reduce costs in many sectors of the economy, such as industry, transportation, services, and agriculture. For instance, low energy prices reduce production costs, which in turn may facilitate economic growth and social welfare.

Proposition IV: As the bonus of the feed-in-tariff (ω) increases, the quantity produced at time 0 decreases and the quantity produced at t increases. In addition, as the bonus increases, the price increases at time 0 and decreases at time t.

Proof:

$$\frac{\partial q_i^0}{\partial \omega} = -\frac{xe^{-rt}}{3\theta(1+e^{-rt})} < 0; \frac{\partial q_i^t}{\partial \omega} = \frac{xe^{-rt}}{3\theta(1+e^{-rt})} > 0; \frac{\partial p^0}{\partial \omega} = \frac{2xe^{-rt}}{3(1+e^{-rt})} > 0; \frac{\partial p^t}{\partial \omega} = -\frac{2xe^{-rt}}{3(1+e^{-rt})} < 0 \quad (27)$$

This may suggest that the incentive from the feed-in-tariff has an impact on the decision-making process of the firms; hence, they might wait to produce energy from a renewable energy generator at time t instead of depletable resource at time 0. Additionally, this proposition suggests that the consumers are better off with the introduction of feed-in-tariffs, because the prices decrease at time t.

3. Numerical examples

In order to examine important variables of the model, namely the probability of deploying a renewable energy project (λ_i), the expected rate of increase in renewable energy production (θ), and the bonus of the feed-in-tariff (ω), we present some numerical examples using plausible parameter values.

We assume an inverse demand function at time 0 of $p^0 = 350 - 3.(q_1^0 + q_2^0)$ and at time t of $p^t = 350 - 3.(q_1^t + q_2^t)$. The marginal costs are $c_D = 27.5$ and $c_R = 0$; these values correspond to variable operations and maintenance costs for generating energy from conventional coal and wind respectively (EIA 2012). The remaining variables are of little concern as we are interested in the effect of λ_i and θ on the profit of the firms and the value added by the option to deploy a renewable energy project; hence, in our examples, we used the following value for each parameter: $Q_1 = 40$, $Q_2 = 40$, $r = 10\%$, $x = 20\%$, and $I = 50$.

β	10%	30%	50%	70%	90%
π_1	7,642	7,870	8,011	8,066	8,034
π_2	7,642	7,870	8,011	8,066	8,034
Option 1	254	396	490	537	536
Option 2	254	396	490	537	536

Table 1: Expected profit and value added by the option as the expected rate of increase in renewable energy production (β) rises

λ_1	10%	30%	50%	70%	90%
π_1	7,204	7,629	8,011	8,349	8,644
π_2	8,551	8,281	8,011	7,741	7,471
Option 1	54	284	490	672	831
Option 2	754	622	490	358	226

Table 2: Expected profit and value added by the option as the probability of deploying a renewable energy project (λ_1) increases

Tables 1 and 2 present the expected profit and value added by the option to deploy a renewable energy project as β and λ_1 increase, respectively. The value added by the option is calculated by subtracting the expected profit at time t of firm i with the option to deploy a renewable energy project by the expected profit at time t of the same firm without the option to deploy the renewable energy project.

In Table1, the expected profits of both firms increase as β increases up to a point between 70% and 90%; this is due to the fact that after this point the marginal cost is greater than the marginal revenue. Hence, although the prices decrease and the quantities increase as β increases (Proposition III), there is a β that maximizes the profit and the firm will probably not increase β above this point. In addition, the value of the option increases up to a point between 70% and 90% (the same point as the profit); this is consistent with the Real Option theory, where the European call option value increases as the asset value increases, and the asset value in this case is the additional profit due to the renewable energy generation.

Table 2 shows that the expected profit of firm 1 increases as the probability of deploying a renewable energy project (λ_1) increases; however, the expected profit of firm 2 decreases. The explanations for these results are twofold. First, a higher probability of deploying a project will yield a higher quantity of energy generated for the market; hence, decreasing the price of energy. Second, as prices fall the profit of firm 2 also decreases. The value of the option also follows the same pattern; in other words, as λ_1 increases the value of the option for firm 1 increases and for firm 2 decreases. From firm 2's perspective, this might suggest that a competitor with a high probability of deploying a project will influence the market, by gaining more market share and reducing the price; hence, this will impact the expected profit and the value of the option. This is consistent with the Real Option theory where competition erodes the value of the option.

ω	**10**	**20**	**50**
π_1	7,969	8,011	8,136
π_2	7,969	8,011	8,136
Option 1	447	490	620
Option 2	447	490	620

Table 3: Expected profit and value added by the option as the constant premium or bonus over the price (due to a feed-in-tariff) increases

In Table 3, the profits and the values added by the option to deploy a renewable increase as the bonus for renewable production increases, due to a feed-in-tariff policy. This may suggest that a feed-in-tariff, which uses a market-dependent model, has a positive impact on the decision-making process; hence, firms will have a higher incentive to invest in renewable energy projects. This is consistent with previous works on feed-in-tariffs, such as the paper from Couture and Gagnon (2010).

4. Conclusion and future research

This paper analyzes important economic variables (e.g., energy prices, allocation of depletable and renewable resources, and profits) in a two stage Cournot oligopoly, where generation companies have the option to deploy a renewable energy project. The option to deploy a renewable energy project is very important to decision makers, because it may increase the profit of the firm. In addition, policy makers might also be interested in this analysis in order to create the right incentives for the firms, while contributing to economic growth, social welfare and sustainability.

The key contributions of this paper are twofold. First, we analyze the impact of the option to deploy the renewable energy project on the profits, economic growth, and social welfare. Second, we calculate the value added by the option of deploying a renewable energy project. The results show that as the probability of deploying the project increases, the prices fall and supply increases, which might facilitate economic growth and social welfare.

As future work, we would like to test other remuneration types of feed-in-tariffs (e.g., the remuneration structures in Couture and Gagnon (2010)), and analyze the impact of these incentives on the same economic variables. This analysis might shed some light on how to facilitate economic growth and sustainability, and improve the decision making process of policy makers.

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