Proceedings of the 2nd Meeting on Energy and Environmental Economics

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18th September 2015

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Department of Economics, Management, and Industrial Engineering (DEGEI)

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2nd Meeting on Energy and Environmental Economics

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DEGEI – Proud to host the 2nd ME3, 2015

The Department of Economics, Management, and Industrial Engineering (DEGEI) of the University of Aveiro was proud to host the 2nd International Meeting on Energy and Environmental Economics conference, which brought together a total of 16 accepted papers, an effort which involved a total of 57 authors and co-authors, following the peer-review process. Research can thus be seen to increasingly be a team effort. This brings the total number of participants in the ME3 2015 to 45 people. Our thanks to the Organizing Committee, the Scientific Committee, the staff of DEGEI, the Nucleus of Economics Students (NEEC), and to the UA Editora. Special thanks to our sponsors who made the 2nd ME3 possible: DEGEI, UA, GOVCOPP, EDP and Trustenergy. In the 2nd ME3 we had the pleasure of welcoming and listening to Monica Giulietti, from the School of Business and Economics, University of Loughborough in UK and Gürkan Kumbaroğlu, President-Elected of the International Association for Energy Economics and Boğaziçi University in Turkey. Our thanks to these keynote speakers for having shared their valuable experience with us. We hope that the 2nd ME3 was as enjoyable for you as it was for us, at DEGEI, and wish you all the best for the future.

Carlos Costa

Full Professor

Director of the Department of Economics, Management, and Industrial Engineering (DEGEI), University of Aveiro

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Organizing Committee Message

As chair of the 2nd International Meeting on Energy and Environmental Economics (ME^3) I was pleased to welcome you all at the Department of Economics, Management and Industrial Engineering (DEGEI) from the University of Aveiro and to wish you all a very pleasant Meeting. I'm here representing four more colleagues which have been working very hard with me to turn this meeting possible. They are Margarita Robaina, Marta Ferreira Dias and Victor Moutinho, all professors from this department and also Jorge Sousa, our colleague and professor at ISEL in Lisbon.

The meeting is very young because it started in 2014. In 2015 we have turned possible its 2nd edition. It is our intention to keep it in the forward years, turning it an annual event, given that this year we have accomplished our goal of increasing the number of submissions and also of international submissions with respect to the previous year. This year, we had 4 parallel sessions, 2 in the morning and 2 in the afternoon, with 16 papers of very high quality.

But the ME^3 consists in a meeting of researchers, companies and institutions working in the energy and environmental economic fields. The meeting has as main goal the share of experiences and results throughout the scientific, entrepreneurial and institutional communities whose interests are the areas of Energy and Environmental Economics.

With this in mind we have also invited companies and institutions whose presentations occurred in the afternoon. The realization of a meeting under these subjects intends to improve the interchange of knowledge and scientific knowledge but also to connect scientific research to company's reality, once that in the meeting we have the simultaneous presence of persons representing companies and institutions connected to energy markets and resources, companies of high national importance. This year we had EDP, REN, Martifer and ADENE.

This 2nd ME^3 was special for another additional reason. There, we also had the formal presentation of the newly created Associação Portuguesa de Economia da Energia – APEEN (or Portuguese Association of Energy Economics), the Portuguese affiliate of International Association for Energy Economics (IAEE).

The idea of creating this association has resulted from some scientific meetings with other Portuguese University researchers, companies and institutions, and from works developed by a group of researchers/professors from University of Aveiro. Thus the opportunity to create in Portugal the APEEN emerged, a future branch of the International Association of Economists of Energy (IAEE). At the gala dinner which happened at day 18th we have formally presented all the founding members of the APEEN (companies, institutions and professors/researchers) and the founding president at its earlier creation and starting date, Professor Doctor Jorge Vasconcelos.

The goals of APEEN as an organization consist in the promotion of the mutual association of persons interested in Energy Economics, in order to create a professional discussion forum; to proportionate means for professional communication and the interchange of experiences and ideas between the persons interested in Energy Economics; to promote the professional communication between the persons interested in Energy Economics in Portugal and from different countries while being an affiliate of IAEE; and to educate the community in questions about Energy Economics.

To be able to fulfil these goals, the association will promote the organization of conferences, meetings and seminars over issues related with Energy Economics and Environment (being the ME3 one of the first in this action field), the dissemination of works, debates and conclusions which result from these activities and other activities considered as relevant for APEEN and its members.

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Legend: Founding Members photo after the signing of the by-laws

Thank you to all participants of the 2nd ME3, to the direction of this department, to the research center GOVCOOP, to our colleagues, department staff and students who helped us is this conference, and to Trustenergy and EDP for their financial support.

So, we wish that you have all enjoyed the meeting and feel free to contact us if you need anything. We wish you the best and thank you all for turning this event possible. We hope to see you again for the next year.

Mara Madaleno (CHAIR do 2nd ME3)
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Contents

Articles successfully submitted to and presented at 2nd International Meeting on Energy and Environmental Economics, 18th September 2015 and whose authors accepted the proceedings publishing

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REVISITING COMPRESSED AIR ENERGY STORAGE

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ABSTRACT

The use of renewable energies as a response to the EU targets defined for 2030 Climate Change and Energy has been increasing. Also non-dispatchable and intermittent renewable energies like wind and solar cannot generally match supply and demand, which can also cause some problems in the grid. So, the increased interest in energy storage has evolved and there is nowadays an urgent need for larger energy storage capacity.

Compressed Air Energy Storage (CAES) is a proven technology for storing large quantities of electrical energy in the form of high-pressure air for later use when electricity is needed. It exists since the 1970's and is one of the few energy storage technologies suitable for long duration (tens of hours) and utility scale (hundreds to thousands of MW) applications. It is also one of the most cost-effective solutions for large to small scale storage applications.

Compressed Air Energy Storage can be integrated and bring advantages to different levels of the electric system, from the Generation level, to the Transmission and Distribution levels, so in this paper a revisit of CAES is done in order to better understand what and how it can be used for our modern needs of energy storage.

Keywords: Renewable Energy, Energy Storage, Compressed Air Energy Storage (CAES).

1. INTRODUCTION

The vision of a low-carbon society is rightly associated with the use of renewable energy sources (RES), such as solar and wind power. The European strategy for Climate Change and Energy sets as targets for 2030 a 40% reduction of greenhouse gas emissions compared to 1990, an increase of 27% of renewable energy, and an improvement of 27% in energy efficiency [1].

Energy policies are promoting distributed energy resources such as energy efficiency, distributed generation (DG), energy storage devices (ES), demand-side management (DSM) and renewable energy resources (RES) [2].

With the increased use of RES and due to their intermittent factor and non-dispatchability there is an urgent need for additional energy storage, in order not to waste the energy that can be generated at low demand periods. So, intermittent generation like wind can cause problems in grids, in balances between supply and demand and in adequacy of power.

Solutions to decrease the problems caused by the variable output of intermittent resources are to add energy storage to the system, to create more flexibility on the supply side to mitigate supply intermittency and load variation, and to increase flexibility in electricity consumption [2].

Energy storage is a process which increases the flexibility of the way we generate, deliver and consume electricity. It provides the ability to balance power supply and power demand, making power networks more resilient, efficient and cleaner than before [3]. It is used to level the load in different time frames. Typically, the energy is stored during low demand periods and released during peak demand hours, to reduce the gap between the tip and the void (daily, weekly and seasonal level).

Energy storage technologies can be divided into several groups (Fig 1):
1. Chemical: Hydrogen; Synthetic Natural Gas and other chemical compounds (ammonia, methanol…).
2. Electrochemical: Lead-acid batteries; Nickel-Cadmium batteries; Sodium-sulphur batteries; Lithium-ion batteries and Vanadium redox-flow batteries.
3. Electrical: Supercapacitors and Superconducting magnetic energy storage.
4. Mechanical: Pumped Hydro Energy Storage; Compressed Air Energy Storage and Flywheel energy storage.
5. Thermal: Hot-water storage; Molten-salt energy storage and Phase change material storage.

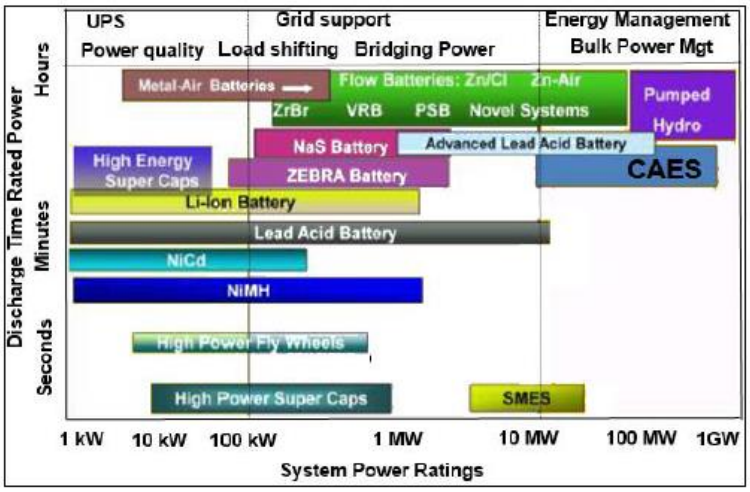

Fig 1- Energy storage technologies comparison. **a)** time to discharge and power; Source: Neumiller, J. L. (2009) [16].

The applicability of different types of storage also depends on the efficiency, lifetime (in operating cycles) and investment costs [2].

One of the larger scale energy storages, are the mechanical types of energy storage, like Pumped Hydro Storage (PHS) and Compressed Air Energy Storage (CAES).

Compressed Air Energy Storage (CAES) is one of the few energy storage technologies suitable for long duration (tens of hours), utility scale (hundreds to thousands of MW) applications [4] and also one of the better storage technologies in terms of cost-effectiveness, reason why it is the chosen technology for this paper.

2. COMPRESSED AIR ENERGY STORAGE (CAES)

Storing energy with compressed air systems emerged in the 1970s as a promising peak shaving option [5] and also because of the oil crisis in the 1970s and searching for alternatives. The interest in the technology has intensified in recent years, because of the increasing interest and need about energy storage.

CAES is nowadays a demonstrated technology (Huntorf CAES Plant and McIntosh CAES Plant are the proof) for storing large quantities of electrical energy in the form of high-pressure air [6]. In a CAES plant, ambient air is compressed and stored under pressure in a geological reservoir or underground cavern or even in surface reservoirs as tanks or pipes; when electricity is required, the pressurized air is heated and expanded in a turbine, driving a generator for power production [3], (Fig. 2).

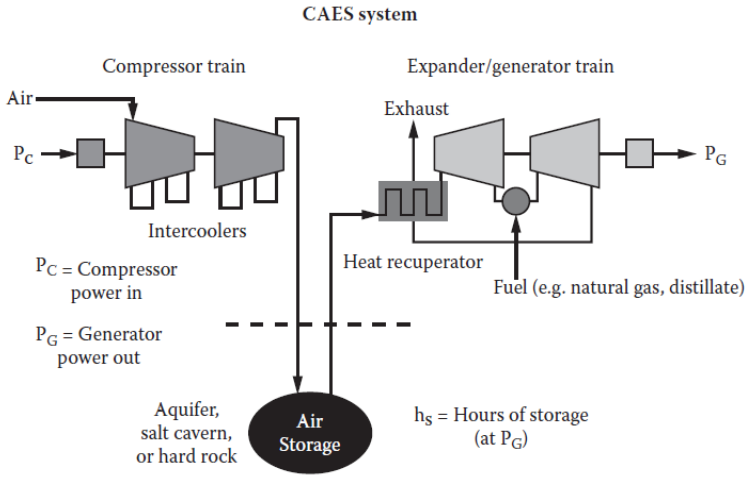

Fig. 2 - Compressed Air Energy Storage System configuration. Adapted from [4, 6]

According to Succar & Williams [4] and Barnes & Levine [6] CAES operation is not very different from a conventional gas operation. These authors describe the process (Fig. 2) as: “During the compression (storage) mode, electricity is used to run a chain of compressors that inject air into an uninsulated storage reservoir, thus storing the air under high pressure and at the temperature of the surrounding formation. The compression chain makes use of intercoolers and an aftercooler to reduce the temperature of the injected air, thereby enhancing compression efficiency, reducing the storage volume requirement, and minimizing thermal stress on the storage volume walls… During expansion (generation) operation, air is withdrawn from storage and fuel (typically natural gas) is combusted in the pressurized air. The combustion products are then expanded (typically in two stages), thus regenerating electricity.”

2.1 CAES Suitable Reservoirs

Carnegie *et al* [7] described a variety of storage means that can be used for CAES, such as salt caverns, hard rock caverns, porous rock formations (like aquifers), abandoned mines, pipes, underwater bladders and above-ground tanks. The same authors also divide CAES into two types according to their capacity of storage and type of reservoirs: a) Bulk CAES, which needs large subterranean geological formations, are the most economical ones and can store from one hundred to thousands of MW for more than 5 hours, usually they store from 300 to 400 MW over the course of 10 to 30 hours. b) Small CAES, which uses above-ground systems, pipes, bladders or other man-made vessels to store the compressed air and usually have capacities on the order of 10 to 20 MW and discharge time less than 5 hours.

Among the geological storage options, salt formations are the most easy to develop and operate. There are two types of these formations, large bedded salt deposits and dome structures and both of them can be used for CAES reservoirs. However, according to Succar & Williams [4] salt beds are usually more challenging to develop if large storage volumes are required, because they tend to be much thinner and often contain a comparatively higher concentration of impurities which present significant challenges with respect to structural stability. On the other hand caverns mined from salt domes can be tall and narrow with minimal roof spans. The only two CAES plants currently operating in the world (Huntorf and McIntosh CAES facilities) use solution-mined cavities in salt domes as storage reservoirs [6].

Caverns in hard rock are also an option for CAES reservoirs, however this is a more expensive alternative due to the cost of mining a new reservoir, unless use is made of abandoned mine cavities [6].

Porous rock formations such as saline aquifers and depleted oil and gas reservoirs are suitable for CAES development too and it appears that this type of geology is the lowest cost option [6]. Depleted oil and gas reservoirs can be used as reservoirs, with more risks associated (like flammability among others, but with three main advantages when compared to saline aquifers: i) containment conditions are proved; ii) the local geology is well known (and therefore require less exploration efforts and investments- of millions of euros of order); iii) the pressure was reduced by hydrocarbons production- injecting air will not cause overpressures and can actually avoid issues such as subsidence.

2.2 CAES Technologies and Efficiency

Although commercial CAES plants have been operating for several decades, the technology is still in a stage of development, which is reflected in the fact that the only two existing plants are based largely on conventional gas turbine and steam turbine technologies [6].

The process of compressing air generates heat, which is usually released into the atmosphere or it could be recovered and also stored. After the compression of air, it is stored in the reservoir and then it is expanded, that is a process that requires heat and where there are always some heat losses. So, according to the ways that a CAES system manages the heat generated in the compression phase and used in the expansion phase, these systems can be classified into three different types.

2.1.1 Diabatic CAES

Diabatic CAES, or Conventional CAES, is the most developed technology and the two existing CAES plants are based on this method. It uses conventional gas turbines where the compression of the combustion air is separated and independent from the actual gas turbine process [3], or according to Carnegie *et al* [7] Diabatic CAES uses heat added during the expansion process to increase the power capacity (Fig. 3). Efficiency of plants based on conventional CAES is around 42% without heat recovery and around 55% with waste heat recovery.

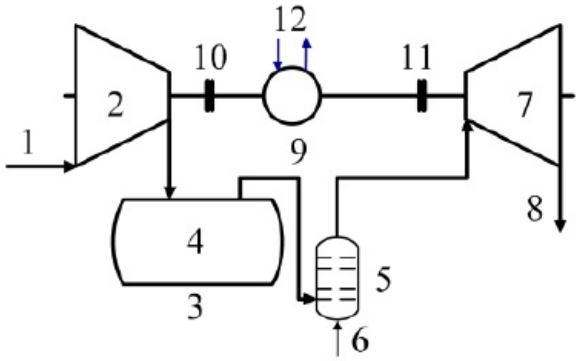

Fig. 3 – Diabatic or Conventional CAES Diagram where: 1- Air, 2- Compressor, 3- Reservoir, 4- Compressed Air, 5- Combustor, 6- Fuel, 7- Turbine, 8- Exhaust, 9- Motor/Generator, 10 and 11- Clutch and 12- Electricity. In: Energy Storage Technologies & Applications, [8].

2.2.2 Adiabatic CAES

The new Advanced Adiabatic CAES Method (AA-CAES) is an evolution of conventional CAES and uses a thermal storage device to capture heat expelled in the compression process and then uses the stored thermal energy to reheat the air during the expansion process [7], (Fig. 4). The heat of compression is recovered and used to reheat the compressed air during turbine operations, so there is no longer any need to burn natural gas to warm up the decompressed air, which diminishes carbon emissions and increases the efficiency of the process to up to 70% [3] alleviating most of the economic uncertainties of CAES [9]. Some Adiabatic CAES projects have been researched and proposed, but until now none has reach design stage. However, there is one project in Germany called ADELE – Adiabatic Compressed Air Energy Storage for Electricity Supply, which has been researched and is more developed and *German Electrical utility (RWE Power)* announced plans to construct the new A-CAES plant [10].

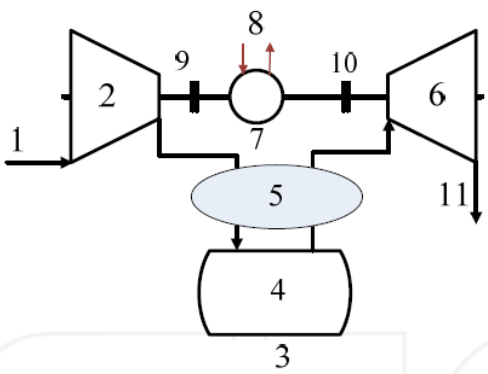

Fig. 4 – Advanced Adiabatic Diagram where: 1- Air, 2- Compressor, 3- Storage Reservoir, 4- Compressed Air, 5- Thermal Energy Storage, 6- Turbine, 7-

Motor/Generator, 8- Electricity, , 9 and 10- Clutch and 11- Exhaust In: Energy Storage Technologies & Applications, [8].

2.2.3 Isothermal CAES

Isothermal CAES technology is an emerging technology that compresses and expands air slowly so that the air temperature remains constant, eliminating the need to burn fossil fuels to reheat the air during expansion, decreases GHG emissions and substantially increases efficiency, theoretically near 100%. The potential for round-trip efficiency is expected to be somewhere between 70% and 80%, although currently there are no commercial Isothermal CAES facilities and it is still an immature technology that requires further research [3].

2.2.4 Considerations on the effciency of CAES systems

The simplest type of a Compressed Air Energy Storage (CAES) facility would be an adiabatic process consisting only of a compressor, a storage and a turbine, compressing air into a container when storing and expanding when producing, this could happen if the machines were reversible and it would have a storage efficiency of 100%; however, in practice due to the specific capacity of the storage and the construction materials, the air is cooled during and after compression, making the CAES process diabatic [11]. The cooling involves exergy losses and thus lowers the efficiency of the storage significantly.

CAES plants have two inputs of energy: electricity to compressor and fuel to burner, that occur at different points in time, so it is not so obvious how to define the efficiency of storage [11]. However, efficiency estimates vary significantly depending on the specific CAES technology (as we previously have seen) and geologic features [7] and it can be defined as a function of exergetic efficiency of compression, storage and production, all together [11].

According to Carnegie et al [7] diabatic CAES is not a pure storage technology, because it is also necessary to burn some fuel and the cost of fuel inputs can significantly raise overall costs. Fertig & Apt [12] described the concept of adiabatic CAES as eliminating the use of fossil fuels, although they say adiabatic CAES (case study in ERCOT, Texas, USA) is likely not cost-effective at current natural gas prices and under the USA GHG regulations, but that situation could reverse under higher gas prices and stricter limits on GHG emissions.

2.3 CAES existing plants

There are two main commercial CAES plants in the world, Huntorf in Germany and McIntosh in USA, and neither was built with the purpose of making use of wind power at the beginning. However, there are several other projects of CAES plants being studied and developed for the future due to the increase and fluctuation of electricity production based on renewable sources.

Huntorf CAES plant, in Germany, was built in 1978 in two salt caverns (310,000 m^3 total) [13], it had a power capacity of 290 MW and in the beginning it had the purpose of providing black-start services to nuclear units near the North Sea and to furnish inexpensive peak power, however it has been increasingly used to help balance the rapidly growing wind output from North Germany [4,6,13].The work by Crotogino et al [13] gives an overview of operation experiences in this CAES plant after 20 years.

According to the same authors the availability and starting reliability for this unit are reported as 90% and 99% respectively and its efficiency is about 42%.

McIntosh CAES plant, in Alabama, USA, has been operating since 1991 in a salt dome (560,000 m^3) and it was built as a source of inexpensive peak power to face the oil and gas prices. The starting reliabilities achieved are described as 91.2% and 92.1% average for the generation cycle and the average running reliabilities are between 96.8% and 99.5% for the compression cycle and its efficiency is around 54% [4,6].

There are several other CAES projects being researched and developed in USA like Norton CAES, in Ohio in an idle limestone mine and a storage reservoir for a 800 MW CAES facility [6]; Iowa Stored Energy park developing an aquifer CAES project directly coupled to a wind farm and with a proposed capacity of 268 MW [6]; Texas CAES projects in Matagorda for a facility of 540 MW [7]; New York State Electric & Gas is developing a 150 MW CAES project in salt cavern [14] and another one aboveground with a 9 MW system [7]. There are also projects being researched in China, in Japan and others also in Europe, like Larne CAES project in Northern Ireland, and ADELE project in Germany.

3. ADVANTAGES AND LIMITATIONS OF CAES

Compressed Air Energy Storage can be integrated and bring advantages to different levels of the electric system, from the Generation level, to the Transmission and Distribution levels.

It has several advantages, including a better management of the grid, ensure energy security, balance supply and demand and converge towards a low carbon economy.

These advantages can be translated in several benefits like reliability and security of the grid, power quality, transmission optimization, black-start functions and arbitrage for utility companies.

The primary benefits of a CAES system are ancillary services provided to the grid, where their applications include: peak shaving, spinning reserve, VAR (Value of Reactive Energy/Reactive Power) support and arbitrage [9]. The advantages of CAES are particularly interesting when coupled with an intermittent source such as wind energy.

Because of the heat generation during the process of air compression and the need for heat in the expansion fase, there are losses which are inevitable, as in any energy conversion. Less energy eventually makes it to the grid if it passes through the CAES system than in a similar system without storage [9]. In any event, the requirement for additional heating in the expansion process is the most significant disadvantage [9], mainly because current CAES systems are based in gas burning.

Another limitation is the fact that for installing a CAES Plant with underground reservoirs it is needed some specific geological conditions that are not available everywhere. So, there are restrictions on the availability of places with suitable geological conditions.

4. CONCLUSIONS

Compressed Air Energy Storage is a proven technique of storing large amounts of energy as the potential energy of a compressed gas, usually referring to the air that is pumped into large storage reservoirs that can be above ground tanks or naturally occurring underground formations.

Compared to other storage technologies, CAES is a cost-effective option for load shifting and one of its main purposes is to store wind energy during times of transmission curtailment and generation onto the grid during shortfalls in wind output [6].

In the light of nowadays Climate Change and Energy European and National regulations, CAES technologies are one of the energy storage technology alternatives that allow to store large amounts of energy for periods where other large systems like pumped hydro storage fails because for instance, lack of water.

CAES also have less environmental impact on land (because its underground reservoirs are precisely underground) and also less impact on water compared to Pumped Hydro Storage and less environmental issues compared to batteries.

Until now the two commercial existing CAES plants (Huntorf and McIntosh) have shown economic feasibility and reliability [15].

However, CAES technologies need further developing, especially needs further developing of their new adiabatic and isothermal CAES technologies concepts and also need to increase CAES efficiency and decrease the losses during the process.

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USING CHOICE EXPERIMENTS AND CONTINGENT VALUATION TO ASSESS ENVIRONMENTAL IMPACTS OF WIND FARMS IN PORTUGAL

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ABSTRACT

Over the last few decades, the number of wind farms installed in Portugal has grown considerably, which has stimulate an intense debate on the environmental impacts associated with wind energy. The use of wind power for electricity generation presents several environmental benefits, but it also presents adverse impacts. Some of the most important benefits mentioned in the literature are the decrease in greenhouse gas emissions (as wind energy partially replaces fossil fuels), a reduction in the external dependency of the economy, and the diversification of the energy mix. The adverse effects of wind farms include noise pollution, landscape intrusion, effects on fauna and flora, electromagnetic interferences and land use impacts. The main objective of this study is to elicit the welfare impacts of the use of wind energy to produce electricity on two groups of stakeholders: local residents (that typically bear the adverse effects) and the general population (who typically enjoys the benefits). To this end three wind farms (Arga, Negrelo & Guilhado, and Lousã II, located in the north and centre of Portugal, respectively) were selected to study the local residents' perspective and a national sample of Portuguese residents was selected to represent the interest of the beneficiaries. The methodologies used in each case are different as the question of interest differs. Concerning local residents we applied the contingent valuation method and elicited the minimum amount of compensation they would require for the nuisances experienced; concerning the general population we applied a discrete choice experiment to elicit the willingness to pay to avoid the environmental impacts of wind farms. The results show that both general population and local residents have clear preferences over wind farms' environmental impacts, and they are willing to pay and receive significant monetary amounts to avoid or be compensated for the environmental impacts, respectively. With the results of this study, we expect to contribute to a more efficient and thorough process of deciding the optimal location of future wind farms or expansion of existing ones, taking into account in a more complete manner the views of these stakeholders.

Keywords: Wind Farms, Contingent Valuation, Discrete Choice Experiments, Environmental Impacts, Public Attitudes.

1. INTRODUCTION

Installed power, production and the number of wind farms (WFs) have all been increasing over the last few decades (Álvarez-Farizo and Hanley, 2002). Several publications document the positive environmental aspects of wind power, identifying it as one of the most efficient renewable energy sources and an important component of the energy mix in many countries. However, despite its doubtless advantages, wind power generation comes along with considerable negative externalities, experienced by the local communities and by the population in general (Drechsler *et al*., 2011). These adverse impacts are due to the inherent operating characteristics of WFs, justifying increasing opposition to the construction of new facilities (Krohn and Damborg, 1999; Álvarez-Farizo and Hanley, 2002; Wolsink, 2007). The environmental benefits of electricity production from wind power are well recognised and accepted, but the environmental costs are less well-known. These are difficult to quantify and are likely to be case-specific. However, any efficient economic assessment of wind energy expansion should incorporate the value of all environmental impacts, both positive and negative (Álvarez-Farizo and Hanley, 2002), in particular not only identify and acknowledge the adverse impacts on the local population but also value them so as to provide a more thorough accounting of the costs.

In this study we focus on three WFs in Portugal and present two complementary approaches to estimate the economic value of the adverse environmental impacts. A thorough review of the literature indicates landscape intrusion (e.g. Wolsink, 2007; Gordon, 2001), land use impacts (e.g. Manwell *et al*., 2009; Denholm *et al*., 2009), noise pollution (e.g. Pedersen *et al*., 2009; Van den Berg, 2005, 2006), impacts on fauna and flora (e.g. Mendes *et al.*, 2002; Travassos *et al*., 2005), and electromagnetic interferences (e.g. Manwell *et al*., 2009) as the most significant negative effects associated with the operation of wind power plants. On the one hand we elicit the willingness to accept (WTA) by the local population to be compensated for sustaining these negative externalities. We apply the contingent valuation (CV) method to estimate a straightforward and narrower economic value related to direct use. On the other hand, we elicit the willingness to pay (WTP) of the general population to compensate the local residents for the damage. We apply the discrete choice experiments (DCE) method to estimate the broader economic value attributed by those not directly affected but who nonetheless are stakeholders. We compare both values to clearly understand whether the damage sustained by local residents can be viably supported by those who benefit from the externality-generating activity. Furthermore, either of those values can be used as useful information for policy makers to account for the adverse impacts in an economic analysis, which is often a neglected component.

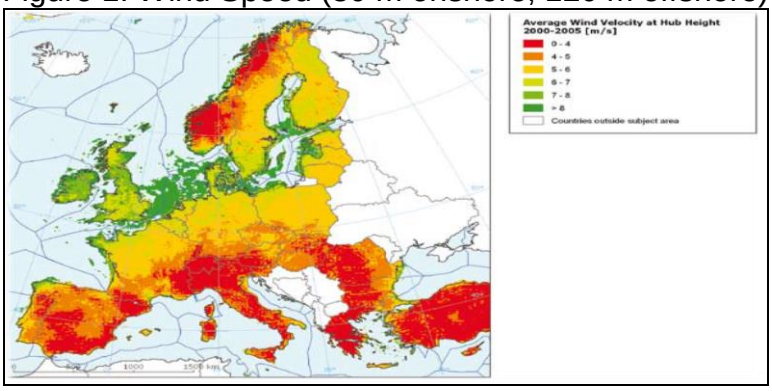
The reminder of this paper is organized as follows. Section 2 presents the current situation of the use of wind for electricity generation in Portugal. Section 3 provides an overview of the main methodological issues, in which the valuation methods are

explained, the survey design described and a brief description of the case studies is presented. Then section 4 presents and discusses the results. Finally, in section 5 the main conclusions of this paper are presented.

2. WIND POWER IN PORTUGAL

Wind is extremely valuable as an energy resource in Europe (EEA, 2008). Figure 1 presents a map with different wind speed regions estimated for different topographic conditions. The wind speed above which commercial exploitation can take place varies considerably between different regions: although countries such as Scotland clearly stand out for having an exceptional potential, we observe that in every European country wind is a technically and economically exploitable resource.

Figure 1: Wind Speed (80 m onshore, 120 m offshore)

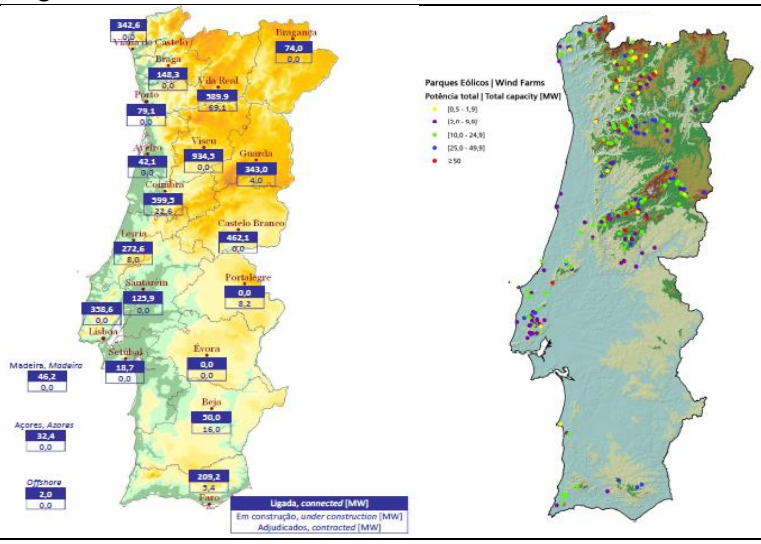


Source: EEA (2008)

Portugal, a mid-sized European Union (EU) country with about 10 million inhabitants, is placed amongst the top ten countries in the world with the highest cumulative wind power capacity at the end of 2013 (EWEA, 2014). This is due to its geographic and geomorphologic characteristics favouring the production of wind energy, along with high investment levels on this energy source in recent decades. In addition, while wind energy investments at the EU level are mostly offshore, all wind energy to date in Portugal is produced onshore (Azau, 2011). It is also important to highlight the role of two essential tools created with the purpose of developing an efficient use of wind power potential in Portugal: the database on wind power potential - EOLOS2.0, which provides information on the physical and energy characteristics of the atmospheric flow in 57 locations on mainland Portugal; and the VENTOS software, which is used for computational simulation purposes of the behaviour of wind flow on complex terrains, whether or not arborized (DGEG, 2007).

Between 2010 and 2013, wind power in Portugal grew 812 MW (21% increase), reaching an installed capacity of 4728.5 MW. Wind farms, as illustrated in Figure 2, are particularly concentrated in the Centre and North of the country, with particular importance in the districts of Viseu, Coimbra, Vila Real, Lisboa, Guarda, Viana do Castelo, Leiria and Faro with the highest installed rated power, all presenting values above 200 MW by December 2013 (INEGI and APREN, 2013).

Figure 2: Location and Installed Power of WFs in Portugal



Note: The Portuguese offshore wind installed capacity consists on the concept demonstration project Windplus. Source: INEGI and APREN (2013)

3. METHODOLOGY

Our study focuses on two groups of stakeholders who value the adverse impacts of WFs. One of them comprises the local residents near three specific WFs in Portugal. To estimate the WTA compensation for the adverse impacts we apply a stated-preference (SP) method that has been used widely in non-market valuation studies: the contingent valuation (CV) method. The other group embraces the general population that benefits from using wind power as an energy source and can potentially value in economic terms the damage sustained by local residents. To estimate this value in terms of the WTP for compensation to the affected parties, we apply a different non-market valuation technique, the discrete choice experiments (DCE), included in the choice modelling approaches. This chapter presents an overview of the applied valuation methods, and briefly describes the three WFs used in the CV study of local residents.

3.1. Contingent Valuation Method

The CV method is a direct survey approach to estimating preferences. Using an appropriately designed questionnaire, a hypothetical (or contingent) market for the good in question is described. This contingent market defines the good itself, the institutional context in which it would be provided, and the way it would be financed. Respondents are then asked to express their maximum WTP or minimum WTA compensation for a hypothetical change in the level of provision of the good (Mitchell and Carson, 1989; Hanley *et al*., 2001; Atkinson and Mourato, 2008).

In this study, we designed a CV survey to estimate the minimum money amount respondents were willing to accept as compensation for all the burdens caused by the presence of a WF in the proximity of their residence. Following Whitehead (2006), each questionnaire was composed of four sections. After an introductory section with general questions on renewable energy sources, section 2 presents specific questions on the production of electricity through wind power, of which we

highlight, due to its relevance, the valuation question. Given that we had no prior information on the distribution of respondents' valuation for choosing the thresholds for a discrete-choice format, this question was formulated as an open question. The chosen payment vehicle was a compensation in the electricity bill, providing a simple and easily understood payment context. The question was formulated as follows:

Taking into account your income and your usual expenses, answer the following question: What is the minimum amount that you would be willing to receive as compensation for the inconvenience that the presence of the wind farm causes to you? The amount would be credited to your monthly electricity bill.

You would be willing to receive _____ Euros per month.

Section 3 contains some additional questions on respondents' preferences and opinions on different energy sources, renewable and non-renewable. Finally, section 4 includes some questions to gather information on the individuals' socio, economic and demographic characteristics (e.g., gender, educational level, family situation, income, etc.). The questionnaire was subject to an interactive test and review process using pilot studies.

For the CV application we focused on three WFs to be able to elicit the economic value for those specific cases. In the following sub-sections, each of the studied WFs will be briefly presented.

3.1.1. Arga Wind Farm

The Arga WF, operating since April 2006, is located in the Serra de Arga, in the parishes of Arga de Cima and Arga de Baixo, municipality of Caminha, district of Viana do Castelo, at an average altitude of 750 meters. This wind farm has an installed capacity of 36 MW spread over 12 wind turbines Vestas model V90 with 3.0 MW of unitary potency, and with 80 meters height of the rotor axis. The Portuguese company Empreendimentos Eólicos do Vale do Minho, S.A. (EEVM) explores and manages the Arga wind farm. The next two figures present, respectively, the exact location and a panoramic view of the Arga plant.

Figure 3: Location of Arga WF

Source: Authors' elaboration

Figure 4: Panoramic view of Arga WF

Source: EEVM:
http://eevm.pt/index.php?option=com_content&view=article&id=337&Itemid=289

3.1.2. Negrelo & Guilhado Wind Farm

The Negrelo & Guilhado WF, with an installed capacity of 22.3 MW, is located in the Serra da Padrela, in the parishes of Soutelo de Aguiar and Vila Pouca de Aguiar, both in the municipality of Vila Pouca de Aguiar, district of Vila Real. This wind farm started operating in March 2009 with 10 wind turbines Enercon model E82 with 2.0 MW of unitary potency to which were added, in December 2011, an additional wind turbine Enercon model E82 with 2.3 MW of unitary potency. The construction of the Negrelo & Guilhado WF was promoted by ENERNOVA – Novas Energias, S.A., a company of the Group EDP Renováveis. The following two figures present, respectively, the exact location and a panoramic image of the Negrelo & Guilhado plant.

Figure 5: Location of Negrelo & Guilhado WF

Source: Authors' elaboration

Figure 6: Panoramic Image of Negrelo & Guilhado WF

Source: APREN and INEGI: http://e2p.inegi.up.pt/index.asp#Tec3

3.1.3. Lousã II Wind Farm

The Lousã II WF, with an installed capacity of 50 MW, is located in the Alto do Trevim, in the municipality of Lousã, district of Coimbra. This wind farm began operating in November 2008 (in full in early 2009) and aggregates 20 wind turbines Nordex model N90 - R80 with 2.5 MW of unitary potency. The exploration of the Lousã II wind farm belongs to the company Parque Eólico de Trevim, Lda. (Group Iberwind). The following two figures present, respectively, the exact location and a panoramic image of the Lousã II plant.

Figure 7: Location of Lousã II WF

Source: Authors' elaboration

Figure 8: Panoramic Image of Lousã II WF

Source: Iberwind: http://www.iberwind.com/pt/parques/20/

3.2. Discrete Choice Experiments

Complementarily, we used the DCE approach to elicit the WTP of the general population to avoid the environmental impacts of WFs. DCE is based on the notion that value is derived from the specific attributes of a good, in accordance with Lancaster (1966) characteristics theory of value. This survey-based approach asks respondents to choose their preferred option out of a series of sets of alternatives that differ by the attributes/levels included. In each choice task, respondents trade off changes in attribute levels against the associated cost (Hanley *et al.*, 1998, 2001; Bateman *et al*., 2002; Pearce *et al*., 2006).

The chosen attributes resulted not only from extensive literature review but also from pilot questionnaires and focus group discussions. The final configuration of the choice sets included the following attributes: landscape, noise pollution, impacts on fauna and flora, and. To be able to transpose those impacts into monetary terms, as per the methodology, we included a price attribute as an increase in the monthly electricity bill. Following the exploratory study the price attribute had three levels (4, 8 and 12 Euros).

Similarly to the CV approach, the DCE questionnaires were also divided in four parts. First, the degree of respondents' familiarity with RES was assessed in an introductory part. Second, there was the choice experiment section, in which individuals were presented with six choice sets, each consisting of a choice between two alternative ways of producing electricity through wind, differing on the levels of specific attributes. Due to its key role in the questionnaire, we present, for illustration purposes, one of the six choice sets given to respondents:

Table 1: Choice Set Example

Consider the choice between form A of electricity generation through wind and form B of electricity generation also through wind. Tick your preferred option:

	Form A	**Form B**
Significant impact on the landscape	No	Yes
Significant impact on the Fauna/Flora	No	Yes
Produces noise affecting population	Yes	No
Increase in the monthly electricity bill €	4	12
Your choice	☐	☐

Then, respondents were presented with two additional sections with questions on respondents' preferences and opinions on different energy sources (section 3) and to gather information on the individuals' socio, economic and demographic characteristics (section 4). The questionnaire was subject to an interactive test and review process using pilot studies explained in Botelho *et al.* (2014).

4. RESULTS

4.1. Local Residents

During May 2014, a total of 57 questionnaires were collected in the vicinity of three WFs: Arga, Lousã II and Negrelo & Guilhado (25, 12 and 20, respectively). The sample has the following socio-demographic characteristics: 66% have education at the primary school level, 50% are retired, 49% are males, mean age is 60 years old and the mean household monthly income per person is approximately 252 Euros. The most frequently identified environmental problem in Portugal is the waste followed by water pollution and air pollution; most respondents know that wind farms, hydropower and photovoltaic are used to produce electricity, however of these sources, photovoltaic energy is considered the least environmentally friendly. Almost all respondents (98%) consider Portugal a country with good conditions for developing renewable energy sources in the production of electricity and consider that renewables bring benefits to the population. In particular, half of respondents mention reduction of the external dependency of the economy as a benefit, followed by generation of employment. Respondents also associate renewable energy with positive environmental effects. Average monthly electricity bill of respondents was approximately 72 Euros. Regarding the respondents' relationship with the specific WF, for 95% of them it is visible from their home, and the effects on landscape and noise are identified as negative. The majority of the respondents (95%) stated a

positive WTA compensation amount (37.95 Euros on average), ranging from 2 to 200 Euros per month.

WTA data collected with the CV method could be interpreted as being generated by two decision' processes. First the respondent decides if he or she is entitled to compensation and then decides the amount of compensation, in integer positive numbers. In addition, it is typically the case of excess zeros. Accounting for the nature of the data, a mixture model should be used. As such we use a mixture model, in particular a zero-inflated negative binomial model to identify the determinants of respondents' WTA amount. According to this specification, the variables determining the decision to be entitled for some compensation need not be the same as those determining the decision on the specific amount. The explanatory variables were selected based on previous empirical applications. However, perfect and imperfect correlation between explanatory variables and estimation feasibility requires some adaptations. The first panel of Table 2 reports the results on the decision to receive compensation, while the second panel reports the results on the amount of compensation demanded.

Table 2: Zero-inflated negative binomial model

		Explanatory Variables	**Coefficient** (robust stdev)
Dependent Variables	**WTA yes/no**	Annoyance	-17.8136*** (0.7209)
		Constant	-2.5567*** (0.6895)
	WTA amount	Incomepc	-0.0008 (0.0007)
		Age	-0.0164* (0.0097)
		Noise Annoyance	0.0259 (0.0858)
		Lousã	-0.0507 (0.4370)
		Vila Pouca Aguiar	0.5317** (0.2755)
		Constant	4.4761*** (0.5736)
		Ln(alpha)	-0.5890*** (0.1890)
N: 57 (zero=3); Wald chi2(4) 9.85*			

Note: *significance level of 10%; **significance level of 5%; ***significance level of 1%

Variables definition: Annoyance: reported degree of annoyance caused by WF (5 point scale); Noise annoyance: reported degree of annoyance caused by noise produced by the WF; Incomepc: reported household income per person.

According to the results presented in the Table 2, it is clear that annoyance is a very important determinant of the decision to be compensated for the environmental negative impacts of the presence of the wind farm, although we would expect a different and positive effect. Regarding the amount of compensation, location and age are significant determinants, with residents in Vila Pouca demanding on average higher amounts of compensation than residents near Arga and Lousã. Older respondents demand, on average, lower amounts. Based on the regression model we predict that the amount of compensation would be on average 34.8 Euros per month, specifically 28.6 Euros in Arga, 34.6 Euros in Lousã II and 42.8 in Vila Pouca Aguiar. The reduced size of the sample collected, resulting from the fact that the villages near wind farms have very few residents, requires some caution in interpreting the results but it does not preclude drawing some implications from the analysis. In particular the amount of compensation demanded is location specific, on average; and, socio-demographic characteristics play some role is the amount of compensation demanded.

4.2. Non-Residents

A stratified random national sample of 250 respondents was selected and questionnaires administered during the first semester of 2014 by a data collecting firm. Respondents are on average 52 years old, 44% of the respondents are male and 38% are retired. Most respondents are married and have secondary level education. In terms of respondents' environmental concerns, air pollution (55%) is identified as the most significant environmental problem in Portugal, followed by waste (45%) and water pollution (40%). According to the data collected, most respondents are familiar with production of electricity through renewables, except for biomass, and consider all sources environmentally friendly and most consider they bring benefits for population. To assess the concern of respondents in renewable energies, they were asked whether they had an interest in knowing the type of energy source used in the production of the electricity they consume, and in fact only 2% did not care about the origin of the electricity. The average monthly electricity bill paid by respondents is 69 Euros. Regarding the choice tasks, 41% of respondents indicated that they considered all attributes during their choices.

Table 3: Binary logit model (with cluster correction)

		Partial effects (stdev)	**Mean WTP** (stdev)
Variables	**Landscape**	-0.1062*** (0.0221)	3.1509*** (0.7675)
	Fauna/Flora	-0.2696*** (0.0272)	7.8035*** (1.2952)
	Noise	-0.2368*** (0.0257)	7.30997*** (1.3036)
	Price	-0.0334*** (0.0040)	------
Log likelihood function			-1858.4726***

Note: *significance level of 10%; **significance level of 5%; ***significance level of 1%

In the present DCE, individuals are asked to choose between two alternatives (each corresponding to a specific *form of electricity generation through wind* production), sequentially six times. The dependent variable is hence a binary variable and each individual is observed repeatedly. Accounting for the nature of the dependent variable, we specify a binary logit model with cluster correction to estimate the partial effects of the attributes on the response probability of an alternative. Table 3 reports the results, and we conclude that all the attributes describing the wind energy source have a negative and statistically significant influence on the utility of an alternative. As expected, the impact on the fauna/flora, on the landscape, the emission of noise and the price (in the form of an increase in the value of the monthly electricity bill) are significant determinants associated with the disutility due to the production of electricity through wind farms. Moreover the most important determinant is the impact on fauna and flora, followed by the impact of noise, while the impact on the landscape appears in the third place. Predictions for respondents' WTP to avoid environmental impacts range from 3.15 Euros per month to avoid significant impacts on the landscape, to 7.80 Euros per month to avoid significant impacts on the fauna/ flora. Respondents' predicted average WTP to avoid production of noise that significantly impacts the local population is approximately 7.31 Euros, thus very close to the value attributed to the impact on fauna and flora.

4.3. Comparing Results

The application of the CV and DCE methods allowed the estimation of the WFs' welfare effects by two distinct stakeholders: the local residents who are directly affected by the negative effects caused by the activity of the WFs installed in the surroundings of their residences; and the population in general who potentially benefit from the advantages of the use of wind for electricity generation (e.g., lower CO_2 emissions) and thus experience welfare benefits. The most relevant difference of the two samples regards income, age, and education, with local residents being older and less educated.

Through the CV method, we were able to predict that the compensation amount demanded by local residents would be on average 37.95 Euros per month. On the other hand, the application of the DCE method among the general population allowed us to conclude that, on average, respondents are willing to pay between [3.2 Euros; 7.8 Euros] depending on the impact considered. Thus, as the number of residents to be compensated are those residing close to the installations, while those willing to pay for compensation are the entire population, it is safe to conclude that the welfare benefits more than compensate the costs and thus, without considering equity issues, the use of WFs for electricity generation is potentially welfare improving.

5. CONCLUSIONS

The use of wind power for electricity generation has unquestionable environmental advantages, particularly if compared with the use of fossil fuels. Nevertheless, several adverse impacts have been associated with the operation of WFs, affecting individuals' wellbeing. In this study, based on the application of two stated preference methods, the CV and the DCE, we were able to value the welfare effects of the environmental impacts caused by the activity of WFs by two distinct stakeholders: local residents and the general population. Among the local residents, we estimated the minimum monetary amount demanded as compensation for the negative impacts

caused by the proximity of three Portuguese WFs (on average 37.95 Euros per month). On the other hand, among the general population in continental Portugal, we computed the value of each environmental impact caused by the activity of WFs, by asking individuals the monetary amount they were willing to pay in order to have electricity generated by WFs, but with the possibility of avoiding specific adverse impacts. The values obtained ranged from 3.2 Euros to 7.8 Euros per month, depending on the impact considered. The results of this paper confirm the relevance of considering the environmental impacts of WFs in the siting decision process. Moreover, as the impacts depend on the site and location of the WFs, policy makers should use this information to integrate these parameters into their decision-making process, otherwise adverse impacts are merely acknowledged rather than fully considered in economic terms.

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TO BE LINEAR OR NOT LINEAR, THAT IS THE QUESTION: A NEW LOOK OVER THE FINANCIAL DEPTH NONLINEARITY: EVIDENCE FROM EUROPE

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ABSTRACT

The nonlinear relationship between Economic Growth and Financial Depth was assessed with a panel of 25 European countries, for the period between 1996 and 2011. These countries share common spatial patterns as was confirmed by the presence of cross-sectional dependence. Furthermore, heteroskedasticity and first order autocorrelation are present in the panel. The Hausman test supports the presence of heterogeneity by selecting the fixed effects model. In accordance, the robust estimator to this phenomena, the Driscoll and Kraay with fixed effects, was used. The nonlinearity of the relationship was confirmed by the *U-test* of Lind and Mehlum. In short, results confirmed that excess of financial development constraint growth for the European countries. The optimal dimension of financial sector should be considered by policymakers.

Keywords: Financial Depth, Panel-data Analysis, Nonlinearity, U-test

1. INTRODUCTION

The relationship between FD and EG was remounts to the early of *XIX* century, when Schumpeter (1912), Robinson (1952), Goldsmith (1969), McKinnon (1973) and Shaw (1973) were, among others, the firsts to document this issue. These former seminal literature on FD reveals a lack of consensus that is persistent. Indeed, financial intermediaries could promote economic efficiency which leads to the EG (Levine, 1997), or could lead to the reverse (e.g. Demetriades and Hussein, 1996). Moreover, the impact of Financial Depth (FD) on Economic Growth (EG) remain a hot topic in literature. The literature evolved to capture the relative dimension of finance in the economy. This financial dimension, has been used in research throughout indicators

such as size of banks, financial institutions and financial markets. Indeed, the FD can be aggregated and related to output.

The nexus of FD-EG remains largely inconclusive to the economies. This lack of consensus materializes on causality direction and it type of specifications. The main objectives of this paper are: (*i*) is there a relationship between EG and FD in Europe; and (*ii*) if this relationship subsists, what is the functional form. It is important to consider this nexus in order to understand the impacts on economy and evaluate if there is some kind of threshold where FD promotes a slower EG.

To disentangle the nexus FD-EG in developed economies, the European Union countries which have available data in the span of time was used. The model included variables such as Gross Domestic Savings, ratio of private sector credit to Gross Domestic Product to measure FD, governmental expenditures, commercial balance, electric consumption and inflation in order to control other interactions that are necessary for FD-EG nexus analysis. Particular attention was provided to the construction of the variable which measures the FD and robust econometric techniques were used. We innovated by adding the dimension of energy consumption to the nexus. The Hausman test selected Fixed Effects model as the most suitable for the estimation. Heteroskedasticity and cross sectional dependence for the counties panel was found, and in accordance the Driscoll and Kraay (1998) estimator was used. Commercial balance, government expenditures, and electrification are drivers for growth. By the reverse, a negative effect occurred to inflation, and to FD. An inverted U – shape form was confirmed for FD through the *U-test* from Lind and Mehlum (2010).

The rest of the paper is organized as follows: Section 2 review of the literature. Section 3 describes data. Section 4 center on empirical methodology. In section 5, the results are discussed. Section 6 concludes.

2. LITERATURE REVIEW

In the last century, FD and EG received several contributions. Since the first approach by Schumpeter (1912), Robinson (1952), Goldsmith (1969), McKinnon (1973) and Shaw (1973) that the literature tries to provide sustained theories to explain the FD-EG nexus. Economic theory suggest that FD has a significant role on growth. In fact, when the number of financial institutions and instruments increases, this contribute to reduce the information and the transactions costs. Thus, developed financial markets help economic agents to trade and diminish transaction risks. These conditions increase the investments and stimulates economic growth (Masten et al., 2008). However, the existence of some constraints, such as geographic, temporal, financial and methodological conditions, allows to reveal a nonlinearity (De Gregorio and Guidotti, 1995). The former authors, along with Demetriades and Hussein (1996) were the first to document the nonlinearity in the FD-EG nexus.

Berthelemy and Varoudakis (1996) introduced the concept of limits to FD. Based on this former study, Rioja and Valev (2004) split countries into groups and established critical values to the limits. This allowed them to determinate the different phases of the impact of FD on EG. Following this path, we can find in first instance that it is necessary to achieve a minimum of financial development value to register EG.

Subsequently, especially in smaller economies, there is a sharp increase in EG, followed by a steady state of the process and, finally, a downward in the process, i.e., FD promotes the corrosion of EG. In the literature, authors also find an absence of the impact on economic growth of financial depth (See Greenwood and jovanovic, 1990; Lee, 1996; Acemoglu and Zilibotti, 1997; Deida and Fattouh, 2002; Rioja and Valev, 2004; and Kim and Lin, 2011).

Stablishing the threshold where FD-EG becomes negative when go beyond a percentage of GDP is a common practice in the literature. The Domestic Credit provided by Banking Sector (*DCBS*) to output critical value is around 90% (Cecchetti and Kharroubi, 2012; and Law and Singh, 2014) and for the ratio of private credit to GDP this limit is 110% (Aracand et al., 2012). The size of countries is also an important factor to stimulate EG. Countries with lower income levels, get EG through capital accumulation, are more qualified to generate growth through FD than those which generate EG from increasing productivity, i.e. with higher levels of income (e.g. De Gregorio and Guidotti, 1995; Deidda and Fattouh, 2002 and Rioja and Valev, 2004).

For Bumann et al. (2013) financial liberalization and development of financial markets have a positive impact on EG. However these two subjects are related and share a common concern, both can promote EG or the reverse, i.e. they are nonlinear. When financial liberalization policies are applied, the financial intermediaries face an upraise of asymmetric information and a cut on profit margins which may conduct to a financial crash (e.g. Hellmann et al., 2000; Bumann et al., 2013). Financial markets can also constrain EG by putting extra pressure on banks. Banks respond with lower interest rates, conducting to a change of consumption habits (Carreira and Silva, 2010). Small interest rates rise the current consumption and lower savings, allied to the retrenchment of investment conducts to low EG rate.

Using cross-country approach, the literature highlights the importance of FD to EG. Guiso et al. (2004) points that the development of financial markets through financial integration is important to achieve growth. Rioja and Valev (2004) identified different levels of relationship between EG and FD inside of the same country. Deidda and Fattouh (2002) find a significant impact of finance on growth to high income countries and insignificant to low income.

More recently, literature has been focusing this issue of a nonlinear relationship between FD-EG nexus. Arcand, (2012) and Samargandi et al. (2015) have similar results, as FD promotes EG but only to a certain point. Moreover, FD has a positive impact on growth at long run but negative on short-run (Loayza and Ranciére, 2006). This trend means that at a certain point we start having excess of financial growth, eroding EG and politicians need to introduce measures to reverse this process. The impact on economic growth of financial depth appears to fade away over time. Samples with longer time spans, feature higher significance of the FD on EG while in recent samples are less significant (Rousseau and Wachtel, 2011). The scarce literature on developed countries involving electrification as a measure of economic sophistication inspire the present study.

3. DATA DESCRIPTION

For the analysis of FD-EG nexus in developed countries, was used annual frequency data from 1996 to 2011 for a group of European countries that shares strong financial integration, namely Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Estonia, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Italy, Lithuania, Latvia, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Spain and Sweden. The chosen period and countries, results from the data restrictions and the tradeoff between more years and less countries or the reverse. This choice results in the exclusion of Austria, Slovakia and Luxembourg of the analysis.

In the literature, there is a lack of consensus in which variables should be used to measure FD and EG mainly due to the body of studied fields, the time periods or, the group of countries analyzed (e.g. Ang and McKibbin, 2007; Jalil and Feridun, 2011; Kim and Lin, 2011; Singh and Huang, 2011; Rewilak, 2013; Samargandi et al, 2015). The study begun with the commonly used variables in the FD literature and the electrification as a proxy of economic development.

To check the FD-EG nexus in Europe was used as dependent variable the Gross Domestic Product *per capita* at constant 2005 US$ (*GDPPC*). Additional independent variables were introduced, namely Domestic Credit Provided by Banking Sector (*DCBS*), Domestic Credit Provided by Private Sector (*DCPS*), Commercial Balance (*TRADE*), General Government Final Consumption Expenditure (*GOV*), Electrification (*E*) and Inflation (*CPIINF*). The first two independent variables, as explained later, are aggregated to measure *FD* (forming FD2SQ), *TRADE* and *GOV* are used to determine fiscal policy impact, *CPIINF* controls price distortion and a new variable electrification as a proxy of country general economic sophistication, i.e. emulates the absent variables. The variables *GDPPC*, *FD2SQ*, *TRADE* and *GOV* were extracted at the *World Development Indicators* (*WDI*). The *CPIINF* was imported from *Ameco* and Electrification from *Energy Information Administration* (*EIA*). The usage of GOV as final expenditure was employed by following the methodology of Hassan et al. (2011). Moreover, variables were expressed in absolute values and not as a percentage of GDP to be easier in retrieving conclusions. Table 1 summarizes the respective descriptive statistics and the cross-section dependence of the variables. For the variables the prefix "*L*" denotes natural logarithms and suffix "*PC*" *per capita*.

Table 1 - Variables description and descriptive statistics

Descriptive Statistics						Cross section dependence (CSD)		
Variable	Obs	Mean	SD	Min	Max	CD-test	Corr	Abs(corr)
LGDPPC	400	9.7401	0.7785	7.7638	10.8396	63.94***	0.923	0.923
FD2SQ	397	4.4982	5.415	0.0202	35.1393	50.14***	0.73	0.83
LTRADEPC	399	9.6539	0.8143	7.4683	11.3314	60.28***	0.872	0.872
LGOVPC	399	8.1070	0.9159	5.2212	9.5223	58.58***	0.848	0.848
CPINF	400	4.9565	14.295	-4.5897	244.96	22.66***	0.327	0.37
LEPC	400	-12.23	0.4755	-13.204	-11.0089	41.90***	0.605	0.684

Note: CSD test has N(0,1) distribution, hunder the H0: cross-section independence. ***, denotes the level of significance of 1%;

Building a variable to measure FD requires some cautions. Financial services are provided by several institutions and likewise to capture fully the financial sector is far from obvious. The literature suggests at least three ways to measure FD, all of them measured as ratios, due to minor the likely high multicollinearity between variables: (i) Ratio of *M2* or *M3* to GDP: the monetary aggregate captures the net liabilities of financial system. This measure of FD has the inconvenience of ignoring the transaction power of channeling funds from the financial sector deposits to investors (Ang and McKibbin, 2007); (ii) Ratio of private sector credit to *GDP*: corresponds to the sum of *DCBS* with *DCPS* to *GDP*. This ratio captures the credit extended to the private sector, allowing the use of funds on more productive activities (Samargandi et al. 2015). This ratio may also capture the differences between credit conceded to state firms or government, and private firms to stimulate growth (King and Levine 1993); (iii) Ratio of commercial bank assets to the sum of the same assets with central bank assets: this variable captures the dimension of the commercial banks in the financial system. This variable is used when is presumed that the commercial banks are more efficient in channeling funds to more profitable investments than central banks (Ang and McKibbin, 2007); and (iv) Principal Components analysis: This multivariate data analysis method extracts indexes and aggregates them into a new variable. The proposal of this method is retaining significant data variation without correlation problems (Çoban and Topcu, 2013). To measure the FD, the former ratio (ii) was used. The following reasons justify the exclusion of the other ratios. The ratio (i) produces non-significant estimations, most likely as they only reflect the ability of transaction services delivered by the financial system (Samargandi et al., 2015). The Ratio (iii) and (iv) restricts the time period and with the concern of having a strongly balanced panel data we exclude these hypothesis.

Was used a polynomial shape of ratio (ii) to capture the nonlinear effect of the FD. A high ratio of FD means a bigger dependence of financial system. *A priori* we expected to capture a nonlinear effect of FD on growth. Indeed, it is not plausible achieve economic growth only through the growth of financial system. Moreover, current studies have shown that the effect of the financial system vanishes with time (e.g. Arcand et al., 2012; Law and Singh, 2014). The econometric analysis was performed using *Stata* 13.1 software.

4. METHODOLOGY AND PRELIMINARY TESTS

It is well known that European countries share several common features. Therefore, panel data techniques are appropriate to control of individual heterogeneity and unobserved characteristics of errors but requires attention to these phenomena. Following similar methodology pursued for Marques and Fuinhas (2012), diagnostic tests were applied to assess the presence of phenomena of colinearity, multicolinearity, autocorrelation, cross-sectional dependence (*CSD*) and heteroskedasticity. Regarding the colinearity assessment, both the correlation matrix and the Variance Inflation Factor (*VIF*) are provided at table 2. The presence of colinearity was assessed both from the correlation matrix and the individual and mean *VIF*.

Table 2 - Correlation matrix and *VIF* statistics

	LGDPPC	FD2SQ	LTRADEPC	LGOVPC	CPIINF	LEPC
LGDPPC	1.0000					
FD2SQ	0.484346	1.0000				
LTRADEPC	0.8828	0.4631	1.0000			
LGOVPC	0.9743	0.4687	0.8805	1.0000		
CPIINF	-0.3516	-0.1476	-0.3304	-0.3758	1.0000	
LEPC	0.7610	0.1916	0.7110	0.7828	-0.2062	1.0000
VIF		1.47	4.58	6.67	1.20	3.01
Mean VIF			3.39			

The Wooldridge test confirms the presence of autocorrelation of first order. The *CSD* was assessed through Pesaran, Friedman, and Frees test. These tests were applied instead of Breusch-Pagan LM test due to the characteristics of the sample, more crosses than time (Hoyos and Sarafidis 2006). The results are inconclusive both to *FE* model and to *RE* model. Pesaran and Friedman tests indicates the presence of *CSD* on contrary to the Frees' test outcome. The Hausman test with the null hypothesis RE model as best option, was used to choose between RE and FE model. This test points for the FE model as the most suitable. Moreover, as the statistically highly significant Hausman p-value ($\chi_5^2 = 36.33$) supports the null hypothesis rejection. At last, the modified Wald test revealed the presence of heteroskedasticity. Table 3 summarizes the results of the tests.

Table 3 - Diagnostic tests

	Pooled	FE	RE
Wooldridge test	146.977***		
Pesaran		5.323***	4.711***
Friedman		47.029***	44.375***
Frees		4.695	4.561
Wald		5092.09***	

Note: ***, represents the level of significance of 1%; the command *xtcsd* with options Pesaran abs, Friedman abs, and Frees abs was used to test *CSD*

Given that the detection of CSD (table 1), the appliance of first generation unit root tests is unnecessary. Indeed, to apprise the order of integration of variables, the second-generation unit root test of the CIPS (Pesaran, 2007) was carried out. This test is robust to heterogeneity under a nonstandard distribution. From the CIPS test, the variables are integrated series of order zero I(0). Table 4 shown the results of unit root tests.

Table 4 - Unit Root test

Variables	LGDPPC	FD2SQ	LTRADEPC	LGOVPC	CPIINF	LEPC
CIPS (Zt-bar)	-3.077***	-1.772**	-1.700**	-2.257**	-4.729***	-1.394*

Note: ***, **, * denotes significance at 1%, 5% and 10%, respectively; Pesaran (2007) Panel Unit Root test (CIPS): series are I(0); lag(1) and no trend specifications were used

The results of diagnostic tests (table 3) appoints Driscoll and Kray (1998) as the most suitable estimator. Moreover, this estimator has the advantage of no restrictions on the size of crosses and time dimensions.

The follow model specification was used:

$$\begin{aligned} LGDPPC_{it} &= \alpha_{1i} + \beta_{11i} FD2SQ_{it} + \beta_{12i} LTRADEPC_{it} \\ &+ \beta_{13i} LGOVPC_{it} + \beta_{14i} CPIINF_{it} + \beta_{15i} LEPC_{it} + \varepsilon_{1it}, \end{aligned} \tag{1}$$

where a_i denotes the intercept and e_1 the error term.

After the model estimation, the *U*-test was applied to check the robustness of the results. This test has the advantage of detecting the form of the relationships between variables, i.e. in *U* or inverted U-shape through an explanatory variable and a quadratic term.

5. RESULTS AND DISCUSSION

The DK, FE and the FE Robust only correct parameters standard errors. Therefore, equal coefficients are expected. Table 5 synthesizes the main estimators used. We use *RE* model as a benchmark.

Table 5 - Results from the estimators

Dependent variable LGDPPC				
Models	DK (I)	FE (II)	FE robust (III)	RE (IV)
Constant	8.24706***	8.24706***	8.24706***	7.60679***
FD2SQ	-0.00424***	-0.00424***	-0.00424***	-0.00451***
LTRADEPC	0.36422***	0.36422***	0.36422***	0.35365***
LGOVPC	0.28160***	0.28160***	0.28160***	0.32689***
CPIINF	-0.00050**	-0.00050**	-0.00050	-0.00039**
LECPC	0.35043***	0.35043***	0.35043***	0.31963***
Statistics				
N	396	396	396	396
R^2	0.9159	0.9159	0.9159	0.9152
F	5711.02	797.17	130.27	

Note: ***, **, * denotes significance at 1, 5 and 10%, respectively; On Stata the DK estimation was carried out with the command *xtscc with options* FE and lag (1)

The results for FD-EG nexus of our model, for Europe, have the same nature as Samargandi et al. (2015) for middle income countries and Arcand et al. (2012) for lower income countries. Therefore, it seems to be that the nexus results are common on the world. As revealed in table 5*, FD2SQ* has a negative and statistically significant coefficient for all estimations. This could result from: (i) The threshold proposed by Arcand et al. (2012) of 110% was overpassed in the ratio of private credit to GDP or 90% in DCBS to GDP; (ii) Existing countries exclusively classified of upper middle income or high-income. As enunciated before, high developed countries have been revealed a slower pass-through from FD to EG.

The Inflation can exert a positive or negative impact on growth. Moreover, the effect can be positive, resulting from the excess of demand and provoking a persistent rise of prices and potentially stimulates the production, or negative due to the fact of measuring economic instability. Attending to the selected group of countries, a negative coefficient was expected and detected. This result indicates that the instability effect is predominant over the excess of demand. A low inflation provides macroeconomic stability and therefore stimulates EG. Other effect could be associated to the negative signal, i.e. suggests that volatility depress growth contrary to the prevalence of a possible monetary illusion. Electrification *(LEPC*) has a positive effect on EG. Indeed this variable embody the effect of both energy, as a resource and as an economic sophistication/development. Indeed, in general a sophisticated economy is more electrified. Commercial balance (*TRADE*) contributes positively for the GDP*.* As expected, when countries open this induces EG. The *GOV*

variable has a positive coefficient too. This former result is the expected because when a government use fiscal policy it provoke EG (Devarajan et al., 1996).

As mentioned before, a quadratic condition was imposed to FD. The exclusive introduction of *FD2SQ* instead of both variables is related with the multicolinearity between them. The estimations solely with *FD*, produce significant and positive coefficients, while with the quadratic term the coefficients are significant and negative. This reinforces the nonlinear relationship between FD and EG. The *U-test* was carried out to confirm the existence of an inverted U–shape (command *utest* with option *quadratic* was used). Table 6 show the results.

Table 6 - U–Test

	Statistics
Lower bound slope	0.41540***
Upper bound slope	-0.24781***
Global test for inverted U-shape	8.45***

Note: *** denotes significance at 1%; H0: Monotone or U-shape; H1: Inverse U-shape.

The null hypothesis of monotone or U-shape was rejected by the U-test, confirming an inverted U-shape between FD and EG. This result means that the use of polynomial shape on FD was relevant. The results found for Europe are consistent with other group of countries, namely lower income and middle income countries, i.e. excess of FD can hamper EG (e.g. Rousseau and Wachtel, 2011; Law and Singh, 2014; Samargandi et al., 2015). Data panel with the Driscoll and Kraay model and U–test confirm the nonlinear relationship between FD and EG. The origin of this phenomenon could be related with financial liberalization from latter 90's. In fact, liberalizing this sector might provoke instability by restricting markup, raising information asymmetries and competition. Indeed, economies are more exposed and prone to financial crashes resulting in negative contributions of FD to EG (Bumann et al., 2013). Financial liberalization encourages another impact. Due to this process of liberalization, markets are pressured to reduce interest rates, encouraging an increase of non-productive consumption and lower levels of investments. An economy focused on present consumption promotes a lower impact of FD in EG. The electrification revealed to be a driver of EG. The analysis of this nexus suggests the necessity of comprehensive models. Indeed, variables such as *TRADE*, *GOV*, inflation and electrification need to be considered.

6. CONCLUSION

This paper contributes to the literature by analyzing the nonlinearity between FD and EG in Europe. The measure of FD consubstantiated in the ratio of private sector credit to GDP revealed to be an effective driver of EG.

The estimator of Driscoll and Kraay with FE was used to 25 European countries for the period from 1996 to 2011. A negative coefficient was found for FD and inflation. Moreover, commercial balance, general government final consumption expenditure, and electric consumption have a positive effect on EG. Addressing the *U–test*, we confirm the presence of an inverted U-shaped between FD and EG, i.e at long run,

finance harms growth so it is necessary to inverse the tendency. In fact, policies aimed to growth of the financial system are ineffective and imprudent. Policymakers must found an optimal dimension to FD and avoid overpassing it. Likewise, liberalization policies to provide bank competition and cut the excess of power on financial sector are recommended to avoid a negative effect of FD on EG. Instead of being worried with the growth of the financial sector, policymakers should be worried with his development.

The research in this area will benefit from the extension of the analysis to other blocks of countries, and different time spans. Instead of financial proxies the Principal Component Analysis could be used on future studies. Furthermore, the role of electrification in the context of FD and EG need to be more scrutinized.

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ASSESSING ENVIRONMENTAL IMPACTS OF PHOTOVOLTAIC FARMS IN PORTUGAL: A STATED PREFERENCE APPROACH

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ABSTRACT

Photovoltaic energy for electricity generation has developed considerably in recent years. In countries with high solar radiation indices, as in the case of Portugal, this energy source can be expected to play a significant role in the electricity production mix. The benefits of using this renewable energy source are undeniable, in particular in its contribution to reaching the European and Portuguese climate change goals. However, the operation and expansion of photovoltaic farms causes environmental impacts, which, unlike the benefits, only affect nearby local communities. Some of the environmental burdens that have been identified are: land use impacts, eventual reduction of farmable land, thermal pollution, fragmentation of the countryside, landscape intrusion, impacts on fauna and flora, glare effect, and electromagnetic interference. Given the asymmetry of the welfare effects expected from the construction of new photovoltaic farms, or extension of the existing ones, it is important to devise methodologies capable of integrating the welfare impacts on these two groups of stakeholders: the general population, who accrue the benefits, and local communities, who bear the costs. The main objective of this paper is to propose and test a novel approach to fully acknowledge these opposing interests and welfare impacts and thus overcome limitations in conventional analyses that fail to account for them. We propose to elicit local residents' and general population's welfare impacts from the presence of photovoltaic farms through the application of two stated preference methodologies, commonly used when valuing environmental goods and services: the contingent valuation method and discrete choice experiments. The former was applied to residents in the vicinity of selected photovoltaic farms installed in the region of Alentejo (Portugal): Hércules, Amareleja, and Ferreira do Alentejo. The latter method was applied among the general population. Our results show that local residents are encumbered by the presence of the photovoltaic farms, and demand significant amounts of compensation. In

addition, members of the general population are willing to pay as compensation significant monetary amounts, which, attesting to the methodology's validity, differ depending on the specific environmental impact considered. As a conclusion, this study underlines the importance of not only acknowledging, but also taking into full consideration (in economic terms) the equity implications of photovoltaic projects when deciding their construction and location.

Keywords: Photovoltaic Farms, Stated Preference Methods, Contingent Valuation, Discrete Choice Experiments, Environmental Impacts, Public Attitudes.

1. INTRODUCTION

The use of solar photovoltaic farms (henceforth PVFs) to produce electricity has increased in the last few decades. There are several advantages to using this energy source when compared with other sources, in particular relative to fossil fuels. One noteworthy example concerns the absence of greenhouse gases emissions during operation, thus contributing to European and Portuguese climate change goals. Also, solar photovoltaic energy explores an endogenous resource, reducing the external dependency of the economy. Since it is a location-specific resource (farms should be installed where the number of hours of sun is greatest), it may in this fashion contribute to local development. Finally it is a renewable resource and thus easily used in a sustainable fashion.

However, the activity of PVFs is also responsible for causing environmental burdens, which are experienced locally, namely land use impacts (e.g. Sarlos *et al.*, 2003; Lackner and Sachs, 2005), possible reduction of farmable land (e.g. Tsoutsos *et al.*, 2005; Srinivasan, 2009), thermal pollution (Gunerhan *et al.*, 2009), countryside fragmentation (e.g. Chiabrando *et al*., 2009), landscape intrusion (e.g. Tsoutsos *et al.,* 2005; Torres-Sibille *et al*., 2009), impacts on fauna and flora (e.g. Chiabrando *et al.*, 2009), glare effect (e.g. Clifford, 2013; Rose and Wollert, 2014), and electromagnetic interference (e.g. Chiabrando *et al.*, 2009).

From an efficiency point of view, costs and benefits should be compared and if the former are outweighed by the latter, then the installation conforms to efficiency criteria. Furthermore from an equity point of view it is crucial to analyse the distribution of costs and benefits between groups of stakeholders. In this respect, while the benefits of producing electricity in PVFs are global in their nature, the negative effects are mostly local. Consequently, the distribution of benefits and costs is asymmetric; in particular, local residents experience mostly the negative effects, while the general population receives the benefits.

There should thus be equity considerations, in addition to efficiency considerations in the decision to construct a PVF, and in deciding its location and size, as the presence and severity of the impacts depends on the selected location and size of the farm. To analyse the efficiency and equity of the decision it is crucial that costs and benefits of both local and general stakeholders are considered and that they are expressed in the same unit of measurement. To this end, we applied two stated preference (SP) methods: the contingent valuation (CV) and the discrete choice experiments (DCE) methods. The former method was applied to elicit the welfare effect on local residents of specific PVFs installed in a Portuguese region with a high level of solar radiation exposure, while the DCE method was applied to elicit the

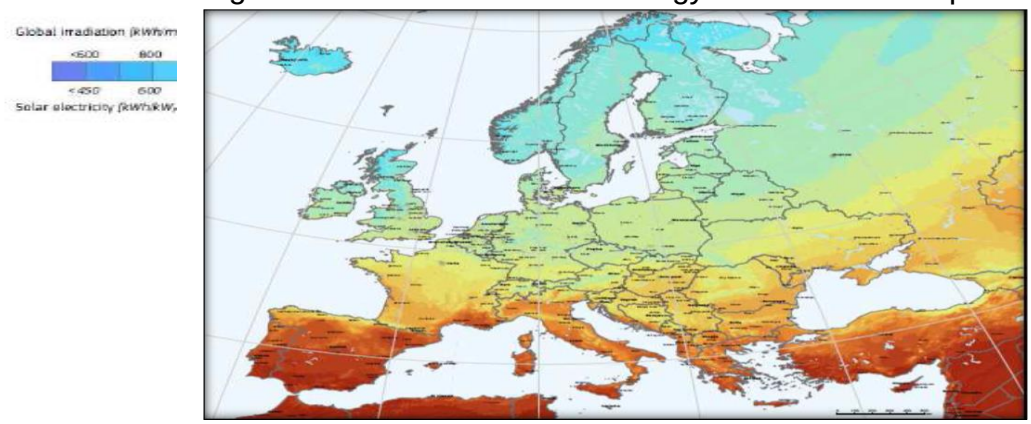
welfare effects among the general population resident in different regions of mainland Portugal.

The reminder of this paper is organized as follows. Section 2 presents the current situation of solar photovoltaic electricity production in Portugal. Section 3 provides an overview of the main methodological issues involved in our two studies, explaining the valuation methods, the survey design and presenting a brief description of the case studies. Section 4 presents and discusses the results. Finally, in section 5 the main conclusions of this paper are presented.

2. SOLAR PHOTOVOLTAIC IN PORTUGAL

The sun annually provides to the atmosphere a huge amount of energy corresponding to about 10 000 times the world energy consumption observed during the same period. In Portugal, the available potential is quite considerable, being one of the European countries with best conditions for exploitation of this resource as shown in Figure 1. The average annual number of hours of sun ranges from 2200 to 3000 on the mainland, and from 1700 to 2200 in the Azores and Madeira, respectively (DGEG, 2014).

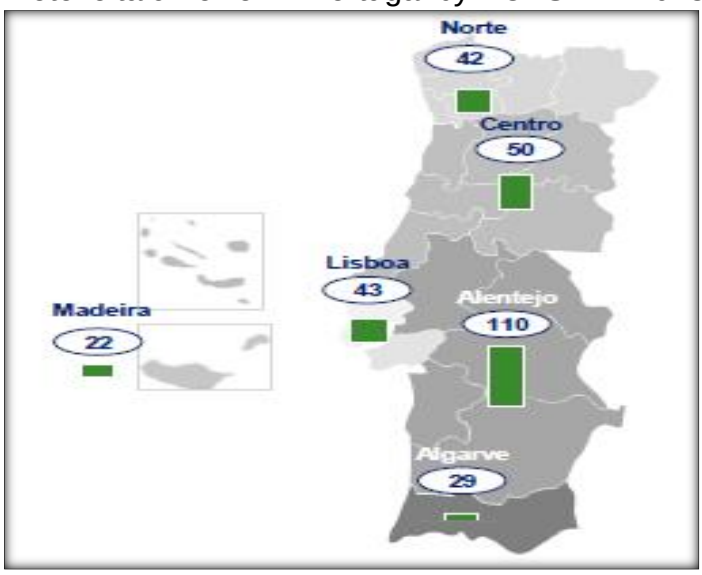
Figure 1: Solar Photovoltaic Energy Potential in Europe



Source: DGEG (2010)

Despite its high potential, photovoltaic (PV) electricity generation is still underexplored in Portugal, with a modest implementation in the country until very recently. Between 2010 and 2013, there was a significant progress in the exploitation of this renewable energy source, with an increase of 122% of the installed PV power. As depicted in Figure 2, in 2013, about 37% of the installed PV power was concentrated in the Alentejo region, followed by the Centre region with about 17%. The remaining regions together accounted for about 46% of installed PV capacity (Deloitte, 2014).

Figure 2: Distribution of Installed
Solar Photovoltaic Power in Portugal by NUTS II in 2013 (MW)



Source: Deloitte (2014)

The installation of PVFs can play an important role in the economic growth of the region of Alentejo which is characterized by low population density, an aging rate above the national average and high unemployment rate (Junqueira et al., 2013). More generally, increased investment in PVFs would contribute to the diversification of the energy mix, to lowering the external dependency of the economy and to the achievement of Portuguese Renewable energy goals.

3. METHODOLOGY

Elicitation of the welfare changes caused by the operation of solar photovoltaic farms requires the application of non-market valuation methodologies as the impacts caused by their operation are not traded in organized markets. In this study we use two valuation methods: the contingent valuation (CV) and discrete choice experiments (DCE). Contingent valuation is applied to elicit the effects on the welfare of the communities in the vicinity of the farms; discrete choice experiments are applied to elicit the welfare impacts on the general population. Both methods are discussed next, as well as the case studies broadly outlined.

3.1. Contingent Valuation

The CV method is a direct survey approach to estimating consumer preferences towards a non-market good or service. Using an appropriately designed questionnaire, a hypothetical (or contingent) market for the good in question is described. This contingent market defines the good itself, the institutional context in which it would be provided, and the way it would be financed. Respondents are then asked to express their maximum willingness to pay (WTP) or minimum willingness to accept (WTA) compensation for a hypothetical change in the level of provision of the good (Mitchell and Carson, 1989; Hanley *et al*., 2001; Atkinson and Mourato, 2008).

In this study, we designed a CV survey with the main aim of estimating the minimum monetary amount respondents would be willing to accept as compensation for all the burdens caused by the presence of a PVF in the proximity of their residence.

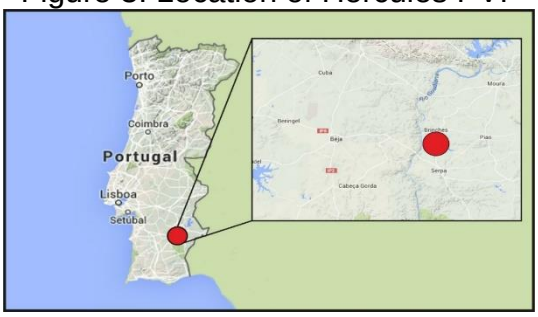
Following Whitehead (2006), each questionnaire was composed of four parts. After an introductory part with general questions on renewable energy sources, part 2 presents specific questions on the production of electricity through PVFs, of which we highlight, for its relevance, the valuation question. Due to the fact that we had no prior information on the distribution of respondents' valuation for choosing the thresholds for a discrete-choice format, this question was formulated as an open question. The payment vehicle chosen was compensation in the monthly electricity bill. Part 3 contains some additional questions on respondents' preferences and opinions on different energy sources, renewable and non-renewable. Finally, part 4 included some questions to gather information on the individuals' socio, economic and demographic characteristics (e.g., gender, educational level, family situation, income, etc.). The questionnaire was subject to an interactive test and review process using pilot studies (Botelho *et al*., 2014).

The elicitation of local residents' welfare changes attributable to the presence of PV farms must be preceded by the selection of specific PV farms. Considering the size and design of the farms three PVFs were selected, all located in the region of Alentejo: Amareleja, Hércules, and Ferreira do Alentejo, The questionnaires were applied during May 2014. In total 60 CV questionnaires were completed, of which 22 were collected in Amareleja, 15 in Hércules and 23 in Ferreira do Alentejo. Sections 3.1.1 through 3.1.3 describe the PVFs.

3.1.1. Hércules PVF

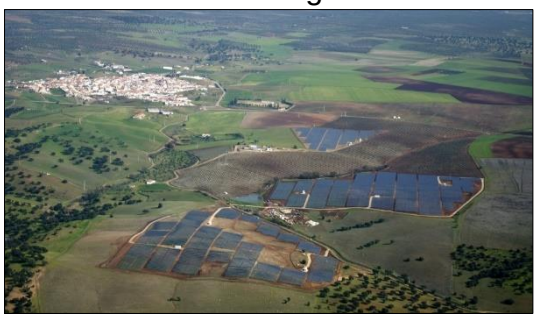
Hércules PV power station is located 200 km southeast of Lisbon, in the agricultural region of Alentejo, more precisely in the parish of Brinches, municipality of Serpa. At the time of its inauguration in 2007 it was the first large PV plant to be installed in the country, generating enough electricity to power up to 8000 homes. It occupies an area of 60 hectares, among olive trees on hillside pasture, and it was built with the concern of maintaining farmland productivity. Furthermore, panels were mounted two meters off the ground, allowing sheep to graze on the grass below (Maso, 2007; DGEG, 2007; GE Energy Financial Services, 2007). Figures 3 and 4 present the exact location and a panoramic image of the Hércules plant, respectively.

Figure 3: Location of Hércules PVF



Source: Authors` elaboration

Figure 4: Panoramic Image of Hércules PVF



Source: Maso (2007)

After eight months of construction, the project began feeding Portugal's electricity grid in January 2007. GE Energy Financial Services owns the facility; Power Light Corporation designed the plant's PowerTracker system, and Catavento, S.A., a major Portuguese renewable energy company, developed the project and is providing management services. The facility consists of a ground-mounted PV system that uses silicon solar cells to convert sunlight directly into energy. The use of the "PowerLight PowerTracker System", following the sun as it moves across the sky throughout the day, increases the system's efficiency by permitting more than 200 kWp to be controlled by a single motor with a rated power of only 0,5 KW (Maso, 2007; DGEG, 2007; GE Energy Financial Services, 2007).

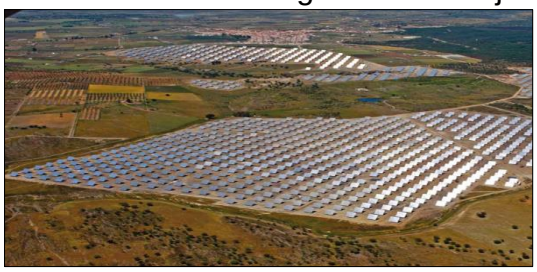
3.1.2. Amareleja PVF

Amareleja PV plant is installed in the small parish of Amareleja, in the municipality of Moura, one of the most inner districts of Portugal, located on the border with Spain and in the right bank of river Guadiana. The Amareleja parish is one of the largest of Moura, with 2564 inhabitants and has the particularity of having the highest sun exposure of the country, a determinant factor in the siting decision of the project (Junqueira et al., 2013). Figures 5 and 6 show the exact location and a panoramic image, respectively, of the Amareleja PV plant, in which it is evident its large dimension, occupying a total of 250 hectares of land.

Figure 5: Location of Amareleja PVF

Source: Authors` elaboration

Figure 6: Panoramic Image of Amareleja PVF



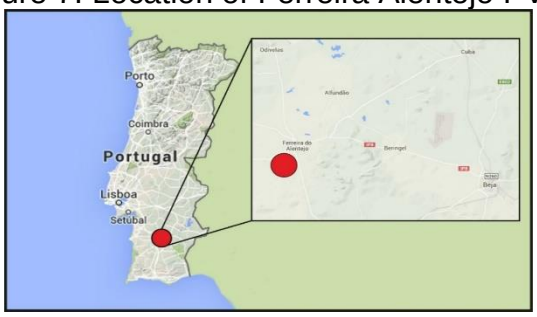
Source: ACCIONA: http://www.acciona-energia.com/activity_areas/solar_photovoltaic/installations/plantaamaraleja/amarelej a-plant.aspx?id=2&desde=

The Amareleja PV plant was considered at the time of its inauguration, in 2008, the world's biggest, producing enough energy to supply around 30000 homes a year. This facility is owned and operated by ACCIONA, a Spanish multinational company with a prominent position in the area of renewables. Despite having created 350 jobs during the plant construction, its operation only requires 15 employees. With the aim of adding value to the local community, the initial project also foresaw the construction and operation of a solar panel manufacturing plant to be installed on the Tecnopolo of Moura industrial property. However, what was actually built was a solar panel assembly plant, which imports all the panel components from China. This company, owned by the Spanish group Fluitecnik, was responsible for employing 100 workers, but since mid-2012 it has stopped producing. With the purpose of developing the local community, the company owning the Amareleja plant set up a 3 million euros social fund to foster development initiatives linked to renewable energy sources in areas such as R&D (a research laboratory), vocational training, community awareness, and support for microgeneration projects (DGEG, 2007; Delicado and Junqueira, 2013; Junqueira *et al*., 2013).

3.1.3. Ferreira do Alentejo PVFs

In Ferreira do Alentejo, a Portuguese municipality in the district of Beja, in Alentejo, there are several PV power plants built and operated by distinct companies. In the following two figures, we present, respectively, the exact location and a panoramic image of some of the PV plants installed in the municipality of Ferreira do Alentejo.

Figure 7: Location of Ferreira Alentejo PVFs



Source: Authors` elaboration

Figure 8: Panoramic Image of Ferreira Alentejo PVFs

Source: GENERG: http://www.generg.pt/pt/portfolio/energia-solar/

Net Plan, a Portuguese renewable energy company, was the first to invest in this municipality, more specifically in the parish of Ferreira do Alentejo, with a PV project, including the construction of a group of five small plants. The installation of the PV plants, with a total of 43000 PV panels and a power of 1,8 megawatts, began in October 2007 and was concluded in May 2009. It should also be noted that the PV panels used were built in a factory installed in the municipality of Oliveira do Bairro, in the district of Aveiro (Net Plan, 2011). Located in an area of 40 hectares west of the town of Ferreira do Alentejo, there is another PV plant operating since September 2009. With an installed capacity of 10 megawatts (MW), this PV plant uses 45440 polycrystalline silicon panels, with a peak power of 230 W, installed on single axis trackers. Finally, a third PV plant, covering an area of 58 hectares in the municipality of Ferreira do Alentejo, was built by the Portuguese Group Generg and is operating since December 2009. This project, with a total installed capacity of 12 megawatts and using 64000 polycrystalline silicon modules, produces 21 GWh of electricity each year. This PV plant has the particularity of being the first in Portugal and one of the first five in the world to be awarded with the German TÜV Rheinland certification which attests the quality of the work, equipment and operation (Generg Group, 2012).

3.2. Discrete Choice Experiments

The elicitation of the general population welfare changes caused by the existence of solar PV farms, in general, was done by applying DCE. DCE is based on the notion that value is derived from the specific attributes of a good, in accordance with Lancaster (1966)'s characteristics theory of value. This survey-based approach has the advantage that respondents are simply required to choose their preferred option out of a series of sets of alternatives that differ by the attributes/levels present. In each choice task, respondents trade off changes in attribute levels against the associated cost (Hanley *et al.*, 1998, 2001; Bateman *et al.*, 2002; Pearce *et al.*, 2006).

During the first semester of 2014, 250 questionnaires were conducted among the general population, residing in distinct regions of mainland Portugal. Similarly to the CV questionnaires, DCE questionnaires were also divided in four parts. First, the degree of respondents' familiarity with renewable energy sources was assessed in an introductory section. Second, there was the choice experiment section, in which individuals were presented with six choice sets, each consisting of a choice between two alternative ways of producing electricity through photovoltaic energy, differing on the levels of specific attributes. Due to its key role in the questionnaire, and to

illustrate the choices respondents were faced with, we present one of the six choice sets given to respondents in the following table:

Table 1: Choice Set Example

Consider the choice between form A of electricity generation through photovoltaic energy and form B of electricity generation also through photovoltaic energy. Tick your preferred option:

	Form A	**Form B**
Significant impact on the landscape	Yes	Yes
Significant impact on the Fauna/Flora	No	Yes
Produces glare affecting population	Yes	No
Increase in the monthly bill €	12	8
Your choice	☐	☐

Then, respondents were presented with two more sections with questions on preferences and opinions on different energy sources (part 3) and to gather information on individuals' socio, economic and demographic characteristics (part 4). The questionnaire was subject to an interactive test and review process using pilot studies.

4. RESULTS

4.1. Local Residents

Local residents' sample is composed of respondents mostly with low education level (24% have primary school), 28% of which are retired, with mean age of 53 years old and mean per capita household income of approximately 422 Euros. Characterizing respondents' environmental concerns, most of them find that water pollution is the most significant environmental problem in Portugal, followed by waste and atmospheric pollution. The vast majority of respondents are familiar with production of electricity through photovoltaic farms, wind farms and hydroelectric power stations, but biomass and wave energy are unknown to most respondents. In addition, most respondents consider photovoltaic, wind and hydropower environmentally friendly, while coal and crude oil are considered unfriendly. Most respondents (59%) observe in detail their monthly electricity bill, which is approximately 78 Euros. Regarding the respondents' relationship with the PVF, the impacts that most bother respondents are: glare, landscape intrusion, and effects on fauna/flora. A considerable number of respondents (60%) stated a positive willingness to accept (WTA) compensation amount (29.59 Euros on average), varying between 5 and 300 Euros per month.

In order to identify the determinants of respondents' WTA amount we estimate a zero-inflated negative binomial model, as respondents have a two stage process, first deciding whether they are entitled to some compensation (which correspondents to a binary yes/no variable) and then decide the amount of compensation (in integer numbers). According to this specification, the variables determining the decision to be entitled for some compensation need not be the same than those determining the decision on the specific amount. In addition this specification contemplates the sometimes excessive number of zeros observed. The explanatory variables were

selected based on existing literature. The variables used are: *annoyance_sn*, takes the value 1 if the respondent reports being annoyed by the presence of the PV farm, and zero otherwise; *Hercules* and *Ferreira Alentejo* are dummy variables taking the value one if the observation was collected in Hércules/Ferreira do Alentejo, and zero otherwise, the omitted category is Amareleja; *self-interested* is a dummy variable taking the value 1 if the respondent, a friend or a family member worked or works in the PV farm, and 0 otherwise; *glare annoyance*, measures the degree of annoyance caused by the glare effect reported by respondents on a 5 point scale (with 5 being the highest level of perceived annoyance); *retired*, takes the value 1 if the respondent is retired and 0 otherwise; *age* is the age of respondents and *gender* takes the value 1 for male respondents. Results are reported in Table 2, where the first panel reports the results on the decision to be entitled to compensation, while the second reports the results on explaining the compensation amount demanded.

Table 2: Zero-inflated negative binomial model

		Explanatory Variables	**Coefficient** (robust stdev)
Dependent Variables	**WTA yes/no**	Annoyance_sn	-23.2169*** (1.2912)
		Hércules	-11.5520*** (13.6998)
		Ferreira Alentejo	3.1186 (1.2531)
		Constant	-2.9682 (0.9942)
	WTA amount	Self-interested	-0.5334* (0.3103)
		Glare Annoyance	0.3402*** (0.1300)
		Retired	0.7609* (0.4160)
		Gender	0.0655 (0.2642)
		Age	-0.0294*** (0.0106)
		Hércules	-0.8296** (0.2766)
		Ferreira Alentejo	-0.3774 (0.3367)
		Constant	4.4815*** (0.6355)
		Ln(alpha)	-0.6816* (0.2568)
N: 60 (zero=21); Wald chi2(9) 45.79*			

Note: *significance level of 10%; **significance level of 5%; ***significance level of 1%

According to the results presented in table 2, general annoyance is the most important determinant of the decision to receive compensation, although it influences it negatively. In addition, location is also significant: residents in Ferreira do Alentejo are less likely to demand compensation than respondents in Amareleja. Regarding the decision about the amount of compensation, results show that retired respondents demand, on average, higher amounts. The glare effect is also responsible for respondents demanding higher compensation amounts. On the other hand, respondents having an interest in the PVF, because they work/worked or know someone that works/worked in the facility, demand lower amounts of compensation. Relative to residents near the Amareleja PVF, residents in Ferreira do Alentejo demand lower amounts of compensation. This, coupled with the result that residents in Hércules are less likely to demand compensation, might be justified by the differences in the size of the PVF: Amareleja plant is the biggest, occupying 250 ha, followed by Ferreira Alentejo (94 ha) and Hércules (60 ha) PV farms. Based on the regression model, we predict that the amount of compensation demanded would be on average 29.59 Euros per month, being 50.46 Euros in Amareleja, 21.38 in Hércules and 14.97 Euros in Ferreira Alentejo. The most significant result obtained is that compensation amounts are clearly site-specific. Also relevant is the fact that populations feel annoyance by the presence of the PVF which influences their decisions regarding the entitlement to compensation, and the amount demanded.

4.2. Non-Residents

The questionnaires were administered during the first semester of 2014 to a sample of 250 residents in continental Portugal. The average age is 50, 47% are men, 35% retirees and most have secondary schooling. Characterizing respondents' environmental concerns, most of them find that waste (65%) is the most significant environmental problem in Portugal, followed by water pollution (57%) and air pollution (55%). For respondents, the most important environmental problem associated with the use of energy from fossil fuels is water pollution (55%), followed by climate change (52%) and CO_2 accumulation (49%). The vast majority of respondents are familiar with production of electricity through photovoltaic farms, hydroelectric power stations and wind farms; biomass energy is unknown to most respondents. Furthermore, 93% of respondents consider wind energy the most environmentally friendly, followed by PVF (92%) and hydropower (86%), while crude-oil and nuclear are considered environmentally unfriendly (76% and 72% respectively). Most respondents (87%) consider important or very important to know the type of energy used in the production of the electricity they consume. Average electricity bill is 75 Euros. Regarding respondents' answers to the choice questions, 42% stated they considered all attributes in their choices, while the others considered only some of the attributes.

Considering that each of the 250 respondents made 8 x 2 choices we have a total of 4000 distinct observations for the choice decisions, 16 for each subject. Thus, in practical terms our data set can be described as a panel data set.

Table 3: Binary logit model (with cluster correction)

		Partial effects (stdev)	**Mean WTP** (stdev)
Variables	**Landscape**	-0.3120*** (0.0223)	7.1243*** (0.7494)
	Fauna/Flora	-0.3713*** (0.0236)	8.1294*** (0.8486)
	Glare	-0.1852*** (0.0140)	4.8365*** (0.5790)
	Price	-0.0401*** (0.0018)	------
Log likelihood function - 1531.53155***			

Note: *significance level of 10%; **significance level of 5%; ***significance level of 1%

Table 3 reports the estimated partial effects of each attribute on individual choice and also respondents' predicted willingness to pay (WTP) for avoiding each environmental impact. All estimates are statistically significant. On average, respondents are 37 percentage points less likely to choose a form of producing electricity in PVFs with impacts on the fauna/flora, than they are if this impact is avoided. In a similar fashion, the presence of significant impacts on landscape decreases the probability of being chosen by the respondents by 31 percentage points, on average. The attribute that most significantly affects respondents' preferences for the form of production is the impact on fauna and flora, and on average respondents are willing to pay a price premium of 8.13 Euros per month to avoid this impact. To avoid significant impacts on landscape they are willing to pay on average 7.12 Euros monthly. The least significant impact is the glare effect, with an average WTP of only 4.84 Euros per month to avoid it.

In sum, the results show that all attributes considered are statistically significant in explaining respondents' choices. In addition, we are able to elicit the order of importance concluding that the impacts on fauna and flora are the most important determinants followed by the effect on the landscape. Least important are the glare effect and the effect of the increased electricity bill. In terms of policy implications, our preliminary results indicate that PV farms, as perceived by the general population, are understood as affecting most significantly the fauna, flora and the landscape, thus the location decision should contemplate these impacts seriously. In addition, it is important to develop more effective information campaigns thus reducing the eventual misinformation regarding some of the impacts. Finally, it is important to stress the robustness of the DCE method revealed by the results as respondents distinguish between different impacts by valuing them differently.

4.3. Comparing Results

Application of the CV and DCE methods allowed the estimation of the welfare effects of PV farms for two distinct groups of stakeholders: residents in the vicinity of the

farms, and population in general. The most relevant difference between the two samples regarding its composition is income, age, and education, with local residents being older, less educated and with less income. This however reflects the different statistical universes from which the samples were drawn.

Through the CV method, we were able to predict that the compensation amount demanded by local residents would be on average 95 Euros per month. On the other hand, the application of the DCE method among the general population allowed us to conclude that, on average, respondents are willing to pay an amount between [4.8 Euros; 8.1 Euros] depending on the impact considered. Thus, as the number of residents to be compensated are those living close to the installations, while those willing to pay are the entire population, it is safe to conclude that the welfare benefits more than compensate the costs and thus, pending equity considerations, the use of PV farms is potentially welfare improving.

5. CONCLUSIONS

PVFs are generally seen as environmentally friendly, however they are not environmentally impact free.

In deciding between energy sources to produce electricity, public decision makers should, in addition to the more traditional efficiency considerations, analyse the "equity implications" of the projects. A proper equity analysis requires identifying all stakeholders and a comparison of the welfare change for each group following the installation of a PVF. This study applies the CV and the DCE approaches in order to elicit an economic value for the environmental impacts caused by the PVFs' activity near two distinct public targets: local residents and the general population. With the answers given by the local residents, we were able to estimate the minimum monetary amount demanded as compensation for the negative impacts caused by the proximity of three Portuguese PVFs. While the answers given by the general population in mainland Portugal, we computed the value of each environmental impact caused by the PVFs' activity, by asking individuals the monetary amount they were willing to pay in order to have electricity generated through solar photovoltaic, but with the possibility of avoiding specific adverse impacts. The results of this paper confirm the relevance of considering the environmental impacts of PVFs in the siting decision process. Moreover, as the impacts depend on the site and location of the dams, policy makers should use this information to integrate these parameters into their decision-making process.

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USING STATED PREFERENCE METHODS TO ASSESS ENVIRONMENTAL IMPACTS OF DAMS IN PORTUGAL: LOCAL VS NATIONAL WELFARE EFFECTS

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ABSTRACT

The construction of dams, particularly large dams, has been highly controversial and the debate over it has become more heated during recent years. Despite their well-known benefits, the activity of dams in the electricity generation process is far from being environmentally harmless. Biodiversity limitation, impacts on fauna and flora, flooding of large areas of farmable land, water quality degradation, landscape intrusion, heritage destruction and noise are just some of the adverse impacts caused by the dams' activity. However, hydropower has considerable advantages compared with other energy sources, namely it does not produce significant amounts of greenhouse gases emissions and contributes to the diversification of the energy mix, also decreasing the external dependency of the economy. The nature of the benefits of using hydropower is mostly national, while the adverse effects are mostly local, which raises an equity question rarely addressed. We propose to elicit the effects of the presence of specific dams on the welfare of local communities in the vicinity, and compare this number to how much the general population is willing to pay to prevent the effects. To elicit the welfare effects on local residents we use the contingent valuation method; while for the second group we elicit respondents' willingness to pay to avoid some environmental impacts of hydropower production. The results show that the presence of the selected facilities affects the individuals' well-being; and that the welfare of the general population is significantly and negatively affected by the environmental effects considered in the study. Thus, the results demonstrate that the welfare of local residents, as well as of the general population, is negatively affected by the existence of large dams and thus the welfare of these stakeholders should be part of the decision-making process regarding the siting of new dams, so as to attain a decision as fair and economically efficient as possible.

Keywords: Dams, Stated Preference Methods, Contingent Valuation, Discrete Choice Experiments, Environmental Impacts, Public Attitudes.

1. INTRODUCTION

A major concern in the energy sector has to do with environmental issues, namely the increase in pollution levels and climate change, along with the shortage of fossil fuel reserves. Moreover, most countries, including Portugal, face significant external energy dependency. These issues represent strong motivations for the development of renewable energy sources (RES), which, besides using domestic resources, present smaller environmental impacts than fossil sources. However, RES are not completely "environmentally benign" and may, in fact, be responsible for causing adverse impacts on the environment and people's wellbeing. Differing either in kind or in intensity between the different technologies, the impacts due to the operation of the different renewables facilities are more noticeable locally and in shorter time horizons in comparison to other energy sources.

Hydropower can play an important role for the fulfilment of the renewables goals in Europe, and contribute significantly to reducing emissions of greenhouse gases. However, dams' activity is responsible for causing adverse impacts, affecting individuals' wellbeing, notably local residents, including biodiversity limitation (e.g. Rosenberg *et al.*, 1997; Abbasi and Abbasi, 2000), impacts on fauna and flora (e.g. Awakul and Ogunlana, 2002; Han *et al.*, 2008; Tullos, 2009), flooding of large areas of farmable land (e.g. Rashad and Ismail, 2000; Wang *et al.*, 2013), water quality degradation (e.g. Rashad and Ismail, 2000; Wang *et al.*, 2010), landscape intrusion (e.g. Ouyang *et al.*, 2010; Theobald, 2010), destruction of architectural, historical and archaeological sites (e.g. Pinho *et al.*, 2007; Han *et al.*, 2008; Gunawardena, 2010), noise (e.g. JKA, 2010), among others. These impacts are important and their economic value must be considered in an efficient and complete cost-benefit analysis (CBA) regarding hydropower developments. In addition, as the impacts, positive and negative, affect different groups of people, it is important to analyse the equity effects of the decision. This paper uses two stated preference (SP) approaches to estimate the economic value of adverse environmental impacts associated with the operation of dams in Portugal. Although we apply this methodology to specific Portuguese dams, and the values are based on the opinion of the interviewed individuals, the results from this study provide useful quantitative and qualitative information for an accurate CBA regarding siting decisions on the construction of future dams.

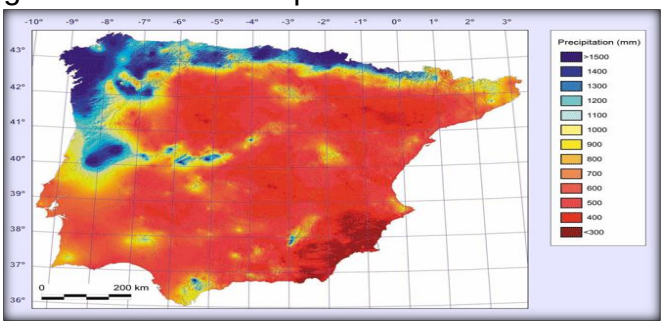
The reminder of this paper is organized as follows. Section 2 presents the current situation of hydropower in Portugal. Section 3 provides an overview of the main methodological issues, in which the valuation methods are explained, the survey design and a brief description of the case studies are presented. Then section 4 presents and discusses the results. Finally, in section 5 the main conclusions of this paper are presented.

2. HYDROPOWER IN PORTUGAL

Portugal is one of the European Union (EU) countries with the highest exploitable hydropower potential. One of the main drivers for this advantageous situation is the high rainfall that characterizes some areas of the country. Figure 1 presents the

average annual precipitation map for the Iberian Peninsula, revealing the strong influence exerted both by the Atlantic Ocean and by elevation. Annual precipitation is above 1 500 mm in some parts of northern Portugal, much of coastal Galicia and along the southern borders of the Pyrenees (Ninyerola *et al*., 2005).

Figure 1: Annual Precipitation in Iberian Peninsula

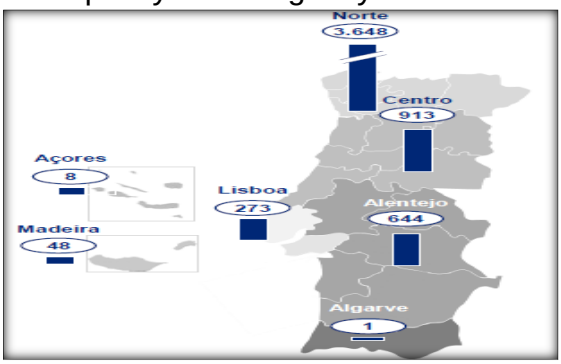


Source: Ninyerola *et al*. (2005)

Hydropower has traditionally played a significant role in Portugal's power mix. In recent years important decisions were taken in this sector with the approval by the Portuguese Government, in December 2007, of the National Programme of Dams with High Hydroelectric Potential (PNBEPH), and other projects, namely power reinforcement operations of several hydropower plants. The PNBEPH primarily aims to increase Portugal`s hydropower capacity and to exploit 70% of its hydropower potential. If coupled with other initiatives for energy production from renewable sources, the PNEBPH is expected to achieve the 2020 target for renewable electricity, thereby contributing to reducing Portugal's dependency on imported fuels, which in turn will reduce GHG emissions. Under this Programme, the construction of ten hydropower plants was decided, representing a total potential capacity of approximately 1 100 MW and an estimated yearly gross electricity output of 1 630 GWh (OECD, 2011).

Between 2010 and 2013, the installed hydropower capacity increased by about 13%. As shown in Figure 2, about 2/3 of the national installed hydropower in 2013 was concentrated in the North, followed by the Centre region with about 16%. The Alentejo region represented about 12% of the total power, of which almost 80% concerns the Alqueva dam that doubled its power in 2012. Together the remaining regions accounted for only 6% of installed hydropower capacity (Deloitte, 2014).

Figure 2: Distribution of Installed
Hydropower Capacity in Portugal by NUTS II in 2013 (MW)



Source: Deloitte (2014)

3. METHODOLOGY

3.1. Stated Preference Methods

Determining the economic value of the environmental impacts of the electricity generation process through the use of dams is far from being simple, since there are no markets for the environmental goods and services impacted and, therefore, prices are not available. Nevertheless, the inexistence of prices for these environmental impacts does not necessarily mean they have no value. These resources are called non-market goods and their value may be estimated through two main valuation methods: revealed preferences (RP) and stated preferences (SP). While in the former methods, the value of goods is inferred from the observation of consumers' behaviour, SP methods ask consumers what they would be willing to pay or accept for a change in an environmental amenity (Adamowicz et al., 1994). These direct methods do not require individuals to make any behavioral change, they only ask individuals to attach an economic value to non-marketed goods and services. Stated preference methods have several advantages: first, they can be used to value any environmental good or service, even at levels of quality that are currently not in existence; second, stated preference methods may be used to elicit values in cases in which the environmental quality change involves a large number of attribute changes (Adamowicz *et al.,* 1994; Bateman *et al.,* 2002; Mendelsohn and Olmstead, 2009). Therefore, we used in this study two SP methods: the contingent valuation (CV) method and the discrete choice experiments (DCE) technique, which we will briefly present next.

3.2. Contingent Valuation Method

The CV method is a direct survey approach to estimating consumer preferences. Using an appropriately designed questionnaire, a hypothetical (or contingent) market for the good in question is described. This contingent market defines the good itself, the institutional context in which it would be provided, and the way it would be financed. Respondents are then asked to express their maximum willingness to pay (WTP) or minimum willingness to accept (WTA) compensation for a hypothetical change in the level of provision of the good (Mitchell and Carson, 1989; Hanley *et al*., 2001; Atkinson and Mourato, 2008).

In this study, we designed a CV survey with the aim of estimating the minimum money amount respondents would be willing to accept as a compensation for the burdens caused by the presence of a dam in the proximity of their residence. Following Whitehead (2006), each questionnaire was composed of four sections. After an introductory section with general questions on renewable energy sources, section 2 presents specific questions on the production of electricity through hydropower, and the valuation question formulated in the format, since we did not have prior information to aid the construction of response thresholds for a discrete choice format. The payment vehicle chosen was a monetary compensation in the monthly electricity bill. Section 3 contains some additional questions on respondents' preferences and opinions on different energy sources, renewable and non-renewable. Finally, section 4 includes some questions to gather information on the individuals' socio, economic and demographic characteristics (e.g., gender,

educational level, family situation, income, etc.). The questionnaire was subject to an interactive test and review process using pilot studies.

During the months of June and October 2014, a total of 50 questionnaires were collected among the residents in the local communities near four dams: Picote, Bemposta, Alqueva and Aguieira. These dams are briefly characterized next.

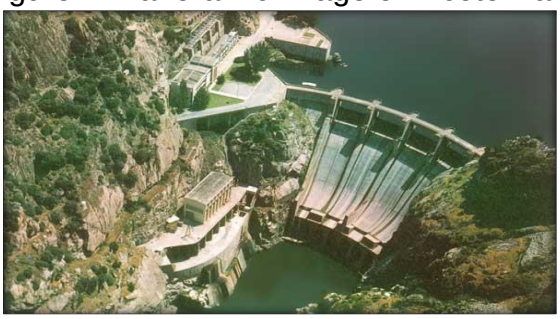
3.2.1. Douro International

Douro international in this study comprises two dams, Picote and Bemposta. The Picote dam is located in the parish of Picote, near the village of Sendim, in the municipality of Miranda do Douro, district of Bragança, in the northeast of Portugal. This plant was built on the international water course of river Douro, downstream of the Miranda hydropower plant and upstream of the Bemposta hydropower plant. The Picote plant has a reservoir of 13.35 hm^3 of useful capacity and its area of influence covers the Portuguese municipality of Miranda do Douro and, in its left margin, Spanish territory. Figures 3 and 4 present the exact location and a panoramic image of the Picote power plant.

Figure 3: Location of Picote Dam

Source: Authors' elaboration

Figure 4: Panoramic Image of Picote Dam



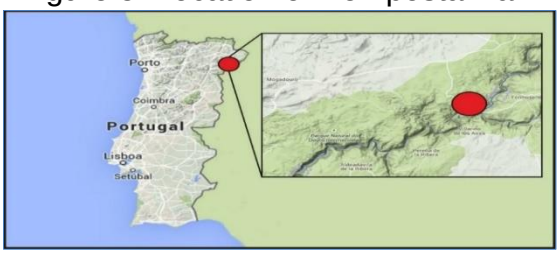
Source: EDP: http://www.a-nossa-energia.edp.pt/centros_produtores/fotos_videos.php?item_id=38&cp_type=he&section_type=fotos_videos

The Picote hydropower plant operates since 1958 and has an installed power of 195 MW (3 groups of 65 MW). This plant has recently been subject to a power reinforcement operation, whereby a new underground plant was built with an installed power of 246 MW, known as Picote II. In this operation, EDP - Energias de Portugal, S.A. (the largest generator, distributer and supplier of electricity in Portugal) invested a total of 140 million euros. The construction works began in March 2007

and ended in December 2011, giving temporary employment to 425 individuals (EDP, 2013).

The Bemposta dam is located in the parish of Bemposta, municipality of Mogadouro, district of Bragança, in the northeast of Portugal. It was built on the international water course of the river Douro, downstream of the Picote plant, creating a reservoir with 20 hm^3 of useful capacity. Its area of influence covers, in the national territory, the municipalities of Miranda do Douro and Mogadouro, and, in its left margin, it covers Spanish territory. The next two figures present the exact location and a panoramic image of the Bemposta plant.

Figure 5: Location of Bemposta Dam



Source: Authors' elaboration

Figure 6: Panoramic Image of Bemposta Dam

Source: EDP: http://www.a-nossa-energia.edp.pt/centros_produtores/fotos_videos.php?item_id=10&cp_type=he&section_type=fotos_videos

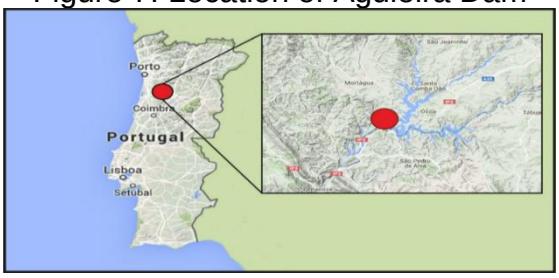
The Bemposta hydropower plant, with an installed power of 240 MW (3 groups of 80 MW), began operating in 1964. Recently, taking advantage of the existing hydraulic infrastructures, an investment of 132 million euros was made in strengthening the installed power with the construction of a new central of 191 MW, known as Bemposta II. Construction works began in January 2008 and almost four years later, more specifically in December 2011, Bemposta II began operating. It is noteworthy that in this project, EDP (the owning company) intended to bring art into the dam, in order to mitigate its negative impacts on a landscape of recognized unique aesthetic value (in 2001, the Alto Douro wine region was classified in the world heritage UNESCO list in the category of cultural landscape). This art project had a total cost of 150 000 euros and was signed by the architect Pedro Cabrita Reis who entitled the project as "Of the Colour of the Flowers": there is a predominance of the yellow colour in the dam's multiple surfaces as an allusion to the colour of the *maia*, a kind of flower that covers the surrounding mountains from the end of May (EDP, 2013).

3.2.2. Aguieira Dam

The Aguieira dam is located in the parish of Travanca do Mondego, municipality of Penacova, district of Coimbra, in the centre of Portugal. It was built on the water

course of the river Mondego, about 1.7 km downstream of the mouth of the river Dão. Creating a reservoir of 216 hm^3 of useful capacity, its zone of influence includes the municipalities of Penacova, Mortágua, Santa Comba Dão, Tábua, Tondela and Carregal do Sal. Figures 7 and 8 present the exact location and a panoramic image of the Aguieira plant.

Figure 7: Location of Aguieira Dam



Source: Authors' elaboration

Figure 8: Panoramic Image of Aguieira Dam

Source: EDP: http://www.a-nossa-energia.edp.pt/centros_produtores/fotos_videos.php?item_id=4&cp_type=he&section_type=fotos_videos

The Aguieira hydropower plant has an installed power of 336 MW and is in operation since 1981. It is also relevant to highlight that this dam, together with the Raiva dam (downstream), is part of a plan to take advantage of the river Mondego for multiple purposes. In addition to energy production, this plan aims to contribute to the regularization of the solid and liquid flow by dampening the winter floods and summer droughts, and the creation of an irrigation system of the Baixo Mondego. The operation management of the Aguieira dam belongs to the company EDP (EDP, 2013).

3.2.3. Alqueva Dam

The Alqueva dam adopts the name of the parish covered by its right bank, belonging to the municipality of Portel, district of Évora, in the southeast of Portugal. It was built in the course of the Guadiana river, creating the largest water reservoir in the country and the largest artificial lake in Europe, with its 25 000 hectares of flooded surface and over 1 100 km of margins covering Portuguese municipalities and Spanish territory. It is important to note that the construction of the Alqueva power plant led to the submersion and the consequent translocation of the village of Luz (municipality of Mourão), which, lying at a quota below 152, was totally submerged by the big lake. Figures 9 and 10 show the exact location and a panoramic image of the Alqueva plant.

Figure 9: Location of Alqueva Dam

Source: Authors` elaboration

Figure 10: Panoramic Image of Alqueva Dam

Source: EDP: http://www.a-nossa-energia.edp.pt/centros_produtores/fotos_videos.php?item_id=5&cp_type=he&section_type=fotos_videos

The Alqueva hydropower plant is integrated in a “multi-purpose” enterprise for Alqueva, and its exploitation is a responsibility of the company EDP. The long period between the first studies and construction of the dam, about 50 years, made the "Alqueva" a polemic project in Portugal. After several years of advances and retreats, the construction started in 1998 and was completed in January 2002, with operations beginning the following month. The Alqueva hydropower plant, with an installed power of 260 MW (2 groups of 130 MW) has been subject to a power reinforcement operation and, since December 2012, a new central known as Alqueva II is operating with 260 MW of additional power. The Alqueva II power enhancement deployed on the right bank of the river Guadiana, involved the construction of a new hydraulic circuit and a new central, excavated in the open, equipped with two reversible generators. Each has the maximum shaft power of 130 MW, which allows doubling of the current installed capacity. With a power of 520 MW, the central Alqueva is the second largest production centre of the country (EDP, 2013).

3.3. Discrete Choice Experiments

Discrete choice experiments are based on the notion that value is derived from the specific attributes of a good, in accordance with the characteristics theory of value of Lancaster (1966). This survey-based approach has the advantage that respondents are presented with several choice tasks and in each task are simply required to

choose their preferred option (comprised of a set of alternatives that differ by the attributes/levels presented). In each choice task, respondents trade off changes in attribute levels against the associated cost (Hanley *et al.*, 1998, 2001; Bateman *et al*., 2002; Pearce *et al*., 2006).

To configure alternative ways of producing electricity through hydropower, the selection' process of the attributes and respective levels was based on an extensive literature review, on the results from pilot questionnaires and on focus group discussions. The final configuration of the choice sets included the following attributes: effects on landscape, impacts on fauna and flora, noise pollution affecting population, damage on heritage, and a price attribute defined as an increase in the monthly electricity bill. Following the exploratory study the price attribute had three levels (4, 8 and 12 Euros). The remaining attributes are binary, assuming two levels: or the impact is present or absent. Through a D efficient Design for a generic DCE (NGENE software) the attributes levels' were combined and paired into eight choice sets, from which the respondents were asked to choose their preferred alternative in a questionnaire conducted during the first semester of 2014, among the general population, residing in distinct regions of continental Portugal. Table 1 illustrates a choice task presented to respondents.

Table 1: Choice Set Example

Consider the choice between form A of electricity generation through hydropower and form B of electricity generation also through hydropower. Tick your preferred option:

	Form A	**Form B**
Significant impact on the landscape	No	Yes
Significant impact on the Fauna/Flora	No	Yes
Produces noise affecting population	Yes	No
Destroys heritage	Yes	No
Increase in the monthly electricity bill €	12	8
Your choice	☐	☐

Beyond the valuation section comprising the 8 sequential choice questions, the DCE questionnaire included three additional sections: The degree of respondents' familiarity with renewable energy sources was assessed in an introductory section; preferences and opinions on different energy sources; and socioeconomic and demographic characteristics of the respondents .The questionnaire was subject to an interactive test and review process using pilot studies explained in Botelho *et al*. (2014).

4. RESULTS

4.1. Local Residents

Local residents were recruited in public places in the villages near the four hydropower plants presented above though interviews were carried out in private. In

total, 50 questionnaires were collected: 16 in Aguieira, 23 in Alqueva and 11 in Douro International (which aggregates Picote and Bemposta).

Regarding the socio-demographic characteristics of the sample, 36% of respondents have primary school level of education, 32% are employed, 70% are males, mean age is 51 years old and mean monthly household income per capita is approximately 374 Euros. Air pollution, followed by climate change and water pollution are the environmental problems in Portugal most frequently selected by respondents; most respondents are familiar with the production of electricity using the wind, hydropower and solar photovoltaic, however among these, hydropower is considered the least environmentally friendly. Almost all respondents (98%) consider Portugal as a country with good conditions for developing RES in the production of electricity and consider that this brings benefits for the population. More than an half of respondents refer that renewables do not produce harmful emissions or toxic wastes. In addition they point to other positive environmental effects from the use of renewables. Average monthly electricity bill of respondents is approximately 68 Euros. Regarding the respondents' relationship with the dams, for 76% of them the dam is visible from their home, and they do not feel much annoyed by its presence. In fact, only the effect on flora and fauna is sometimes identified as negative. About 46% of the respondents stated a positive willingness to accept (WTA) compensation amount, which varied between 1 and 500 Euros per month, for an average of 44.4 Euros per month.

In order to identify the determinants of respondents' WTA amount we estimated a zero-inflated negative binomial model. This specification is adequate for WTA type data. It assumes that respondents first decide whether or not they are entitled to compensation (a binary variable) and then if yes, they decide on the amount (expressed in positive integers). In addition, according to this specification, the variables determining the decision to be entitled to compensation need not be the same as those determining the decision on the specific amount. The explanatory variables were selected according to previous studies and, when necessary for estimation feasibility, for example due to perfect collinearity between explanatory variables, the specification was adapted.

Table 2: Zero-inflated negative binomial model

		Explanatory Variables	**Coefficient** (robust stdev)
Dependent Variables	**WTA yes/no**	Annoyance_sn	0.9711 (1.0696)
		Self-interested	1.3033** (0.6164)
		Constant	-0.5899 (0.4190)
	WTA amount	Incomepc	0.0000 (0.0002)
		Gender	0.7266*** (0.2753)
		Annoyance	0.3622 (0.2206)

		Alqueva	1.0887*** (0.3521)
		Douro International (Picote + Bemposta)	-1.1498*** (0.3093)
		Constant	2.0966*** (0.3571)
		Ln(alpha)	-1.1363*** (0.3334)
		alpha	0.3210 (0.1070)
N: 50 (zero=27); Wald chi2(4) 103.22***			

Note: *significance level of 10%; **significance level of 5%; ***significance level of 1%

Variables' definition: annoyance_sn, takes the value one if annoyance was reported and zero, otherwise; Self-interested, takes the value one if the respondent, a family member or friends work or have worked in the dam, and zero otherwise; Incomepc, monthly family income per household member; gender takes the value one if male, zero if female.

According to the results presented in the Table 2, we conclude that self-interest is the most important determinant of the decision to receive compensation, with respondents having an interest in the dam because they work/worked, or know someone that works/worked in the dam, being more likely to demand compensation. Regarding the determinants of the amount of compensation, location plays a significant role with residents in Alqueva demanding on average higher amounts than residents in Aguieira, while residents in Douro International demand lower amounts than residents in Aguieira. This result might be explained by: (1) the morphology of the area, as Douro International's dams are in deeper and narrower valleys than those of Aguieira and Alqueva; (2) by the difference between the size and age of the Alqueva and Aguieira Dams, since Alqueva is significantly newer and bigger. Distinctly from expected, the monthly household income per person was not a determinant statistically significant to explain the WTA amount. Based on the regression model we predict that the amount of compensation would be on average 24.1 Euros per month, being 7.9 Euros in Aguieira, 45 Euros in Alqueva and 4.2 Euros in Douro International. The most significant result obtained is that compensation amounts are clearly site specific. Also relevant is the fact that self-interest and demographic characteristics play some role in the computation of the welfare cost.

4.2. Non-Residents

A set of 250 completed questionnaires were collected during the first semester of 2014 on a national scale. Respondents are on average 49 years old, 29% have a university degree and 36% are employed. Approximately 46% are male. The most significant environmental problem associated with the use of fossil fuel energy they identify is water pollution, followed by CO_2 accumulation and climate change. With respect to renewable energies, most respondents are familiar will almost all sources, except for energy from waves and geothermal. Among renewables, wind and photovoltaic energy is considered environmentally friendly by 99%, followed by

hydropower (98%). Respondents reveal a significant interest in knowing which type of energy source is used in the electricity consumed in their homes, and only 6% consider it irrelevant. On average, respondents pay 77 Euros of electricity per month, and most of them see/ have visual contact with some form of electricity production using a renewable energy daily (79%). Regarding the choice tasks presented to respondents, they faced eight choices between two alternatives each (rendering a total of 4000 choices made by all respondents), and 22% of respondents state they considered all attributes in their choice tasks.

Respondents' choice data was modelled as a binary logit model with cluster correction, accounting for the binary nature of the dependent variable and the fact that each respondent makes eight different choices. Table 3 presents the estimates of the marginal effects of the attributes considered on respondents' wellbeing and estimates of respondents' WTP for the same attributes.

Table 3: Binary logit model (with cluster correction)

		Partial effects (stdev)	**Mean WTP** (stdev)
Variables	**Landscape**	-0.1073*** (0.0190)	5.8300*** (1.1782)
	Fauna/Flora	-0.2936*** (0.0297)	15.1030*** (3.8913)
	Noise	-0.1677*** (0.0127)	9.1016*** (2.3059)
	Heritage	-0.0777*** (0.0156)	4.1770*** (1.5732)
	Price	-0.0185*** (0.0044)	------
Log likelihood function -2489.9155***			

Note: *significance level of 10%; **significance level of 5%; ***significance level of 1%

The attribute (environmental impact) that is considered most important and that impacts respondents' utility most drastically is the impact on fauna and flora. The second most important attribute is the impact of noise; considerably less important are the attributes landscape intrusion and destruction of heritage. Avoiding significant impacts on the fauna and flora increases the probability of choosing an alternative by 0.3 relative to having significant impacts. The effect of significant impacts on landscape, noise and heritage on the probability of choosing an alternative is0.1, 0.16 and 0.08, respectively; for example if an alternative avoids significant impacts on noise it is 16% more likely to be chosen relative to one that does not avoid noise impacts. In line with the marginal effects estimated, respondents are willing to pay, on average, 15 Euros more in their monthly electricity bill to avoid significant impacts of hydropower on the fauna/flora; to avoid significant inconvenience of noise to populations, they are willing to pay on average an increase in their electricity bill of 9 Euros. To avoid significant damages to the landscape and heritage they are willing to pay on average 5.83 Euros and 4.18 Euros, respectively.

In interpreting these results it should be stressed that these WTP estimates of welfare loss imposed by the presence of dams are not additive. The results obtained contain important implications for the location decision regarding dams as location crucially influences the severity of the impacts, namely the morphology of the place. Also, all impacts introduced in the study were considered relevant by respondents. However, not all impacts were equally important. Thus, the decision to locate a dam should pay particular attention to the specific impacts in each location. Finally, it should be noted that respondents attach significantly more importance to the impacts on animals, plants and humans, than impacts on human and natural assets, like landscape and heritage.

5. CONCLUSIONS

The use of hydropower for electricity generation has many advantages when compared with other energy sources, particularly with fossil fuels: it does not generate CO_2 emissions, it is renewable, and it is storable to some extent. Nevertheless, it also has some important adverse environmental impacts associated with the dams' activity and that are strongly dependent on location and size. The joint application of the CV and DCE approaches allowed the analysis of the welfare effects of two types of stakeholders: local residents (potentially affected by the negative effects caused by the presence of four specific dams installed near their residence) and the population in general (that benefit from all the advantages associated with having electricity generated through the use of a renewable energy source and thus experience some welfare benefits). The most relevant difference of the two samples regards income, age, and education, with local residents being older, less educated and with less income, which reflects the underlying population characteristics. With the study of local residents, we were able to estimate the minimum monetary amount demanded as compensation for the negative impacts caused by the proximity of the four Portuguese dams. Based on the regression model we predict that the amount of compensation would be on average 24.1 Euros per month, being 7.9 Euros in Aguieira, 45 Euros in Alqueva and 4.2 Euros in Douro International. While the study of the general population in continental Portugal, allowed us to compute the value of each environmental impact caused by the dams' activity, by asking individuals the monetary amount they would be willing to pay in order to have electricity generated through hydropower, but avoiding a specific adverse impact. Respondents are willing to pay, on average, 15 Euros more in their monthly electricity bill to avoid significant impacts of hydropower on the fauna/flora; 9 Euros to avoid significant inconvenience of noise to populations; and to avoid significant damages to the landscape and heritage they are willing to pay on average 5.83 Euros and 4.18 Euros, respectively.The results of this paper confirm the relevance of considering the environmental impacts of dams in the siting decision process, from an economic perspective, since the values estimated are far from negligible. Moreover, as the impacts depend on the site and location of the dams, policy makers should use this information to integrate these parameters into their decision-making process concerning specific projects.

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POLICY INTERACTION AND RESOURCES SUBSTITUTION

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ABSTRACT

This paper examines the relationship between economic growth and a cleaner environment in a model where production uses non-polluting renewable and polluting non-renewable resources. There is policy intervention through a tax on emissions and a subsidy to renewables extraction/production. In a model extension, renewables producers can invest in knowledge to reduce costs and knowledge becomes complementary to the subsidy. Results show that it is important to use both instruments together and that, in equilibrium, their values are connected through a stable relationship and need to be within a certain interval. If the tax is non-decreasing and/or the subsidy is increasing, the renewables intensity of production continuously increases and, with a non-decreasing tax emissions *per* output, continuously decrease. The empirical analysis shows that the marginal benefits of a higher tax are decreasing; hence, the best for the economy-environment dilemma is to choose a moderate tax level.

Keywords: Renewable and non-renewable resources; Government intervention; Pollution; Economic growth.

1. INTRODUCTION

The last decades have witnessed an increasing attention to environmental problems, in particular, climate change, and, more recently, there has been a strong emphasis on Renewable Energy Sources (RES). Nonetheless, with the present economic crisis, the concerns with economic growth and unemployment represent the risk of sending the environmental problems to the background of the political agenda. Additionally, there are constraints to finance RES. The debate about the relationship between economic growth and the environment seems more important than ever and it is crucial to know if using, for instance, a carbon tax to finance RES incentives, such as subsidies (following a similar logic to the Green Tax Reform) will or not harm the output. The main questions are whether the economies are able to produce more and pollute less and what mechanisms can be used to achieve that outcome, particularly with governmental intervention. For example, the analysis of the evolution of emissions per level of output shows a continuous decrease in this ratio for most countries, as shown in Fig. 1.

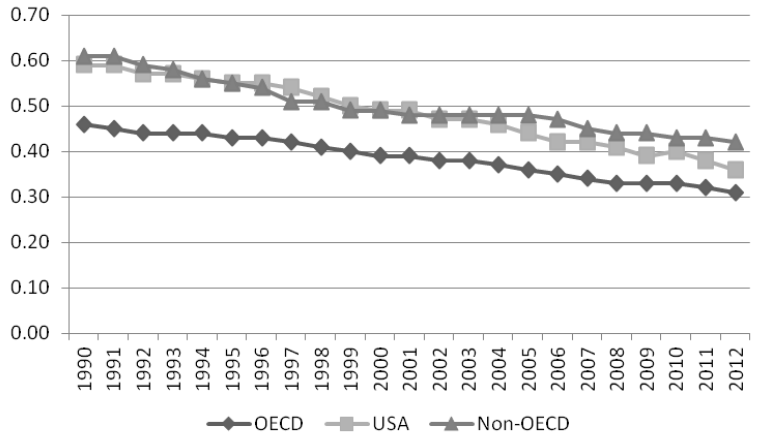


Fig. 1 - Emissions per output ratio
Source: from http://www.iea.org/statistics.

This paper is intended to contribute to the economic growth-resources-environment literature, using a framework to analyze the responses to fuel-switching incentives.

Studies concerning the impact of environmental policy on economic growth have reached different conclusions. Some authors conclude that environmental policy reduces economic growth (e.g., Grimaud, 1999; Ligthart and van der Ploeg, 1994), while others find compatibility between the two aspects (e.g., Bovenberg and Smulders, 1995; Porter and van der Linde, 1995; Hart, 2004).

One side of this relationship is the fact that, in order to produce, economies consume polluting non-renewable resources, which raises two main problems: resource exhaustion and pollution. The first problem, resource scarcity, has been addressed in a large number of studies (e.g., Hotelling, 1931; Stiglitz, 1974; Solow, 1974; Dasgupta and Heal, 1974). Many authors show how to overcome this problem through, for instance, technical change (TC) (e.g., Stiglitz, 1974; Barbier, 1999; Grimaud and Rougé, 2003; Scholz and Ziemes, 1999). The second problem, pollution, is often ignored in the economic growth literature (examples of studies that include pollution are Silva *et al.*, 2013a; Grimaud and Rougé, 2005; Schou, 2000, 2002). The pollution problem can be assessed using environmental policy, which sometimes harms output and also technical advances (e.g., Schou, 2000, 2002; Grimaud and Tournemaine, 2007).

An important route to reduce pollution without reducing output, which is the focus of this paper, is the substitution of polluting non-renewable resources for non-polluting renewable resources. For example, Tahvonen (1997) extends the Hotelling model to include pollution and a backstop technology. The paper analyzes the optimal consumption strategy. The model does not include a policy tool to support the backstop technology (henceforth TC). Tahvonen and Salo (2001) study the transition between the two types of resouces accompanyng economic growth. The model does not include pollution or any policy tool. André and Cerda (2006) focus on the technical aspects of resource substitution and the sustainability of extraction, but ignore the environment. Di Vita (2006) considers both renewable and non-renewable resources in an endogenous growth model and focuses on the effects of the rate of technical substitution among resources. The author analyzes physical waste instead of emissions and does not include a policy tool to promote renewables while

concentrating on the social planner optimization problem. Fisher and Newell (2008) evaluate the relative performance of several policies to reduce emissions and promote innovation and diffusion of renewables. This is a discrete time model which does not account for resources depletion. The authors use a bottom-up approach to focus on electricity generation and hence ignore, for instance, economic growth. Acemoglu *et al.* (2012) study the chances of an environmental disaster occurring while maintaining economic growth and the role played by governmental policies, particularly in directing technical change. In their model, production uses a clean and a dirty input, there is resource exhaustion and pollution, and policies that induce resources substitution (e.g., a carbon tax and a subsidy to research for the clean input) are present. Since this last paper includes most aspects we consider important, we may say that it is the one closer to ours. However, we perform a totally different analysis on the policy interaction possibilities, our subsidy is not to research but to the direct renewables extraction/production, and we consider the Cobb-Douglas situation, which is ignored by those authors.

In line with this debate, our aim is to study the relationship between economic growth and the environment, continuing the analysis started in Silva *et al.* (2013b), in a context where resource substitution is possible and there is government intervention. We then use an equilibrium model, which considers both resource exhaustion and pollution. We focus on the decentralized equilibrium and on the interaction between a tax on emissions and a subsidy to RES. Additionally, contrarily to most models cited, we assume specific functional forms of the equations. This implies a certain loss of generality, but at the same time it allows the analysis of aspects that are lost when general functional forms are considered. Most papers focus on optimal extraction or the resources path in the balanced growth, and we focus on the resources response to policy instruments in equilibrium. None of the articles cited above includes all this elements together and to the best of our knowledge there is no other article studying policy interaction between a tax on emissions and a subsidy to renewables as we do here.

In our analysis we assume initially that extraction/production costs are constant for both types of resources (other authors assume costless extraction, e.g., Aarrestad, 1990; Agnani *et al.*, 2005; Andre and Cerda, 2006). Then, in an extension of the model, we include TC to increase the realism of the model. In particular, we consider that the producers in the renewables sector can invest in knowledge to decrease extraction/production costs. In both cases, only non-renewable resources generate pollution. To investigate resource substitution, we analyze what happens to the ratio of renewables over non-renewables use. To investigate the compatibility between economic growth and the environment we focus on the ratio of emissions *per* output and the elasticity of emissions in relation to output.

One of the main findings of this paper is that it is important to use both policy instruments simultaneously to achieve the goal of higher output and lower emissions, which is in line with Acemoglu *et al.* (2012) and Fisher and Newell (2008). In equilibrium, the values of the two instruments are connected through a stable relationship and should be maintained within a certain interval. If the tax is non-decreasing and/or the subsidy is increasing, the renewables intensity of production continuously increases and with a non-decreasing tax, emissions *per* output continuously decrease. In the extended version of the model, we show that TC plays

a complementary role to the renewables subsidy. The empirical simulation confirms the conclusions of the theoretical analyzes and additionally shows that the marginal benefits of a higher tax are decreasing.

The article is organized as follows. Section 2 presents the main feature of the base model and develops its extended version, exploring the equilibrium conditions and their implications. Section 3 performs a sensitivity analysis to the tax, the subsidy and the renewable resources' knowledge stock. Section 4 shows a numerical simulation, focusing on two main relationships – the relation between the level of renewable resources and non-renewable resources used and the relation between emissions and output. Section 5 concludes and highlights some policy implications.

2. THE MODEL

We consider a model in continuous time with three sectors: homogenous final-goods, non-polluting renewable resources (*R*-sector) and polluting non-renewable resources (*F*-sector). The final-goods sector is perfectly competitive, but we introduce monopoly power in the resources sectors. The reasoning to assume a monopolistic structure in the resources sectors has two main arguments. Firstly, empirically, firms related to energy generation or natural resources exploitation have at least a certain monopoly power. Secondly, even in theoretical terms, the firms need to have monopoly rents (at least temporarily) to have an incentive to invest in knowledge accumulation.

The consumers of this economy are also shareholders of the monopolistic firms, which guarantees that profits remain in the economic system. We focus on the decentralized equilibrium. The dynamic general equilibrium is defined by the path of resources allocation and prices, such that: (i) consumers and firms solve their maximization problems; (ii) Research and Development (R&D) free-entry conditions are met; and (iii) markets clear. Additionally, in the extended version of the model, the endogenous growth mechanism is as follows: by decreasing the production costs through knowledge accumulation, there is a saving for the firms/shareholders in the *R*-sector which allows having more resources for investment and consumption. As in Fisher and Newell (2008), we highlight key features, ignoring unnecessary aspects.

In the presentation of the equilibrium conditions and characteristics, we firstly consider extraction/production costs to be fixed. Then, we extend the model to include technical evolution in the *R*-sector that reduces extraction/production costs.

There is a mass [0,1] of identical individuals who own assets and there is no population growth such that all aggregate variables can be interpreted as *per capita* quantities. [1] Consumers have the following instantaneous utility function:

$$U(C,E) = \ln C_t - \ln E_t \tag{1}$$

The consumers' utility increases with consumption, *C*, and decreases with emissions, *E*, i.e., agents value a clean environment. Marginal consumption utility is positive, U_C

[1] Apart from the debate on the consideration of population growth and the introduction of other production factors, we abstract from these points, in order to isolate the effects of natural resources on economic growth and the environment.

> 0, but decreasing, $U_{CC} < 0$. On the other hand, pollution reduces utility, $U_P < 0$, but at an increasing rate, $U_{PP} > 0$.

Individuals maximize intertemporal utility subject to the budget constraint, $\dot{B}_t = i_t B_t - C_t - T_t$, where *B* represents the assets owned by individuals and corresponds to the monopoly gains given that consumers are also shareholders of the monopoly firms, *i* is the interest rate and *T* is a lump-sum transfer from the government. The maximization condition for consumers, which results from the maximization behavior described before, is the usual:

$$g_{C_t} = i_t - \rho \tag{2}$$

where ρ is the discount rate, g_x is the growth rate of any variable x, and $g_{C_t} = g_{Y_t}$ since, in steady-state, consumption is a given proportion of the output ($C_t = \gamma Y_t$). This expression reflects that individuals postpone consumption if saving (i.e., earning the return rate) compensates for the time-preference rate and the consumption's marginal value change.

The government imposes a tax (τ_t) on the consumption of *F* which generates polluting emissions and gives a direct subsidy to *R* extraction/production (σ_t). The government's budget is balanced each time and the revenues from the tax are used to finance the subsidy and the lump-sum transfer to consumers. This shows that the article could be related to the Green Tax Reform literature. However, that is beyond our scope.

2.1 Constant costs

As referred, initially, extraction/production costs are constant. Therefore, there is no endogenous TC mechanism. In equilibrium, output or final-goods are used for consumption and resources production/ extraction, $Y_t = C_t + c_R R_t + c_F F_t$, where *Y* is the final output; c_R is the constant extraction cost faced by the *R* monopolist; c_F is the cost faced by the *F* monopolist; R_t is the amount of *R* consumed at time *t* and F_t is the amount of *F* consumed at time *t;* the final-good price is normalized to one.

<u>Final-goods sector</u>

For simplicity, no capital or labor are considered and, as referred, we assume no population growth so that all aggregate variables can be interpreted as *per capita* quantities. There are *N* (*n* = 1,..., *N*) final-goods producers who face perfect competition. Each firm has the following production function:

$$Y_{n,t} = \phi {R_{n,t}}^{\alpha} {F_{n,t}}^{1-\alpha} \tag{3}$$

where ϕ is a parameter representing the general efficiency of the economy, α can be interpreted as the elasticity of output in relation to *R* and $(1-\alpha)$ the elasticity of output in relation to *F*. Following the relevant literature, we use the Cobb-Douglas production function (Fisher and Newell, 2008; Di Vita, 2006; Barbier, 1999; Stiglitz, 1974; Smith, 1974). This function implies that the two types of resources are imperfect substitutes, i.e., the two are always necessary for production and no resource will be completely driven out of the market – which does not affect the qualitative results of our analysis.

The use of fossil fuels generates polluting emissions, $E_{n,t} = \psi F_{n,t}$, where ψ is an efficiency parameter.

These final-good firms maximize the profit function:

$$\pi_{Y_{n,t}} = 1\, Y_t - p_{R_t} R_{n,t} - p_{F_t} F_{n,t} - \tau_t F_{n,t}$$

subject to the production function, where: (i) as referred, the final-good price has been normalized to one; (ii) p_R and p_F are, respectively, the price paid for *R* and *F*. The first order conditions (FOCs) give the demand functions of *R* and *F*, respectively, which may by aggregated for all economy ($\sum_{n=1}^{N} R_{n,t} = R_t,\ \sum_{n=1}^{N} F_{n,t} = F_t,\ \sum_{n=1}^{N} Y_{n,t} = Y_t$):[2]

$$R = \left(\frac{\alpha\phi}{p_R}\right)^{\frac{1}{1-\alpha}} F \tag{4}$$

$$F = \left(\frac{(1-\alpha)\phi}{p_F + \tau}\right)^{\frac{1}{\alpha}} R \tag{5}$$

The demand functions show the degree of complementarity between the two types of resources since the amount used of one resource increases the use of the other. However, since *F* consumption generates pollution, to achieve economic growth without harming the environment, it will be necessary to replace *F* for *R*. This is the governments challenge in this model. To carry on with the equilibrium analysis, next, we determine the *R* and *F* supply functions.

<u>Renewable resources sector</u>

In this sector there is a monopolistic firm which "extracts" resources and sells them to final-goods producers. For now, this firm faces a constant extraction cost, c_R. We do not consider scarcity or regeneration for *R* and, hence, we are not focusing on truly extractable resources. Thus, those costs are not necessarily physical extraction costs, they may refer to costs of building wind parks, or dams, or electricity generation costs.

In each period, the monopolist chooses the price p_{R_t} to maximize profits:

$$\pi_{R_t} = \left(p_{R_t} + \sigma_t - c_R\right) R_t$$

subject to the demand function, (4). From the FOC we have the *R* supply function:

$$p_R = \frac{c_R - \sigma}{\alpha} \tag{6}$$

As expected, the cost of using *R* increases with extraction/production costs, but decreases with the subsidy. Additionally, the subsidy has to be lower than c_R, otherwise the price would be negative. It is also possible to see that $g_{p_R} = -\left(\frac{\dot{\sigma}}{c_R - \sigma}\right)$, i.e., the *R* price decreases at a rate proportional to the increase in the subsidy.

Gathering the demand and the supply functions, we obtain *R* consumption:

[2] To simplify notations, we suppress the time argument *t* and will do so in most of the following deductions.

$$R = \left(\frac{\alpha^2\phi}{c_R - \sigma}\right)^{\frac{1}{1-\alpha}} F \tag{7}$$

Given the governments goals of maintaining or increasing output and decreasing emissions, the subsidy will be fundamental in order to promote an increase in *R* use.

Non-renewable resources sector

In the *F* sector there is also a monopolistic firm which extracts resources and sells them to final-good producers. The behavior of this firm is similar to the one in the renewables sector. However, it faces an additional aspect which is resource scarcity. The *F* stock/reserves evolves according to the following motion law: $\dot{S}_t = -F_t$. Thus, $g_{S_t} = -\frac{F_t}{S_t}$. As before, extraction costs for *F*, c_F, are constant.

The monopolist intertemporal profits are given by:

$$\pi_{F_t} = \int_0^\infty e^{-\rho t}\{[(p_{F_t} - c_{F_t})F_t] - \lambda_t F_t\}\, dt$$

He/she maximizes intertemporal profits subject to the demand function of final-good producers (5), and the reserves motion law. After substitution, the Current Value Hamiltonian (*CVH*) is:

$$CVH = (p_{F_t} - c_{F_t} - \lambda_t)\left(\frac{(1-\alpha)\phi}{p_{F_t} + \tau_t}\right)^{\frac{1}{\alpha}} R$$

where λ_t is the dynamic multiplier of the *F* stock, i.e., the variation in profits induced by an infinitesimal change in *F* reserves. The FOCs give, respectively, the *F* supply function and the law motion of the shadow price:

$$p_F = \frac{c_F + \lambda + \alpha\tau}{1-\alpha} \tag{8}$$

$$\frac{\dot{\lambda}}{\lambda} = \rho \tag{9}$$

The *F* supply function shows, as expected, that the cost of using *F* increases with extraction costs and with the tax on emissions. The higher the tax level, the more expensive it will be to use *F* because they generate pollution. Both in the *R* and in the *F* sectors, the policy instruments are directly reflected in the cost of using the resources. However, the tax is paid by final-goods firms, hence its effect is affected by α. The demand and supply functions, together, give *F* consumption:

$$F = \left(\frac{(1-\alpha)^2\phi}{c_F + \lambda + \tau}\right)^{\frac{1}{\alpha}} R \tag{10}$$

The simultaneous use of the tax and the subsidy allows us to change relative prices in order to stimulate *R* use and discourage *F* use (if the subsidy is positive). From *F* and *R* expressions, we obtain the expression that represents resource substitution in our model:

$$\frac{R}{F} = \left(\frac{\alpha^2\phi}{c_R - \sigma}\right)^{\frac{1}{1-\alpha}} = \left(\frac{c_F + \lambda + \tau}{(1-\alpha)^2\phi}\right)^{\frac{1}{\alpha}} \tag{11}$$

A higher tax and a higher subsidy increase $\frac{R}{F}$.

Proposition 1: *If the subsidy is increasing and/or the tax is non-decreasing, the growth rate of R use is higher than the growth rate of F use, which means a continuously increase in the share* $\frac{R}{F}$.

Proof: Appendix B.1.

Given the previous relationship, the tax and the subsidy are related in the following way:

$$\sigma = c_R - \frac{\alpha^2 \phi^{\frac{1}{\alpha}} (1-\alpha)^{\frac{2-2\alpha}{\alpha}}}{(c_F + \lambda + \tau)^{\frac{1-\alpha}{\alpha}}} \tag{12}$$

Proposition 2: *With only a carbon tax and a subsidy to renewables extraction/production, the values of the two policy instruments are necessarily connected through a stable relationship: a higher tax allows having more revenue to provide a higher subsidy. Additionally, it is necessary that* $0 < \sigma < c_R$ *and* $\tau > \frac{\alpha^{\frac{2\alpha}{1-\alpha}} \phi^{\frac{1}{1-\alpha}} (1-\alpha)^2}{c_R^{\frac{\alpha}{1-\alpha}}} - c_F - \lambda$.

Proof: Appendix B.2.

For the environment-economic growth dilemma, we consider the ratio:

$$\frac{E}{Y} = \frac{\psi(1-\alpha)^2}{c_F + \lambda + \tau} = \frac{\psi(c_R - \sigma)^{\frac{\alpha}{1-\alpha}}}{\alpha^{\frac{2\alpha}{1-\alpha}} \phi^{\frac{1}{1-\alpha}}} \tag{13}$$

A higher tax and a higher subsidy decrease $\frac{E}{Y}$.

To comprehensively analyze the relationship between the environment and the economy, we need to consider both output and emissions levels and their growth rates, indicating present and future levels. To obtain the growth rates we use the Hotelling rule and the equilibrium conditions. Appendix A.1 shows the deduction of the conditions:

$$g_Y = i - \left(\frac{\dot{\tau}}{c_F + \tau}\right) \tag{14}$$

$$g_F = g_Y - g_{(p_F + \tau)} = i - \left(\frac{\dot{\tau}}{c_F + \tau}\right) - \left(\frac{\lambda\rho + \dot{\tau}}{c_F + \lambda + \tau}\right) \tag{15}$$

Proposition 3: *In equilibrium, if the tax is non-decreasing, emissions grow slower than the output, i.e., there is a continuously decreasing level of emissions per unit of output* ($\frac{E}{Y}$).

Proof: Appendix B.3.

We may calculate another important ratio, $\frac{g_E}{g_Y}$, which represents the elasticity of emissions in relation to output:

$$\frac{g_E}{g_Y} = 1 - \frac{(\lambda\rho + \dot{\tau})(c_F + \tau)}{(c_F + \lambda + \tau)(i(c_F + \tau) - \dot{\tau})} \tag{16}$$

$$= 1 - \frac{\alpha\dot{\sigma}(\alpha^{\frac{2\alpha}{1-\alpha}}\phi^{\frac{1}{1-\alpha}}(1-\alpha)^2 - \lambda(c_R - \sigma)^{\frac{\alpha}{1-\alpha}})}{(1-\alpha)(c_R - \sigma)\left[i\alpha^{\frac{2\alpha}{1-\alpha}}\phi^{\frac{1}{1-\alpha}}(1-\alpha)^2 - \lambda(c_R - \sigma)^{\frac{\alpha}{1-\alpha}} - i\dot{\tau}\right]}$$

Both the tax and the subsidy have an uncertain effect on this elasticity.

3. EMPIRICAL SIMULATION

We have already analyzed some important relationships in our model. Now, we perform an empirical analysis focusing on two main relationships: the relation between the amount of renewable resources and non-renewable resources used (representing resource substitution) and the relation between emissions and output (representing compatibility between economic growth and the environment). We study several scenarios and determine the policy values in each one. We also draw some graphics on the evolution of the main variables. First, we describe the calibration process and then we present scenario results. Since knowledge accumulation plays a role similar to the subsidy and we have no specific policy tool to promote it, we focus on the case where extraction/production costs are constant.

3.1 Calibration

To calibrate the initial extraction/production cost values, we focus on the electricity sector and consider the example of the United States of America (the USA). For simplicity, we focus on only one *F* and one *R* for electricity generation, taking into account the productive structure of the generation sector. We opt for coal since it is the most used and cheapest non-renewable generation source. For renewable sources, we exclude hydropower because it is already a mature source. We choose, instead, to focus on wind power. This renewable source has presented a significant growth in the last years and has become closely competitive with other sources. Our base year is 2010.

For the costs of using *F* and *R* we use the levelised cost of electricity (LCOE) which allows a more accurate comparison between such different technologies based on NEA (2010). We consider $c_F = 0.07249$ and $c_R = 0.1012$.

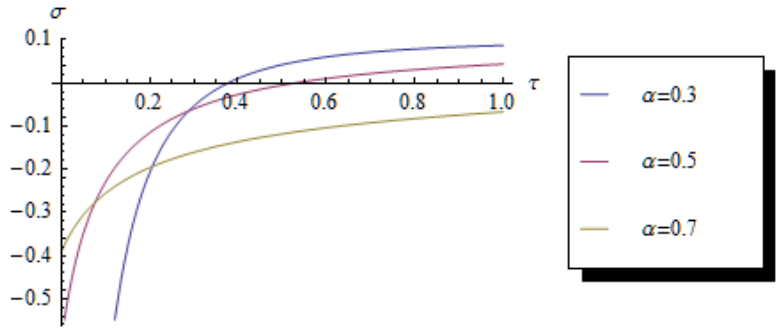
In line with Lin and Zhang (2011), the shadow price of coal is set at $39.8\ USD\ /ton$. If we convert this to MWh, knowing that the electricity generated by the *ton* of coal is

approximately 2.46 MWh/ton, we obtain a shadow price of $16.18\ USD\ /MWh$ or $0.01618\ USD\ /kWh$.

The discount rate is 2% (e.g., Chakravorty *et al.* 1997; Kurosawa, 2004) and we consider an interest rate of 3%, which is in line with, for example, Davidson and Segerstrom (1998). For simplicity, we assume $\psi = 0.1$. For the largest part of the simulation, we consider the same elasticity of output for both resource types ($\alpha = 0.5$), however, initially, we perform a sensitivity analysis considering also $\alpha = 0.3$ and $\alpha = 0.7$. In line with Afonso (2012), ϕ is assumed to be 1. For the analysis of higher tax levels we assume there is a onetime increase in τ, i.e., it increases once and does not increase anymore, such that $g_\tau = 0$.

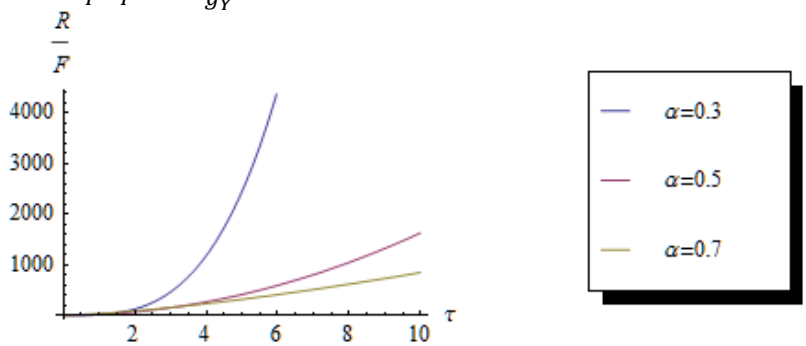
3.2 Empirical results

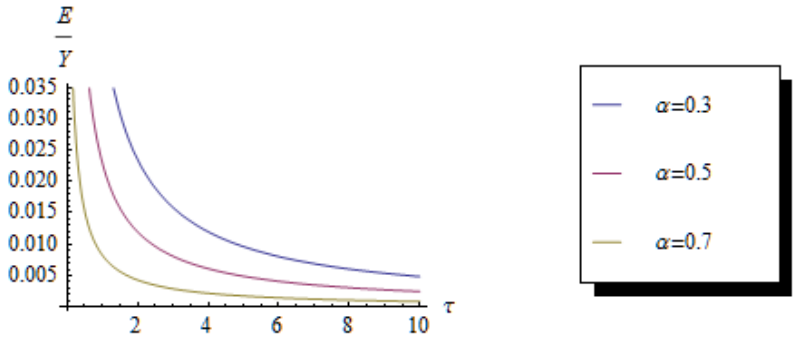
Using the calibration described above, and performing a sensitivity analysis for α, we obtain the following relationship between the tax and the subsidy:

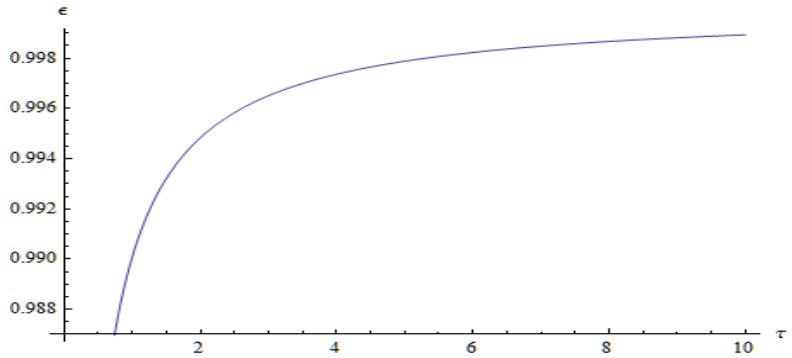


For $\alpha = 0.5$, we know that $0 < \sigma < 0.1012$. For that value we have that $\tau > 0.528919$. If the renewables elasticity is 0.3, the subsidy becomes positive earlier, while for a higher renewables elasticity it never becomes positive. Additionally, we see that the subsidy value is always relatively low when compared to the tax level.

The evolution of $\frac{R}{F}$, $\frac{E}{Y}$ and $\frac{g_E}{g_Y} = \varepsilon_{E,Y} = \varepsilon$ are as follows:

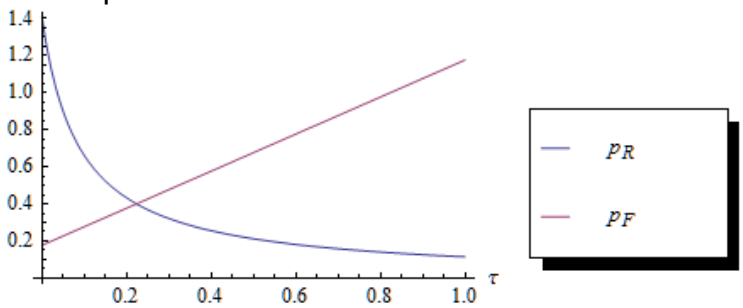






For all values of α, with a higher tax (and consequently a higher subsidy), $\frac{R}{F}$ increases (the increase is more pronounced the lower α) while $\frac{E}{Y}$ decreases (higher α represents a lower emissions *per* output ratio for all levels of τ), which is consistent with Fig. 1. This shows that the joint use of both policy tools helps to improve the trade-off between economic growth and the environment as the economy relies more intensively on renewable resources than on non-renewable resources. It is however noticeable, from the elasticity of emissions in relation to output, that the environmental-economic benefits of increasing the tax are decreasing. This elasticity is not affected by different α values.

For the following analysis we consider $\alpha = 0.5$. We may analyze the relationship between the resources prices:



p_R always decreases but at a faster rate for low tax levels, p_F increases at a steady rate. Using *F* is cheaper than using *R* if $\tau < 0.223317$. This shows that even for non-positive *R* subsidies, renewables become cheaper than non-renewables through the tax effect.

We now compare the equilibriums obtained for several policy values, including when the tax and the subsidy are used alone. Results are summarized on Table 2.

Table 2. Scenario comparison

	Case 1	Case 2	Case 3	Case 4	Case 5
$\boldsymbol{\sigma}$	***-0.603661***	***-0.0991289***	***0***	***0.0104454***	***0.1010***
$\boldsymbol{\tau}$	***0***	***0.223317***	***0.528919***	***0.6***	***312.411***
p_R	1.40972	0.400658	0.2024	0.181509	0.0004
p_F	0.17734	0.400658	0.706259	0.77734	312.589
$\frac{R}{F}$	0.125798	1.55737	6.10266	7.58826	1.5625×10^6
$\frac{E}{Y}$	1.12778	0.0801315	0.04048	0.0363019	0.00008
$\varepsilon_{F,Y} = \frac{g_F}{g_Y}$	0.87835	0.965426	0.982534	0.984337	0.999965

Case 1 corresponds to the hypothetical situation where the subsidy is used alone. Using the equilibrium relationship $\frac{R}{F} = \left(\frac{\alpha^2\phi}{c_R - \sigma}\right)^{\frac{1}{1-\alpha}} = \left(\frac{c_F+\lambda+\tau}{(1-\alpha)^2\phi}\right)^{\frac{1}{\alpha}}$, with a zero tax level, we determine that $\sigma = -0.603661$. A negative subsidy corresponds to a tax on *R* use, which, in this case, determines that $\frac{R}{F} < 1$ and $\frac{E}{Y} > 1$. This situation is not desirable under the environmental perspective.

Case 2 is when the prices for both resources are equal, but the subsidy is still negative. Even in that situation we see that $\frac{R}{F} > 1$, that is, the economy chooses to use *R* more intensively and for that reason $\frac{E}{Y}$ decreases significantly when compared to Case 1.

Case 3 corresponds to the situation where the tax is used alone. There is a significant increase in $\frac{R}{F}$, indicating resources substitution and decrease in $\frac{E}{Y}$, indicating more compatibility between economic growth and the environment.

Case 4 was chosen to represent a situation where the subsidy is positive but not maximum. It is possible to see that for the subsidy to achieve its maximum value the tax tends to infinity. Hence, in Case 5, we chose the subsidy value of 0.1010 which corresponds to a very high tax. These two cases show how sensitive the tax value and $\frac{R}{F}$ are to an increase in the subsidy. The emissions elasticity shows that marginal benefits of increasing the tax are decreasing. This analysis shows that there is only one equilibrium value for the ratios of renewables over non-renewables and emissions over output. The use of the two instruments together allows several equilibrium combinations which can be determined by the economic-environment agenda. Additionally, if a government wants to use both policy instruments, the tax has to be higher than 0.528919 for the subsidy to be positive.

Summing up, we may conclude that a higher tax (with the corresponding higher subsidy) promotes resource substitution, allowing more compatibility between economic growth and the environment. However, the elasticity of emissions in relation to output increases with the tax, i.e., the marginal benefits of a higher tax are decreasing.

4. CONCLUSIONS AND POLICY IMPLICATIONS

We built an equilibrium model to analyze the interaction and compatibility between economic growth and a cleaner environment when there is resource substitution and policy interaction. We have considered two policy tools: a tax on emissions and a subsidy to renewables extraction/production. First extraction/production costs are constant and, in an extended model, renewables' producers may invest in knowledge to decrease those costs.

The theoretical analysis shows that both a higher tax and a higher subsidy, promote resource substitution, contributing to a relatively greener economy and improving the economic growth-environment dilemma. An increasing subsidy and/or a non-decreasing tax continuously increase the renewables intensity of production and a non-decreasing tax continuously decreases the emissions *per* output ratio. The two policy instruments need to be used simultaneously and remain within a given interval. The tax alone decreases both emissions and output while the subsidy alone increases both. Additionally, the knowledge stock in the renewables sector plays a complementary role to the subsidy.

The empirical analysis highlights that the use of the two instruments together allows several equilibrium combinations which can be determined by the economic-environment agenda. Finally, the marginal benefits of a higher tax are decreasing and hence, a moderated tax level is desirable. However, it is evident that the higher the tax, the larger the efforts demanded to tax payers and since there are decreasing marginal benefits from imposing a higher tax, the ideal would be to impose a moderate tax level.

This article provides interesting insights to the economic growth-environment debate. For future research, it would be interesting to analyze the differences between the direct subsidy to renewables extraction/production and a subsidy to knowledge accumulation in this sector.

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Appendix A.1 - equilibrium derivation
For simplicity, we will ignore time subscripts in the following derivations.
The monopolist total revenue (TR) is given by $(p_F - c_F)F$. Knowing that $p_F = \frac{c_F+\lambda+\alpha\tau}{1-\alpha}$, the marginal revenue (MGR) is given by $\frac{\alpha c_F+\lambda+\alpha\tau}{1-\alpha}$ and the growth rate is $\frac{\dot{MGR}}{MGR}$.
<u>Constant costs</u>
With constant costs, $\dot{MGR} = \frac{\partial MGR}{\partial c_F} \times \underbrace{\dot{c_F}}_{0} + \frac{\partial MGR}{\partial \lambda} \times \dot{\lambda} + \frac{\partial MGR}{\partial \tau} \times \dot{\tau} = \dot{\lambda} + \alpha\dot{\tau}$. Then $g_{MGR} = \frac{\alpha\dot{\tau}+\dot{\lambda}}{\alpha c_F+\lambda+\alpha\tau}$. The Hotelling rule gives (considering that $\dot{\lambda} = \lambda\rho$):

$$\rho = \frac{\alpha\dot{\tau} + \lambda\rho}{c_F + \lambda + \alpha\tau}$$

If we solve this expression in order to ρ, and replace it in (2), the output growth rate is given by:

$$g_Y = i - \left(\frac{\dot{\tau}}{c_F + \tau}\right)$$

From the final-goods production function, $g_Y = \alpha g_R + (1-\alpha) g_F$ or $g_R = \frac{g_Y - (1-\alpha) g_F}{\alpha}$. F consumption gives: $g_F = -\frac{1}{\alpha} g_{(p_F+\tau)} + g_R$. Therefore, $g_F = g_Y - g_{(p_F+\tau)}$. With $g_{(p_F+\tau)} = \frac{\dot{\lambda}+\dot{\tau}}{c_F+\lambda+\tau}$ and $\dot{\lambda} = \lambda\rho$, we have:

$g_F = g_Y - \left(\frac{\lambda\rho+\dot{\tau}}{c_F+\lambda+\tau}\right) = i - \left(\frac{\dot{\tau}}{c_F+\tau}\right) - \left(\frac{\lambda\rho+\dot{\tau}}{c_F+\lambda+\tau}\right)$.

Appendix B.1

From the R consumption, we know that $g_R = -\left(\frac{1}{1-\alpha}\right) g_{(c_R-\sigma)} + g_F$, where $g_{(c_R-\sigma)} = g_{p_R} = -\left(\frac{\dot{\sigma}}{c_R-\sigma}\right)$. Therefore, we know that R grows faster than F if $\left(\frac{1}{1-\alpha}\right)\left(\frac{\dot{\sigma}}{c_R-\sigma}\right) > 0$.

From the F consumption, we know that $g_F = -\left(\frac{1}{\alpha}\right) g_{(c_F+\lambda+\tau)} + g_R$, where $g_{(c_F+\lambda+\tau)} = g_{(p_F+\tau)} = \frac{\lambda\rho+\dot{\tau}}{c_F+\lambda+\tau}$. Hence, $g_R = g_F + \frac{\lambda\rho+\dot{\tau}}{c_F+\lambda+\tau}$. And we know that $\lambda\rho > 0$.

Appendix B.2

The subsidy needs to be positive to promote renewables use. Solving the relationship $\sigma = c_R - \frac{\alpha^2 \phi^{\frac{1}{\alpha}} (1-\alpha)^{\frac{2-2\alpha}{\alpha}}}{(c_F+\lambda+\tau)^{\frac{1-\alpha}{\alpha}}}$ and solving it in order to the tax level, to obtain a positive subsidy it is necessary that $\tau > \frac{\alpha^{\frac{2\alpha}{1-\alpha}} \phi^{\frac{1}{1-\alpha}} (1-\alpha)^2}{c_R^{\frac{\alpha}{1-\alpha}}} - c_F - \lambda$. Additionally, the renewables price has to be positive, which imposes a ceiling to the subsidy: $\sigma < c_R$.

Appendix B.3

We know that $g_F = g_Y - g_{(p_F+\tau)}$ or equivalently $g_Y = g_F + g_{(p_F+\tau)}$. Then, $g_Y > g_F \; if \; g_{(p_F+\tau)} > 0$ i.e, $\lambda\rho + \dot{\tau} > 0$, and we know that $\lambda\rho > 0$, therefore it is necessary that $\dot{\tau} \geq 0$.

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RENEWABLE ENERGY AND GREENHOUSE GAS EMISSIONS FROM THE WASTE SECTORS OF EUROPEAN UNION MEMBER STATES: A PANEL DATA ANALYSIS

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ABSTRACT

This study analyses the effects of environmental variables and the renewable energies generated by the waste sector in relation to the greenhouse gas emissions (GHGs) resulting. The research sample covers a panel of 15 European Union member states with data both on the landfill disposal of waste and on waste generated renewable energies and electricity and deploying the real GDP per capita as a control variable and thus testing the environmental Kuznets curve hypothesis for the 1995-2012 period. Our results demonstrate that recourse to waste as an energy source returns relevant impacts in terms of the replacement of fossil fuels, hence, the consumption of renewable fuels does contribute to reducing GHGs while the electricity produced also has some positive impact on emissions even if far below that which would happen should the waste based generation of renewables not take place. The pollution curve returned is N-shaped and conveys how waste sector economics have not yet managed to resolve the problem with a corresponding need for new economic, institutional and media instruments to further aid in mitigating this situation.

Keywords: EKC-W, GHG emission, Panel Data, Renewable Energy, Waste sector, European Union

1. INTRODUCTION

The recent acceptance of the need to manage natural resources and the surrounding environment has demonstrated fundamental facets inherent to balancing the relationship between human beings and nature in 21st century society. Various studies have shown how economic development results in negative environmental impacts and thereby imposing on modern society major challenges as regards reducing and shrinking the negative externalities associated with human social and economic activities.

Within the global scope of actions, there has been the mitigation of greenhouse gas emissions (GHGs) and, at the regional and local levels, a reduction in the rising amount of waste thrown out has taken place. This overall rise in waste has otherwise

generated concerns whether from the sanitary or the economic point of view and with political, social and environmental impacts (Teixeira et al., 2014; Antonioli and Massaruto, 2012; Sjöstrom and Östblom, 2010; Shemelev and Powell, 2006). In global terms, as a source of GHGs, the waste sector makes a significant contribution towards climate change (Sevigné Itoiz et al., 2013) and incorporates a great deal of uncertainty given how the waste generated shall continue to rise in proportion to the growth in income per capita (Mazzanti and Zoboli, 2008; EEA, 2013).

Despite the positive effects of European policies over the last two decades having led to a substantial reduction in the quantity of waste ending up in landfills and thus significantly boosting the level of treatment, some studies have reported a level of inconsistency in the results attained and correspondingly concluding that the elimination (of the waste products) has yet to be fully resolved with further studies required to bring about the “closure” of this cycle (Magrinho et al., 2009). In addition, the strategic management of waste needs simultaneously aligning with the mitigation of GHGs in order to ensure the attainment of the pollution reduction targets set for 2020.

In order to empirically examine this framework, we formulated a model encapsulating the generation of GHGs by the solid waste sector before applying it to a diverse sample of EU member states and across a temporal horizon consisting of various years (panel sample data). This thereby applies the panel data methodology that the respective literature describes as returning various different advantages in relation to exclusively using sector based or transversal or temporal series data sets. One of these advantages stems from the ability of these models to control for heterogeneity between countries (Hsiao, 2003; Baltagi, 2005; Hill, Griffiths and Judge, 2012).

The first contribution made by this research derives from it providing new facts, figures and conclusions to the current literature as, to the best of our knowledge, there is no other study on GHGs that interrelate these with factors such as the quantity of waste deposited in landfills, the consumption of waste by renewable energy generation, waste based electricity generation, real GDP per capita and that also applies linear, squared and cubed models in which the introduction of technology measured by a proxy duly takes into consideration the specific amount of waste produced in the sample set of EU states and throughout our study period of analysis. We should duly reference that we found only four studies within roughly the same scope and that we are able to inventory. One of them also draws upon panel data to study the relationship between the consumption of non-renewable (primary, fossil energy) and renewable energies (hydro, wind, solar and tidal), economic growth and carbon dioxide (CO2) emissions (Bölük and Mert, 2014) alongside the three others that deal only with the relationship between the consumption of renewable energies and economic growth (Apergis and Payne, 2010; Chien and HU, 2008; and Sardorsky, 2009).

However, this study differs in various core aspects such as its scope, the variables applied and the period taken into account. Furthermore, the study also makes an additional contribution within the terms explored by Rothman (1998), Gawande et al. (2000), Seppälä (2001) and Johnstone and Labonne (2004) in terms of the environmental Kuznets curve (EKC). Thus, this study tests the EKC hypothesis based on the relationship between GHGs, renewable energy consumption and per

capita income and specifically by the waste sector. This aligns with the belief that it is essential to analyse these relationships in order to assist decision makers in drafting effective and efficient environment policies whether for the waste sector in particular or to guide stakeholders more generally in preparing for and taking political decisions to combat global warming and the problems deriving from the appropriate elimination of waste.

Thus, the main objective of this research is to examine the influence of solid waste generated renewable energy consumption within the scope of strategies to partially mitigate GHGs from this sector in the EU and alongside the secondary objective of testing the EKC curve as its respective identification may reveal an important economic (waste market) contribution to resolving this problem whilst its absence (an inverted-U) or its presence in an N shape may reveal even greater environmental problems should the market not be placed under an adequate regulatory system.

The remainder of the article is organised as follows; in the second section, we set out some of the waste generation indicators, GHG emissions, treatment methods and alongside a brief and current review of the literature. The third section deals with both the methodology applied and some of the preliminary empirical results before the fourth both sets out and discusses the estimated results returned. Finally, we close by summarising some of the most important research results and propose some environmental policy measures capable of contributing towards resolving GHG related problems and global warming through ensuring the economy and society engage in more environmentally friendly waste management processes.

1.1 Waste generation indicators, GHG emissions and treatment measures: the empirical evidence

The waste sector emits three types of polluting gases; CO2, methane gas (CH4) and nitrous oxide (N2O) in addition to three fluoride gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6)) (EUROSTAT, 2014; IPCC, 2006). The sector's emissions account for between 5.5 and 6.4% of total GHGs (Zuberi and Ali, 2015). The United Nations Framework Convention on Climate Change (UNFCCC) duly takes these emissions into account and distributes them according to the processes they result from: (i) depositing in landfill sites; (ii) incineration and (iii) the recycling of materials3 (Hoornweg and Bhada-Tata, 2012; EUROSTAT, 2014).

It was over the course of the last two decades that a growing consensus grew up around the scale of this problem that correspondingly began raising public concern in a movement that triggered the implementation of various strategic waste management plans in various developed countries. This has proven particularly the case in the European Union (EU) (EEA, 2013) where member states have had to adopt new norms and obligatory targets included within the scope of the energy and climate change package approved by the EU: a 20% reduction in GHGs on 1990 levels (EC, 2012) and generating 20% of energy consumption from renewable sources with specific and concrete measures for electricity, heating and cooling and the biofuel sectors (www.reshaping-res-policy.eu, 2015). In this context, the waste sector has received particular attention, especially as regards improving the

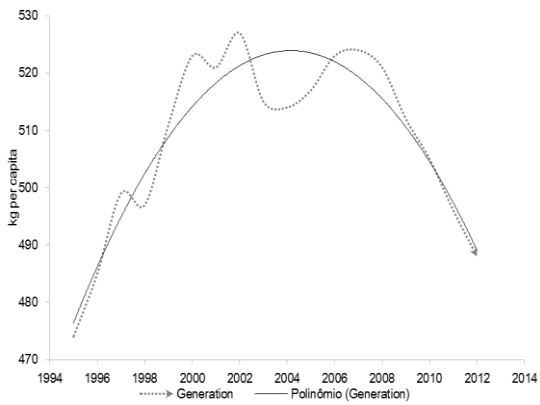
3 This refers to the recycling of both organic and non-organic materials (EUROSTAT, 2014)

efficiency of waste management and the capacities in place for treatment (EUROSTAT, 2014; Mazzanti and Zoboli, 2008). The EU has a priority political agenda strongly focused on the sector that combines technology and the reconversion and recovery of waste turning such into renewable resources within the overall goal of returning benefits from the means of this waste conversion in terms of energy and thus also helping in resolving the problems surrounding the elimination of waste (Teixeira et al., 2014).

Europe is considered the cradle of energy recovery technologies for the production of renewable fuels (Pirotta et al., 2013; Raj et al., 2011). Methane gas represents one valuable energy source that powers and drives various industrial processes that result in electricity among other purposes (Noor et al., 2013; Zuberi and Ali, 2015). According to the directives handed down by the Intergovernmental Panel on Climate Change (IPCC, 2006), the gas resulting from waste causes the emission of both methane and carbon dioxide, the origins of landfill gas, with such proving the main raw material for the generation of renewable energies. Transforming waste into renewable energies constitutes a fundamental step due to the increase in demand for electricity in the economy as a whole with the enthalpy thereby resulting yet another alternative for raising the provision of this power source (Sadorsky, 2009).

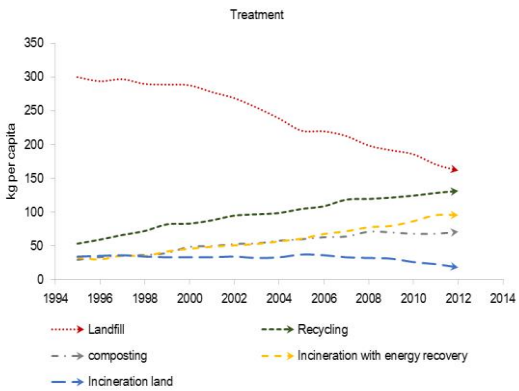
In the EU, the GHG emissions associated with the means of waste disposal, landfill, incineration and material recycling break down into 95%, 3% and 2% respectively (EUROSTAT, 2014). Over the course of the last two decades, treatment processes have been implemented under the auspices of Directives 94/62/CE (packaging), 99/32/CE (landfills) and 08/98/CE (wastes), which have had significant impacts on mitigating the waste generated, the total quantities destined for landfills, the methane gas given off by organic residues and in addition to the recycling of non-organic residues having risen substantially (see Figures 1 and 2) (EEA, 2013).

Figure 1. Intensity of EU-27 waste generation



Source: based on Eurostat data (2014)

Figure 2. Intensity of EU-27 waste treatment



Source: based on Eurostat data (2014)

However, to attain the overall targets established by the EU, serious efforts are required at the member state level. In cases such as Cyprus, Estonia, Greece, Hungary, Malta, Poland and Portugal, there is a need to boost the annual recycling rate by between 2% and 4% annually through to 2020. Only four EU-27 states (Austria, Belgium, Germany and the Netherlands) managed to attain the stipulated recycling rates for the period between 2001 and 2010. The situation proves still more

complicated in the case of five other member states (Bulgaria, Latvia, Lithuania, Romania and Slovakia) that need to boost their annual recycling rates by over 4% per year through to 2020 (EEA, 2013).

The literature conveys how the initial experience of development sees countries produce both more waste and GHGs (pollution) (Granados and Carpintero, 2009). According to Maddison (2006), EKC focused studies assume that the coefficients estimated attain significance and return the expected results and thereby confirming that there is a relationship with the EKC. Whilst a substantial part of the literature surrounding EKC and Waste (EKC-W) does not extend beyond verifying the existence of the inverted-U, some results (such as those from Andersen et al. (2007) for example), do convey how the problematic issues surrounding the pollution caused by waste prove far more complex than might be initially imagined as these questions take on greater consistency in the rationale maintaining the EKC-W takes on an N shape rather than the traditional inverted-U format (Mazzanti and Zoboli, 2008). This dimension to the research literature on waste has received little overall attention. Rothman (1998) reports that he did not find any empirical evidence associating the reduction in waste or a downturn in the level of waste emissions taking place in conjunction with rising income levels per capita before affirming that the evidence for the inverted-U in the waste sector is only applicable to a specific number of cases.

In this sense, the research that we were able to inventory from the literature on EKC-W broadly divides into two subgroups with the first containing research projects adopting “cross-section” and “time-series” data analysis. For example, Beede and Bloom (1995) explore statistics on the generation of waste structured into these two forms and as reported by 36 countries. The results reveal that the generation of waste is positively associated to the EKC and that the latter is inelastic in terms of income per capita and elastic according to population size. Berrens et al. (1997) apply only “cross-section” data for a single country and only for the category of hazardous waste and returned empirical findings compatible with the EKC hypothesis whilst emphasising that the interrelationship between the variables in the formulation of the inverted-U curve themselves incorporate a diverse range of interpretations.

The second group contains panel data based analysis. One of the major advantages of analysis structured in this way derives from how this enables both the expansion of and the increase in the number of observations gathered within the “time-series” and “cross-sections”, which renders the analysis more statistically robust by enabling an increase in the number of degrees of liberty and their respective efficiency and contrary to research that applies only temporal data and/or only transversal data with the results varying in accordance with the sample, its temporal scope and the econometric techniques applied (Pao and Tsai, 2010; Ozcan, 2013; Baltagi, 2005). One of the first works applied to waste as an indicator of environmental quality through recourse to this type of data analysis came from Cole et al. (1997) with these authors launching studies on EKC-W by adopting hazardous wastes and pollutants as their dependent variable. Their results demonstrate that across a broad range of environmental indicators reported by OECD member states, the EKC was significant only for gaseous wastes and correspondingly failing to identify any inverted-U for organic and non-organic wastes (municipal solid waste – MSW).

While some studies do portray measures for growth and consumption to evaluate the levels of pollution, as is the case with Rothman (1998) for example, there are other instances when the tendency to reduce pollution as a function of income is not well defined with MSW constituting one example: firstly, as this incurs local and easily externalised environment impacts; and secondly, due to the high level of costs incurred in controlling and managing such wastes. Within this scope, according to Stern et al. (1996) and Ekins (1997), authors who set out a systematic and detailed revision of the literature on EKC, and in addition to Rothman (1998), the majority of environmental conditions do not improve with advances in economic growth rates due to the fact that their negative effects are restricted only to specific social groups.

Gawande et al. (2000), in interrelating internal migration in the United States with the sites of hazardous waste storage, returns empirical evidence in favour of a EKC-W based on the movement of wealthy families away from polluted sites (landfills). Seppälä et al. (2001) also employ panel data but did not return any empirical evidence for the EKC-W for material flows between five industrialised countries between 1970 and 1994. In turn, Johnston and Labonne (2004) apply a range of statistics to OECD member states spanning the rate of MSW generation, economic and demographic variables and reporting findings in favour of an EKC-W.

In accordance with the conclusions in the literature testifying to how the EKC-W has not yet been fully clarified, this research project therefore extends the analysis in the sense presented by Rothman (1998) and advancing still further the discussion surrounding the compatibility between the waste sector variables identifying the presence of an EKC-W. As Cole et al. (2005) propose, the intensity of pollution represents a positive function of energy usage and the intensity of the natural/material capital deployed in the economy with renewable energies deriving from sources of waste simultaneously serving as both a source of energy and of mitigating solid and gaseous wastes.

2. ECONOMETRIC MODEL

The scope of the framework in terms of the research variables and econometric techniques available in the literature span a variety of procedures applied for the identification of EKCs, whose results vary in accordance with the respective choice of approach made by the researcher (Harbaugh et al., 2002). The relationships between the environment and economic development may be obtained by three types of specifications for the EKC hypothesis. In general terms, the equation commonly gets expressed as follows:

$$P_t = \beta_0 + \beta_1 Y_t + Z_t + \varepsilon_t \qquad (1)$$

where Pt is the proxy designated to represent per capita environmental pollution, Yt represents income per capita, Zt conveys external factors such as technology or the regional characteristics of each individual (country) for example and ε provides the term of error supposedly with a null average and constant variance. Where β_1>0, we may state that any increase in income per capita produces a linear rise in pollution. However, where β_1<0 this relationship decreases evenly and steadily. In both cases, the relationship only proves valid when the coefficients attain statistical significance.
In the second case, equation (2):

$$P_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + Z_t + \varepsilon_t \quad (2)$$

An EKC could be achieved where β_1>0, β_2<0 with this correspondingly reflecting how the rise in pollution in conjunction with increasing income in the early phases of development may eventually enter into a reduction as from a particular point of inflection caused by the level of income at a particular moment. In other words, the point of inflection emerges out of the adjustments made by the first and the second derivatives in relation to income per capita and forming an inverted-U shaped curve.

As there are a series of econometric procedures testing the EKC hypothesis, the inclusion of the cubic term might prove of relevance to research in enabling greater flexibility in the subsequent modelling. Through applying the following equation 3, the results returned may convey a function presenting an EKC in the form of an N whenever also meeting certain criteria (Torras and Boyce, 1998):

$$P_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_3 \mathrm{Y}_t^3 + Z_t + \varepsilon_t \quad (3)$$

In this case, where β_1>0, β_2<0 and β_3>0, the relationship between pollution and income per capita may be obtained. However, where the coefficients are returned with inverted signs, β_1<0, β_2>0 and β_3<0, this may identify a mirrored format taking an S shape (Hervieax and Darne, 2013; and Huang et al., 2008).

Therefore, we decided to apply equation (3) in this project as, in the case that the squared term of income per capita does not prove able to identify an inverted-U, the cubic term of income might serve to aid in portraying the true situation and involving the diverse factors simultaneously contributing to environmental degradation and resulting in renewable energies such as is the case with solid wastes. Indeed, adopting this procedure may clarify many doubts about EKC-W such as how the function might be better indicated for this type of research. Thus, jointly analysing all of the factors, especially whenever faced by the presence of an inverted-U, would provide an insight into whether this economic sector is proving able to overcome such problems and, in its absence or whenever in the presence of an N-shaped EKC-W, additionally portraying the existence of more serious problems should the market not be experiencing an appropriate level of environmental regulation.

Hence, the waste sector GHG emissions of fifteen European Union member states were selected in accordance with the economic, environmental and energy variables from the respective sector and then subject to modelling. The regression model to examine the impact of these indicators based upon the EKC-W conceptual model may be set out as follows:

$$CO_2W_{it} = \alpha_i + \beta_1 T_{it} + \beta_2 Landfill_{it} + \beta_3 Cren_{it} + \beta_4 EfW_{it} + \beta_5 Y_{it} + \beta_6 (Y_{it})^2 + \beta_7 (Y_{it})^3 + \varepsilon_{it} \quad (4)$$

where i= 1, 2, ..., N represents the i-th country in the panel, t=1,2, ...,T (trend), the time period, CO_2W_{it} total waste sector GHG emissions in thousands of tCO2 eq per capita; Landfillit the quantity of waste disposed of by such means, in kg per capita/year; Crenit the renewable energy fuel quota extracted from waste as a percentage of total energy consumption corresponding to both solid and liquid

biomass, industrial wastes and MSW; EfWit conveys the waste generated electricity in tons per capita of oil equivalent – TOE; Yit represents real GDP per capita, and Y2it is the squared of GDP real per capita; and Y3it is the cubic term of real GDP per capita in constant 2005 dollars; εit is the term of error supposedly with a null average and constant variance.

The tendency towards a deterministic T was included in the model in order for this proxy to take due and specific account of technological development (Fredriksson and Vollenbergh, 2009) and other external factors such as the wastes generated by all panel countries as well as the respective period of analysis. The data on GHG sector emissions transformed into CO2W eq, direct means of disposal (landfill) and the electricity generation from waste sources (EfW) were accessed from the Eurostat database while the data on real GDP per capita (Y) and renewable energies (Cren) were drawn from the World Bank World Development Indicators (WDI).

For the β_1 parameter, a negative result is expected in accordance with technological progress serving to inhibit emissions over this period of time. For the β_2 parameter, however, a positive result is expected whilst again returning to the negative expectations as regards the β_3 parameter. Hence, whenever there is an increase in the quantities of waste going into landfills, the GHG emissions will return a positive impact; in contrast, however, where there is a rise in renewable energy consumption, the GHG emissions get reduced and thereby expecting the β_4 parameter to return a positive result as the generation of electricity produces a net emission of GHGs but lower than those resulting from the production of electricity through recourse to fossil fuels. The interpretation of the other model parameters proceeds in conjunction with the general equations (1), (2) and (3) as regards the EKC.

2.1 Sample characteristics and period of analysis

The number of countries and the timeframes were established in accordance with the availability of the information provided by the respective aforementioned databases. The sample included the following range of countries: Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. The other EU member states were excluded from the sample for returning inconsistent data on the electricity generated from waste variable. The timeframe spans the period from 1999- to 2012 for the Czech Republic and Portugal, 1996 to 2012 for Finland and 1995 to 2012 for the remainder of the panel. All the series were converted into natural logarithms in accordance with that stipulated by the literature and thereby reducing data heteroscedasticity/variance.

2.2 Preliminary data processing

In this study, we applied the centred values for the independent variables, thus, this proceeded with the removal of the averages for each country and, based on linear real GDP per capita, this correspondingly returned the squared and cubed forms of the model. According to Böluk and Mert (2014), this approach reduces multicollinearity among the variables and specifically among the economic variables applied in the models specified in the linear, squared in an inverted-U, and cubed in an N shape that studies on EKC hypotheses have overlooked over many years (Böluk and Mert, 2014). The VIF (variance inflation factors) statistics and the correlation matrix of the explanatory model variable feature in Table 1. The mean

value of coefficient VIF of 3.21 proves that the problem is reduced, thus, the collinearity is not a concern.

Table 1. Correlation matrix with centred variables and the VIF statistic

	CO_2W	Landfill	Cren	EfW	Y	Y^2	Y^3	VIF
CO_2W	1							
Landfill	0.373	1						2.06
Cren	-0.344	-0.677	1					2.33
Efw	-0.222	-0.494	0.556	1				1.93
Y	-0.225	-0.494	0.603	0.647	1			6.19
Y^2	0.038	0.084	-0.114	-0.153	-0.369	1		1.61
Y^3	0.094	-0.241	0.384	0.444	0.832	-0.576	1	5.13
Mean VIF								3.21

Note: 1 obtained with command stat VIF

The approach applied to the panel data extends over the estimation of three models, the fixed effect model (FEM), the random effect model (REM) and the pooled (OLS-PLM) or grouped model with the latter serving as a benchmark. In order to confirm the non-observed effect (εit) does not correlate with the explanatory variable (i.e. that we do not encounter problems with endogeneity), we deployed the Hausman test. This procedure begins by estimating the coefficients or parameters based upon the fixed effect (FEM) and random effect (REM) models before then calculating the variance in the differences between both coefficients taken in conjunction with the same parameter and ends by calculating the probability of the effects of both models being individually equal. In REM model cases, as stated above, we might encounter problems with endogeneity as the independent variables might prove to correlate with the term of error of the regression model, a problem that when existing may stem from errors in measurement, autocorrelation between the errors, the problem of simultaneity and as well as the possible existence of omitted variables.

Based on the results of the Hausman test (χ^2_5 = 13.96 (p-value = 0.015)), the null hypothesis emerged as regards the existence of correlation between the residuals and the regressive variables and correspondingly recommending the utilisation of FEM to better improve the level of analytical efficiency. Based upon this diagnosis, we also undertook certain procedures (tests) to verify for any possible infringements of the base hypothesis and therefore testing for heteroscedasticity and autocorrelation among others. In order to examine for heteroscedasticity among the modelling errors, we applied the Modified Wald Test with the results enabling the rejection of the null hypothesis of homoscedasticity, as (χ^2_{15} = 19912.60 (p-value = 0.000)) and hence explaining the conclusion that the model does report heteroscedasticity among its errors. We also applied the contemporary correlation test through recourse to the Breusch-Pagan statistic for cross-sectional independence for the residuals included in the FEM model (χ^2_{105} = 505.079 (p-value = 0.000)) with the result returned testifying to how the residuals do correlate. We also applied the Woodridge test with the objective of verifying whether there is series

autocorrelation between the same model errors and having obtained F(1,14) = 38.891 (p-value = 0.000) and a result that confirms the presence of autocorrelation in the first order between the model errors. In order to resolve these problems, we once again made recourse to the estimate equation (4), applying the FEM estimators with the standard Driscoll-Kraay errors (1998); robust FE and in addition to the OLS-PLM benchmark as a means of correcting the problems detected and ensuring the robustness of the model estimates and which thus led to the results we present below.

3. THE EMPIRICAL ESTIMATE RESULTS

Based on the newly estimated results (see Table 2), the coefficients prove statistically significant at the 1% and 5% levels with the R-squared result of 0.754. The signs obtained prove in accordance with that stipulated by economic theory for the variables (Landfill, Cren and EfW) with the coefficients statistically significant at the 1% level. Given the fact that waste sector GHGs are heavily influenced by treatment processes such as recycling, composting or converting into energies and depositing in landfills, a 1% rise in landfill depositions brings about a 0.118% increase in tCO2 eq of GHGs with this amount to a greater or lesser extent measuring the contribution of landfills to global warming. On the contrary, however, a 1% rise in the amount of renewable fuel extracted from waste (Cren) results in a reduction of 0.089% in GHG emissions.

For each additional percentage point of EfW, GHG emissions decline by 0.057% tCO2 eq, a result that demonstrates two scenarios as regards opportunity costs: the first is the rising consumption of renewable energies as, according to the IEA (2015), in 2012, the electricity produced through recourse to fossil fuel sources in Europe represented 48.22% against the 1.20% of waste based electricity generation, or, in relation to the 20.86% of the electricity total measured in Gwh produced by all renewable energies in the EU-28. This result conveys how boosting energy availability through recourse to waste generation significantly reduces the quantity of waste being deposited in landfills. The second opportunity cost stems from the reduction in GHG emissions by the sector given that the European Directive 2006/32/CE states that the fossil fuel generation of electricity in the EU, specifically coal, gas and diesel) cause emissions of 3.956 (kg CO2 eq/TOE), 2.897 (kg CO2 eq/TOE) and 3.098 (kg CO2 eq/TOE), respectively, emission factors far greater than the energy generated by landfill site treatment processes.

Analysis of the variables (real GDP per capita (Y), its squared and cubed terms, leads us to infer that the EKC-W curve does not prove consistent with the inverted-U hypothesis but rather with that advocating an N. As this conveys an N curve for emissions, the analysis of function may be divided into three distinct phases as set out below.

In the first, GHG pollution by the waste sector enters into decline alongside GDP coeff. -0.498, with a 5% level of significance and may be related to actions taken at the individual level of public policies focused on the waste sector of each country and at the overall EU level with the Directives 94/62/CE, 99/32/CE and 08/98/CE contributing to reducing the waste heading into landfills. However, the policies have proven to fall short of the level of income per capita in countries with high income per

capita rates as is the case with the majority of European countries. This means that such countries continue to experience very high levels of consumption and consequently generate more waste due to the influence of income per capita.

Table 2. Panel results for waste sector CO2W in the EU-European Union.

Models (dependent variable = CO_2W emission)				
Variables	OLS-PLM	FEM	FEM Robust	FEM D-K.
Cons	-1.8e+01	2.4e+01***	2.4e+01	2.4e+01**
trend	0.004	-0.016***	-0.016	-0.016***
Landfill	0.134***	0.118***	0.118***	0.118***
Cren	-0.233*	-0.089**	-0.089	-0.089***
EfW	-0.001	0.057***	0.057	0.057***
Y	-0.709	-0.498*	-0.498	-0.498**
Y^2	1.696	1.550*	1.550	1.550**
Y^3	2.4e+01	1.7e+01***	1.7e+01*	1.7e+01***
Diagnostic statistics				
N	261	261	261	261
R^2	0.159	0.754	0.754	
R^2_a	0.136	0.732	0.747	
F	6.864***	1.0e+02***	1.4e+01***	1.5e+03***

Note: ***, ** and * are 1%, 5% and 10% significant levels, respectively.

The second phase exactly incorporates the consequences resulting from the influence wielded by income per capita in the first phase as, in the second phase, in which evidence of the inverted-U shaped relationship was expected given the impact of economic development and favouring the reduction in GHG emissions from the waste sector coeff. 1.550, at the 5% significance level, in fact, this coefficient reports that GHG emissions by the sector continue to rise throughout the current phase of development. In the third phase, the level of income per capita drives a still sharper rise in pollution, coeff. 1.7e+01, significant at the 1% level, with this result encapsulating how the economy alone is not able to return a solution for waste and GHG emissions. In this case, there is a need for new institutional policies to adjust to the problem. In turn, the variable t (trend), a proxy used to capture the effects of technologies, proves a very important factor and susceptible to contributing not only towards a better performance in terms of energy generation but also to the reduction in emissions. As would be expected, we did gain empirical evidence that technology reduces emission levels by 0.161% for each additional year as its coefficient also attains statistical significance at the 1%.

Therefore, our model indicates that even in the presence of positive GHG emissions, the conversion of waste into energy represents an attractive alternative for mitigating and whether for the quantity of waste going into landfills or the sector's overall GHG emissions and, still furthermore, resulting in an overall reduction in emissions. These results, while stemming from a different methodological perspective, are in keeping with those of Pirotta et al. (2013), Sevigné Itoiz et al. (2009), Mohareb et al. (2008) and Zuberi and Ali (2015), authors who study the GHG emissions of the waste sector by means of inventories and monitoring emissions throughout the phases of waste elimination and who correspondingly advocate that cutting GHGs and better dealing

with waste requires investment in energy recovery techniques based upon the installation of treatment processes.

In general terms, our study contributes alongside the other research projects in the literature focusing on waste such as Rothman (1998), Seppälä (2001) and Cole et al. (1997), who also did not conclude in favour of the existence of an inverted-U applying waste indicators as a means of environmental quality even whilst these authors did not make any recourse to any EKC-W cubic format. However, our study stands in contrast with those by Gawande et al. (2000), Johnstone and Labonne (2004) and Yanrong et al. (2011), of whom only Yanrong et al. (2011) applied the function structure as a squared terms and the cubed terms for income per capita to test the EKC-W hypothesis. All these authors report empirical evidence of an inverted-U when testing for the EKC hypothesis through recourse to waste, for example. Furthermore, according to Pirotta et al. (2013), one of the principles to converting energies and solid waste mass involves considering future forecasts for waste generation. Within this framework, Andersen et al. (2007) state that there are forecasts of 15% to 20% growth through to 2020 in waste generation per capita for the majority of European countries with Mazzanti and Zoboli (2008) affirming that only a limited number of EU member states shall prove able to stabilise the generation of waste interrelated with economic growth and that countries attaining success in this field will be those setting down management strategies consistent with the diversion of waste from landfills and towards either conversion into renewable energies or for transformation into new raw materials.

Despite the favourable results returned for the utilisation of waste sector derived renewable energies, we would here propose further approaches to identify national standards that may be compared in terms of their performances in relationship to the individual GHG mitigation targets for each country and thus thereby establishing a better understanding around this core, essential sector to society, to the economy, especially in terms of energy security, and to raising the overall environmental standard.

4. **CONCLUSION AND POLICY IMPLICATIONS**

This study examined the influence of renewable energies generated by the waste sector as a means of mitigating part of the GHG emissions generated by this sector across a 15-country panel of European Union member states. The energy model variables (Cren – the share of waste generated renewable energies and EfW – the generation of electricity through the utilisation of waste) returned opposing results with the former demonstrating its capacity for reducing GHG levels while the second favours an increase in emissions. This result proves fairly logical given that EfW, because despite being positive, nevertheless does mean a reduction in the levels of CO2W in opposition to fossil energy consumption within the overall EU electricity production mix.

Specifically, the retention of pollutant emissions such as CO2, CH4 and N2O also serves as a means of mitigating part of the GHGs due to the flow of waste otherwise destined for landfills instead diverted and converted into energy through incineration. According to the IPCC (2006), the potential for global warming from the latter two pollutants are 21 and 310 times more potent in terms of environmental degradation

than the emissions of the former and that stem not only from the break-down rotting phase in the life cycle of a landfill but also during the electricity generation process of waste powered thermoelectric plants.

Another highly important result stems from the empirical evidence demonstrating how new technologies, capable of turning in higher levels of efficiency, do favour the reduction of emissions. These results should not get overlooked as this model does indeed seem to convey to political decision makers and waste sector management teams that it is indeed worthwhile investing in the means necessary to raising recourse to waste as a source of energy.

In addition, the N curve identified by the model demonstrates just how the waste management sector throughout the EU is not able to come up with solutions to this problem of its own accord. Within the regulatory framework, as a public policy initiative targeting the waste sector, the incentives for replacing those fossil fuel energy sources generating the higher GHG emission coefficients by waste sources through new economic and institutional instruments, and in conjunction with media campaigns, may prove an alternative to correct the problems and deepen the conditions necessary to the economy functioning based on these new energy sources and thus carrying out a transition in this sector towards a lower level of GHG emissions across the EU. Therefore, our conclusion is that there are two scenarios of relevance both at the level of each individual member state and the EU as a whole: the first scenario is conservative and incorporating the hypothesis of not leveraging these resources and therefore only ever worsening the potential scope for global warming and; the second scenario is progressive and encapsulating the reutilisation of waste as resources that, beyond proving able to reduce the emission of pollutants generated by waste, also prove able to contribute to energy security and lower levels of dependence on fossil energy sources through capitalising effectively on the solid wastes produced within the scope of society itself. Furthermore, the reutilisation of waste proves susceptible to not only boosting economic growth but also bringing about the better conservation of energies and raw materials and all the while bringing about a transition in the waste sector with its resulting new phase of development reflecting in lower levels of polluting emissions and hence fostering a cleaner environment.

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CLEAN AND DIRTY TECHNOLOGIES UNDER ENVIRONMENTAL POLICY

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ABSTRACT

This paper aims is to study the contributions of environmental policies to the production of ecological goods, when consumers are indifferent between ecological and dirty goods. It develops a Schumpeterian R&D growth model with endogenous directed technological change. By solving the transitional dynamics numerically and by removing the scale effects, it is shown that, through the price channel, 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. Furthermore, if there is a positive change in the green technological environment, it strongly fosters R&D towards quality improvement of ecological goods, increasing their production.

Keywords: Endogenous growth, Technological change, Environmental Policy, Environment.

JEL codes: C61; O13; Q55; Q58.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change has stated that carbon dioxide (CO_2) concentrations in the atmosphere have been increasing significantly over the past century, compared to the rather steady level of the pre-industrial era. Among the many human activities that produce Greenhouse Gases (GHGs), the use of energy represents by far the largest source of emissions (IEA, 2014). Since “eco-friendly” technologies enhance the environmental sustainability by inducing more ecological goods production, through low-carbon technologies, attention should be addressed to TK to reduce these emissions.

In line with this thought, this paper develops a dynamic general equilibrium growth model with endogenous skill-biased technological change to study the contributions

of environmental policies to produce relatively more ecological goods, with fewer CO_2 concentrations.

This model is based on Schumpeter´s notion of creative destruction, the competitive process by which firms are constantly looking for new ideas and innovations that will make rival's ideas obsolete. In recent years, the economic and financial crises have changed consumers' behavior. Some studies (e.g., McKenzie et al, 2011 and Kaytaz et al, 2014) have found that during recession periods consumers switch a significant amount of expenditures towards essential goods and lower priced goods. As a result, we will assume that consumers are indifferent between dirty and ecological goods, as their main interest is surviving to uncertain future conditions rather than taking into account social or ecological concerns. This work relates to papers that analyze the environmental policy using endogenous growth models focused on the direction of technological change (e.g., Acemoglu et al. 2011; Grimaud et al., 2008; Hart, 2008; Ricci, 2007). However, in contrast to these works, our study stresses the price channel role in directing R&D towards the higher priced good. Three productive sectors are considered: the final goods (FGs), the intermediate goods (IGs) and the research and development (R&D). FGs can be produced by ecological or dirty technology, i.e., FGs can be produced either by more advanced and quality improved renewable technologies or by less advanced and less quality improved technologies. 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 the IGs is raised by (vertical) innovations resulted from 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

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

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

(i) A is the exogenous productivity level reflecting the dirty technological environment (A_D) or the ecological technological environment (A_E); (ii) $x_n(k,j,t)$ are IGs adjusted by the highest environmental quality, $q^{k(j,t)}$ with $q>1$, obtained by each successful R&D; (iii) $j \in [0, J]$ is for dirty IGs (D-IGs) and $j \in]J,1]$ is for ecological IGs (E-IGs); (iv) E and D are the skilled and the unskilled labour; (v) $\alpha \in]0,1[$ and (1-α) indicate the labour and the IG shares; (vi) $e>d\geq 1$ guarantees an absolute productivity advantage of E over D; (vii) n and (1-n) assure that E is relatively more productive in producing FGs indexed by larger n, while D is relatively more productive in producing FGs indexed by smaller n. This implies that, 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 $0 \leq n \leq \bar{n}$ ($\bar{n} < n \leq 1$):

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

$$Q_D(t) \equiv \int_0^J q^{k(j,t)(1-\alpha)/\alpha} \, dj$$

and $Q_E(t) \equiv \int_J^1 q^{k(j,t)(1-\alpha)/\alpha} \, dj$ (3)

The aggregate quality indexes in (3) evaluate the technological knowledge (TK) and the ratio $Q_E/Q_D=B$ measures the (ecological) TK bias. Equation (2) represents a "proxy" for the environmental quality. Small $\bar{n}$ means a relatively higher level of ecological goods production and thus, a better environmental quality and vice-versa.

All resources, *Y*, can be consumed, *C*, used in the IGs production, *X*, or directed to R&D, *RS*:

$$Y(t) = X(t) + RS(t) + C(t) \quad (4)$$

Unlike FGs, 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 FGs, the marginal costs (*MC*) of both IGs and FGs are equal (*MC*=1). Since consumers are assumed to be indifferent between ecological or dirty goods, firms will not have the incentive 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, government needs to encourage 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 (Baumol et al., 1994). Furthermore, they are believed to be more effective in inducing technological change as they offer a permanent incentive to use lesser environmental commodities.

Assuming that government can subsidise the *E*-IG and tax the *D*-IG, the *MC* after a subsidy or tax is ($MC+\varphi_x$), where φ_x denotes subsidies ($-s_x$) or taxes (τ_x). Thus, the profit maximization price of the IG firms yields:

$$p = (1+\varphi_x)/(1-\alpha) \quad (5)$$

and the limit pricing used to capture the whole market is:

$$p = q(1+\varphi_x), \text{ where } (1+\varphi_x)<q(1+\varphi_x) \leq [(1+\varphi_x)/(1-\alpha)] \quad (6)$$

In turn, the price indexes ratio of ecological and dirty FGs is:

$$p(t) = p_E(t)/p_D(t) = [\bar{n}(t)/(1-\bar{n}(t))]^{\alpha}, \begin{cases} p_D = p_n(1-n)^{\alpha} = \exp(-\alpha)\bar{n}^{-\alpha} \\ p_E = p_n n^{\alpha} = \exp(-\alpha)(1-\bar{n})^{-\alpha} \end{cases} \quad (7)$$

Small $\bar{n}$ implies more FGs produced with ecological technology and hence, a small relative price of these goods. Thus, 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 et al., 2002).

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

$$V(k,j,t) = \Pi(k,j,t) / [r(t) + pb(j,k,t)] \tag{8}$$

The denominator is the interest rate plus the Schumpeter's creative destruction rate. R&D improves IGs and, hence, the quality indexes (3), while creatively destroying the previous profits.

Following Aghion et al. (1992), the instantaneous probability – or the Poisson probability distribution - of a successful innovation is given by:

$$pb(k,j,t) = rs(k,j,t)\, \beta q^{k(j,t)} \xi^{-1} q^{-(1/\alpha)k(j,t)} M^{-1} h(j) \tag{9}$$

(i) $rs(k,j,t)$ is the flow of FGs devoted to R&D; (ii) $\beta q^{k(j,t)}$, $\beta>0$, is the positive learning effect of accumulated TK from past successful R&D; (iii) $\xi^{-1} q^{-(1/\alpha)k(j,t)}$, $\xi>0$, is the adverse effect caused by the increasing complexity of quality improvements; (iv) M^{-1}, with $M=D$ if $0 \le j \le J$ and $M=E$ if $J<j\le 1$, is the adverse effect of market size; (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:

$$h(j) = \begin{cases} 1 & , if\ \ 0 \le j \le J \\ [1 + A_E/(A_E + A_D)]^{\sigma} & , if\ \ J < j \le 1 \end{cases} \qquad \text{where: } \sigma = 1 + A_E/A_D \tag{10}$$

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:

$$pb(j,k,t)\, V(k+1,j,t) = (1 - s_r)\, rs(k,j,t) \tag{11}$$

s_r is an ad-valorem subsidy to R&D that decreases R&D costs, which can be specific to *E*- or *D*-R&D.

Re-arranging the terms, the instantaneous probability can be written by:

$$pb_M = \frac{b}{x}\frac{(1+f_{x,M})}{(1-s_{r,M})}\frac{(q-1)}{q}\left(\frac{p_M A_M (1-a)}{(1+f_{x,M})}\right)^{1/a} m\, h(j) - r(t) \tag{12}$$

Therefore, the TK growth rate equilibrium, Q_M, is given by the following TK path:

$$E(\Delta Q_M / Q_M) = \dot{Q}_M / Q_M = pb_M \left[q^{(1-\alpha)/\alpha} - 1\right] \tag{13}$$

$[q^{((1-\alpha)/\alpha)}-1]$ is the R&D effect on TK and pb_M is the probability of successful R&D.

From (13), it is clear that R&D equilibrium rates reply negatively to the interest rate, r, and to a raise in $\tau_{x,D}$ and positively to an increase in $s_{r,M}$ and $s_{x,E}$. 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:

$$\tau_k r(t)\int_0^1 K(a,t)da + \tau_M w_M(t)\int_0^1 [u_w(a,t)M(a,t)]da + \tau_{x,D} X(t) = s_{x,E} X(t) + s_{r,M} RS(t) \qquad (14)$$

The left-hand side of (14) 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 that use *E*-technology, $s_{x,E}X(t)$, and for R&D that enhance the environmental quality of both *E*- and *D*-specific IGs, $s_{r,M}RS(t)$.

Regarding the consumption, it is assumed a time invariant number of heterogeneous individuals, $a \in [0,1]$, that decide between consuming the aggregate FG and saving. For simplicity, $a \le \bar{a}$ are unskilled-workers assumed to perform better using *D*-technology, while $a > \bar{a}$ are skilled-workers assumed to perform better using *E*-technology. The utility function for the individual is given by:

$$U(a,t) = \int_0^\infty \left[\frac{c(a,t)^{1-q} - 1}{1-q}\right] \exp(-rt)\, dt \qquad (15)$$

where $c(a,t)$ 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:

$$\dot{c}(a,t)/c(a,t) = \dot{c}(t)/c(t) = \dot{C}(t)/C(t) = (1/\theta)\,[(1-\tau_k)\,r(t) - \rho] \qquad (16)$$

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

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. Therefore, the stable and unique steady-state endogenous growth rate, $g^*(\equiv g_D^* \equiv g_E^*)$, is:

$$g^* = \left(\frac{\dot{Y}}{Y}\right)^* = \left(\frac{\dot{X}}{X}\right)^* = \left(\frac{R\dot{S}}{RS}\right)^* = \left(\frac{\dot{Q}_D}{Q_D}\right)^* = \left(\frac{\dot{Q}_E}{Q_E}\right)^* = \left(\frac{\dot{C}}{C}\right)^* = \left(\frac{\dot{c}}{c}\right)^* = \frac{1}{\theta}\left[(1-\tau_K)r^* - \rho\right] \Rightarrow \left(\frac{\dot{p}_E}{p_E}\right)^* = \left(\frac{\dot{p}_D}{p_D}\right)^* = \left(\frac{\dot{\bar{n}}}{\bar{n}}\right)^* = 0 \qquad (17)$$

By setting (16) equal to (13) we get the constant steady-state interest rate, $r^*(\equiv r_D^* \equiv r_E^*)$. By plugging *r** into (16) we get *g**. Equalizing the steady-state TK paths, $(\dot{Q}_D/Q_D)^* = (\dot{Q}_E/Q_E)^*$, it can also be found p_M* and $\bar{n}^*$.

By $s_{x,E}$ and $s_{r,M}$, government intervention affects positively *r** and thus *g**. Indeed, $s_{x,E}$ and $s_{r,M}$ stimulate R&D by increasing monopolistic profits and by reducing R&D costs, respectively. Conversely, $\tau_{x,D}$ and τ_K affect negatively *r** and thus *g**. In fact, $\tau_{x,D}$ and τ_K discourage R&D. The former because it reduces monopolistic profits and the latter due to the smaller expected marginal benefit. As τ_W is absent in equilibrium, it does not directly affect g^*.

4. TRANSITIONAL DYNAMICS AND SENSITIVITY ANALYSIS

From (13) and since *r* is unique, the stability of *B* is:

$$\frac{\dot{B}}{B}=\frac{\dot{Q}_E}{Q_E}-\frac{\dot{Q}_D}{Q_D}=\frac{\beta}{\xi}\left(\frac{q-1}{q}\right)(1-\alpha)^{1/\alpha}\exp(-\alpha)\left\{e\left(1+\frac{A_E}{A_E+A_D}\right)^{\sigma}\left(\frac{1-s_{x,E}}{1-s_{r,E}}\right)\left(\frac{A_E}{1-s_{x,E}}\right)^{1/\alpha}\right.$$
$$\left.\left[1+\left(\frac{Q_E}{Q_D}\frac{e\ E}{d\ D}\right)^{-1/2}\right]^{\alpha}-d\left(\frac{1+\tau_{x,D}}{1-s_{r,D}}\right)\left(\frac{A_D}{1+\tau_{x,D}}\right)^{1/\alpha}\left[1+\left(\frac{Q_E}{Q_D}\frac{e\ E}{d\ D}\right)^{1/2}\right]^{\alpha}\right\} \tag{18}$$

We solve the model numerically to illustrate the effect of government intervention on both TK bias, *B*, and FG bias, $\bar{n}$, using the parameter values in Table 1. The parameter calibration is based on empirical literature and on theoretical specifications. The mark-up ratio, q=(1/(1-α)), is set in line with the mark-up estimates of Kwan et al. (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, 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.

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 $\bar{n}$ with and without government intervention are displayed in Fig.1 and Fig. 2, respectively.

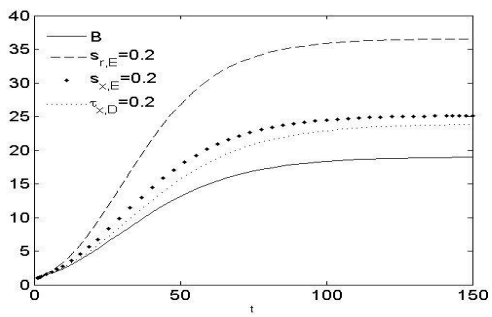

Fig. 1 Transitional dynamics of TK bias (*B*) under government intervention

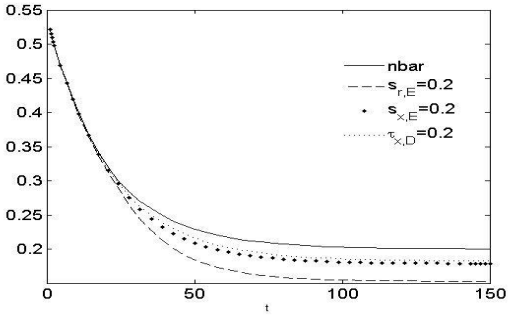

Fig. 2 Transitional dynamics of FGs bias ($\bar{n}$) under government intervention

Fig. 1 and Fig. 2 compare the baseline steady-state values of, respectively, *B* and $\bar{n}$, under no government intervention to the ones with government intervention.

With a raise of each type of subsidies and tax, it is clear that $s_{r,E}$ is the most contributor to heighten both the TK bias and the final good sector bias while $\tau_{x,D}$ is the least contributor. Indeed, $s_{r,E}$ reduces *E*-R&D costs, stimulating *E*-R&D and increasing the *E*-TK growth rate. Conversely, $\tau_{x,D}$ decreases the profits of *D*-IG producers discouraging *D*-R&D in favour of *E*-R&D. Thus, the production of *E*-IG rises, increasing the number of *E*-FGs, whose relative prices decrease continuously towards the new steady-state. Therefore, $\bar{n}$ decreases, showing an improvement of the environmental quality, see (2). Hence, as a result of the price channel, *B* is increasing, but at a falling rate until it reaches its new higher steady-state and $\bar{n}$ is decreasing, but at a falling rate until it reaches its new lower steady-state.

Table 2 presents the steady-state values of both the TK bias, *B*, and the environmental quality bias, $\bar{n}$ under no government intervention. Table 3 depicts the steady-state values of both the TK bias and the environmental quality bias under government intervention.

Table 2. Steady-State Values of *B* and $\bar{n}$ under No Government Intervention

Variables	Initial Values	Steady-state values under no government intervention
B	1	18.96
$\bar{n}$	0.52	0.20

Table 3. Steady-State Values of *B* and $\bar{n}$ under Government Intervention

Variables	Steady-state values under government intervention		
	$s_{r,E}=0.2$	$s_{x,E}=0.2$	$\tau_{x,D}=0.2$
B	36.53	25.13	23.82
$\bar{n}$	0.15	0.178	0.18

Considering, now, an improvement in the exogenous environmental quality, the paths of *B* and $\bar{n}$ with and without government intervention are displayed in Fig.3 and Fig. 4, respectively.

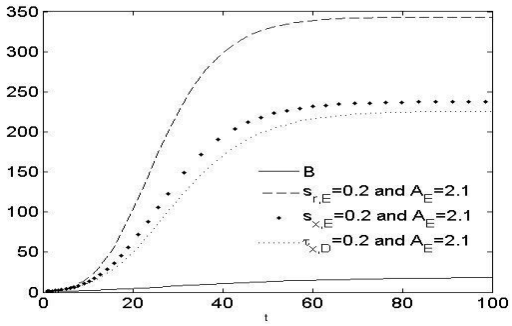

Fig. 3 Transitional dynamics of TK bias (*B*) under both government intervention and an improvement in the exogenous environmental quality

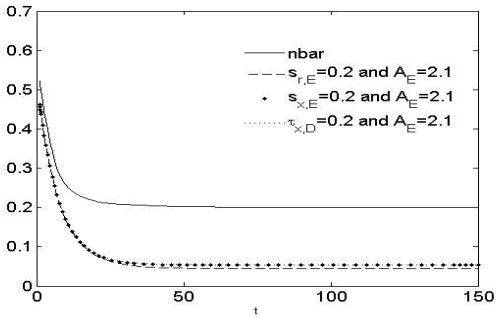

Fig. 4 Transitional dynamics of FGs bias ($\bar{n}$) under both government intervention and an improvement in the exogenous environmental quality

Fig. 3 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 (10), *h*(*j*) jumps immediately 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.

In turn, Fig. 4 shows that an increase in A_E heightens $\bar{n}$ in favour of *E*-FGs. Notwithstanding, at *t*=0, it also causes an instantly drop in $\bar{n}$, due to the rise in A_E without change in *B*. The increase in *E*-FGs (a decrease in $\bar{n}$) diminishes their relative prices, discouraging ecological TK, which implies that $\bar{n}$ is decreasing, but at a falling rate until its new lower steady-state. Once in steady-state, with a constant *B*, $\bar{n}^*$ remains constant. With a sufficiently TK absorption effect, $\bar{n}^*$ is smaller than under the baseline scenario, with no increase in A_E.

As a result of the price channel, the paths of *B* and $\bar{n}$ in Fig. 1 and Fig. 2, respectively, are strongly smoothed compared to the path of *B* and $\bar{n}$ in Fig. 3 and Fig. 4. 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, $\bar{n}$.

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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ON THE RELATIONSHIP OF ENERGY AND CO2: THE EFFECT OF FINANCIAL DEEP ON OIL PRODUCING COUNTRIES

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ABSTRACT

The relationship between energy and carbon dioxide emissions (CO2) and the financial depth was apprised within a panel of thirteen oil producing countries. The role of CO2 is analysed as economic growth driver and as explained variable. An Autoregressive Distributed Lag model with annual frequency data for the period from 1970 to 2012 was used. Our findings shown that CO2 promote economic growth in the short-run. The CO2 cause growth in long- and in short-run. The ratio between oil production and primary energy consumption impacts economic growth and the reduction of CO2 in long- and in short-run. The financial depth increases CO2 in short-run and depress economic growth both in long- and in short-run. The results for oil producing countries points to bidirectional causality between the CO2 and the economic growth. Therefore, policymakers of oil producing countries should be aware that economic growth may lead to an increase of CO2.

Keywords: ARDL; carbon dioxide emissions; financial development; oil producing countries.

1. INTRODUCTION

The paper studies the relationship between energy and carbon dioxide emissions (CO2) and highlights the financial depth effect on oil producing countries. The role of CO2 is analysed as economic growth driver and as explained variable. To scrutinize the nexus, a panel data entry with thirteen countries and a time period between 1970 and 2012 was used. The inclusion of inflation fulfil a gap on this nexus. Indeed, this indicator can be used as a proxy of economic instability for the oil producing countries.

The oil production and consumption has an active role on the literature. In fact, more than understanding their impact on economic growth, we need to realize other effects in the energy–growth nexus. This nexus raises concerns related with the environment, namely pollution and CO2. The relationship between CO2 and energy consumption is positive (Saidi and Hammami, 2015). In special, the role of financial

development should be better comprehended to supplant the current lack of consensus (e.g. Goldsmith, 1969; Minier, 2009; Sadorsky, 2010; Kaminsky and Reinhart, 1999; Deidda and Fattouh, 2002; Wachtel, 2003). This lack of consensus could be explained by the focus of research tends to be directed for the oil exporter countries (Fuinhas et al., 2015).

The main objective of this paper is to understand the relationship between energy and CO2, highlighting the financial depth effect. To capture these effects, variables such as CO2, Gross Domestic Product, Oil Consumption, Exports, Oil Rents, Production, International Crude Oil Prices, Inflation, and Financial Depth were used. The fact of analysing a long- time period allows dynamic relationships between variables and therefore, the Autoregressive Distributed Lag (ARDL) model comes out as the most suitable. An empirically supported multivariate panel was elaborated with the following specifications: (i) Group of oil producing countries with available data; (ii) A review of the ratio between oil production and primary energy consumption; and (iii) verify the impacts of the second oil shock. Following the procedure, the econometric techniques allows: (a) the evaluation of long- and short-run effects (b) to overpass the issue of the order of integration of variables. The used estimator allows to work with variables integrated I(0) and I(1); and (c) the usage of long- time span allow evaluate the co-integration or the long- memory (fractional co-integration) relationships among variables.

The rest of the paper is organized as follows: Section 2 review of the literature. Section 3 describes data and methodology. Section 4 is centred on the results. In section 5, the results are discussed. Section 6 concludes.

2. LITERATURE REVIEW

The analysis of the relationship between energy and CO2 highlighting the effect of the Financial Depth and Inflation is largely a new approach given that the topic is rarely addressed. By the reverse, growth-energy nexus is well known study area. A literature survey on energy-growth nexus can be seen in Omri (2014) and Menegaki (2013).

The causal relationship between energy and growth suggests the incorporation of environmental issues and CO2. A literature survey on CO2-energy-growth nexus can be seen in Omri (2013). Furthermore, financial development associated with the growth-energy nexus is also featured at the literature. Financial depth can enhance economic growth and affect the demand for energy (Sadorsky, 2010). The empirical results reveal a positive and significant relationship between financial development and energy. This phenomenon occur when financial development is measured by the deposit money bank assets to GDP, financial system deposits to GDP, or liquid liabilities to GDP (Sadorsky, 2011). Following Karanfil (2009), Dan and Lijun (2009) examined the effect of financial development on primary energy use in Guangdong, China. They found unidirectional causality from energy use to financial development. The concern with the environment is reported in some studies, namely in the causality field. A literature survey on energy consumption, financial development, and economic growth and CO2 emission can be seen in Ziaei (2015).

Due to the complex relationship of causalities and despite of the huge amount of studies in this area, the consensus among authors was far from reached. In an empirical overview, there are five possible occurrences: (1) Growth hypothesis – energy as a positive effect on growth; (2) Neutral hypothesis – absence of causality; (3) Conservation hypothesis – unidirectional causality from growth to energy; (4) Feedback hypothesis – bidirectional causality between growth and energy; (5) Resource curse hypothesis – "negative" energy produces growth.

The resource curse hypothesis is suggested in the literature to analyse the causality relationships between energy and growth. This phenomenon may be described as an economic constraint to oil producer's countries. Indeed, these countries expect to receive economic and social benefits from the wealth, generated by encouraging the local and national economy or indirectly by increasing tax revenues, as result of government involvement (Costa e Santos, 2013).

In the analysis of CO2 embodying the nexus growth-energy and oil producing countries development, there are two decisions that must be done: (1) what is the most relevant energy variable to explain CO2?; and (2) with oil production, what is the most suitable ratio to explain the relationship between energy-growth-development and CO2? To answer to the first question, following seminal literature the oil consumption is the one that produce most appropriate results. Moreover, primary energy consumption and the decomposition of oil primary energy consumption in other power sources can also be used. Decomposing a variable allows a better comprehension of the main role of oil consumption in primary energy context (Fuinhas et al., 2015). The same authors highlight the importance of integrating oil consumption and productions variables as well as oil prices and international oil prices. It is expected that oil producer countries reveal some idiosyncrasies, i.e. the existence of price volatility due to special circumstances, derived of the high correlation between fossil fuels and CO2.

The nexus complexity may be harmed by the endogenous resources availability. That availability can be controlled through the computation. A literature gap can be verified with the lack of inflation on the group of financial variables. Furthermore, inflation may exert a positive or a negative impact on growth. The positive effect can occur due to the excess of demand and inciting a tireless rise of prices, and the negative effect stems of measuring economic instability, suggesting a possible economic volatility. With the oil producer countries, a negative coefficient is expected. In fact, the inflation and the relationship between energy and CO2 is not in focus at the literature and therefore there is a limited understanding of this variable.

3. DATA AND METHODOLOGY

For the analysis of the relationship between economic growth and CO2, was used a panel with annual frequency data from 1970 to 2012, for a group of oil producing countries, namely Saudi Arabia, Algeria, Australia, Denmark, Egypt, Ecuador, United States of America, India, Italy, Malaysia, Mexico, Peru and Trinidad and Tobago .These countries were chosen due to letting a continuous sample for the longest time span possible. The source of the raw annual data was the World Bank Data, for gross domestic product (GDP), exports of goods and services, oil rents, population, domestic credit provided by banking sector, domestic credit provided by private

sector, and consumer price index; and the BP Statistical Review of World Energy, June 2014, for carbon dioxide emissions, oil consumption, oil production, primary energy consumption, and crude oil prices. The raw data variables used are: (i) GDP (constant local currency unit); (ii) exports of goods and services (% of GDP); (iii) oil rents (% of GDP); (iv) population (total of persons); (v) carbon dioxide emissions (million tonnes); (vi) oil consumption (million tonnes); (vii) oil production (million tonnes); (viii) primary energy consumption (million tonnes oil equivalent); (ix) crude oil prices (US dollars per barrel, 2013); (x) inflation (measured by first differences of logs of consumer price index); (xi) financial depth (% of GDP). The option of using a constant local currency unit allowed the influence of exchange rates to be circumvented. The econometric analysis was performed using Stata 13.1 and EViews 9 software.

The raw variables were transformed in: (a) CO2 emissions *per capita* (CO2PC); (b) Gross Domestic Product *per capita* (YPC); (c) Exports of goods and services *per capita* (XPC); (d) Oil rents *per capita* (ORPC); (e) Oil consumption *per capita* (OCPC); (f) Ratio between oil production and energy consumption (SE) - this ratio is used to control the heterogeneity and the oil production (Fuinhas et al., 2015), and can measure the importance of oil production in terms of primary energy; (g) Ratio between oil production and consumption (SO) – this ratio registers the progress made during a time period of the relative weight of oil production to oil consumption, and is used to control the heterogeneity of oil producers; (h) Oil prices (P) – defined as the international oil price, this variable is equal to all countries. (i) Inflation (INFL) – computed as the first differences of the natural logarithms of the consumer price index; (j) Financial Depth (PF) – computed as the aggregation of the Domestic Credit Provided by Banking Sector (DCPS) and the Domestic Credit Provided by Private Sector divided by the GDP.

The study follows two different approaches: (i) the first one evaluates the impact of CO2 as a source of economic growth with inflation as background; (ii) the second, using the same data, tries to capture the economic growth effect on CO2. Both approaches can be found at the literature. It is common to use Gross Domestic Product, measures of energy consumption, energy prices and traditional production factors. Occasionally, variables like exportations, CO2 *per capita* or urbanizations (e.g. Mohammadi and Parvaresh, 2014) or oil prices and production in scale (Fuinhas et al., 2015) or even financial development are used (Nili and Rastad, 2007). The inflation is rarely used in these approaches. This variable can have either coefficient signals, positive (as a result of excess of demand causing a rise of production and prices) or negative (as a result of measuring economic instability).

The dynamical effects are expected due to the long span of time. Different behaviours in the long- and short-run are also expected. The computation of the variables was made through the UECM from the ARDL, introduced by Pesaran and Shin (1999). The ARDL estimator possesses all the necessary properties to generate consistent and efficient parameters. Moreover, the estimator can deal with variables with integration order I(0) and I(1) and work as a support to the standard errors. The variables used are expressed in Logarithms (L) and first differences (D). The first coefficients match to the elasticities and the seconds to the semi-elasticities.

The relationship between energy and CO2 will be tested with two different processes to capture the financial depth effect. First the growth model (YPC) evaluate the CO2 effect over the economic growth. Second, the CO2 model (CO2PC) assess the drivers of CO2. Severe attention must be paid to the individual coefficient interpretation. Indeed, with multivariate models all the independent variables are relevant and contribute to describe the dependent variable. The explanations provided should have in count the dynamical effects.

The used countries share some common characteristics like oil production. Like that, Cross Section Dependence (CSD) is expected. This phenomenon implies interdependence between the crosses due to the common shocks (Eberhardt, 2011). If countries react in the same way to shocks the existence of correlations is verified. This fact suggests the existence of common non-observable events. Taking this in account, Table 1 with the descriptive statistics, coefficients of variation and individual CSD test is presented.

Table 1

Descriptive statistics and CSD

Variables	Descriptive statistics						CSD		
	Obs	Mean	Std. Dev.	Min.	Max.	CV	CD-test	Corr	Abs (Corr)
LCO2PC	559	-12.3393	1.21235	-14.788	-10.095	-0.0983	17.93***	0.31	0.634
LYPC	559	9.8655	1.29406	7.02201	12.6021	0.13117	37.07***	0.641	0.706
LEPC	559	-13.3529	1.1935	-15.963	-10.974	-0.0894	26.42***	0.457	0.615
LOCPC	559	-14.0588	1.1426	-17.164	-12.281	-0.0813	-1.34	-0.023	0.643
LOEPC	559	-14.2418	1.42846	-17.405	-11.061	-0.1003	46.74***	0.809	0.809
LXPC	558	8.41733	1.56812	5.02178	12.7704	0.1863	37.16***	0.643	0.694
SE	559	1.49718	2.47482	0	18.1184	1.65299	8.49***	0.15	0.523
SO	559	2.6922	3.499	0	23.7244	1.29968	4.30***	0.073	0.42
LORPC	557	6.25801	2.0772	0.12944	10.8107	0.33193	35.76***	0.628	0.643
LP	559	3.76559	0.60456	2.37893	4.74686	0.16055	56.39***	1	1
LINFL	547	1.80612	1.08989	-2.8623	6.07035	0.60344	21.30***	0.376	0.38
PF	559	1.18E-09	1.95E-09	1.67E-11	1.09E-08	1.65254	4.12***	0.067	0.452
DLCO2PC	546	0.01988	0.0612	-0.3042	0.34734	3.07883	3.81***	0.067	0.165
DLYPC	546	0.01972	0.04012	-0.1812	0.21532	2.03422	5.93***	0.104	0.187
DLEPC	546	0.0218	0.05657	-0.2947	0.31923	2.59447	4.63***	0.081	0.169
DLOCPC	546	0.00876	0.09277	-0.9672	0.59167	10.5943	3.19***	0.056	0.156
DLOECP	546	0.04126	0.09966	-0.6286	0.5448	2.41544	4.60***	0.08	0.153
DLXPC	545	0.03771	0.18545	-2.1872	1.94233	4.91845	12.21***	0.213	0.296
DSE	546	-0.03919	0.51879	-4.4162	4.56445	-13.239	-0.89	-0.019	0.178
DSO	546	-0.0405	0.83563	-7.5098	6.84536	-20.63	-0.14	-0.006	0.163
DLORPC	544	0.077	0.39113	-1.1777	3.06568	5.07939	40.35***	0.732	0.732
DLP	546	0.05598	0.29864	-0.6655	1.15456	5.33472	54.97***	1	1
DLINFL	528	0.00567	0.59625	-3.0568	3.20465	105.26	10.54***	0.193	0.215
DPF	559	1.18E-09	1.95E-09	1.67E-11	1.09E-08	1.65254	3.55***	0.066	0.131

Notes: CV denotes coefficient of variations, i.e. the ratio of the standard deviation to the mean; CD test has N(0,1) distribution, under the H_0: cross-section independence. *** denotes significant at 1% level. The Stata command *xtcd* was used to compute CSD tests.

Through the Table 1 the highly dependence of the variables can be checked. With significance values of 1%, this shows that an introduced shock may affects in the same way all the countries. The CO2 was increased less than the economic growth. Moreover, CSD is not present in the variables LOCPC, SE and SO. This fact suggests that the countries react in different ways to the oil consumption and to de ratios oil production to oil consumption or primary energy consumption.

The unit root tests of first and second generation were applied to verify the integration order of the variables, i.e. I(0) and I(1). The first generation tests used were Levin Lin e Chu (2002) (LLC), ADF-Fisher (Maddala e Wu, 1999), ADF-Choi (Choi, 2001), while the second generation test was CIPS (Pesaran, 2007). This test has the advantage of being robust for heterogeneity and relax the cross-sectional independence assumption. After computing the tests, it was confirmed that the variables are integrated I(0) and I(1). The absence of I(2) variables allows consistent estimations for the dynamical estimators. The results can be checked at Annex A.

Another issue referred at the literature is the collinearity, i.e. the correlation between variables. Correlated variables mean that the independent variables explain in the same way the dependent variable. The correlation coefficients can be viewed at Table 2 and VIF statistics, to test the multicollinearity, at Table 3. The VIF statistics were computed in level and first differences for both models, YPC and CO2PC.

Table2

Matrices of correlations

	LCO2PC	LYPC	LEPC	LOCPC	LOECP	LXCP	SE	SO	LORPC	LP	LINFL	PF
LCO2PC	1											
LYPC	0.6711	1										
LEPC	0.9964	0.6417	1									
LOCPC	0.9218	0.5615	0.9237	1								
LOECP	0.9297	0.6453	0.9329	0.7501	1							
LXCP	0.685	0.9007	0.6692	0.603	0.6324	1						
SE	-0.0535	-0.1061	-0.0521	0.0639	-0.2064	0.0386	1					
SO	0.0109	-0.082	0.0237	0.0118	-0.0407	0.0961	0.8993	1				
LORPC	0.3254	0.4123	0.3292	0.2709	0.3147	0.5606	0.4276	0.5247	1			
LP	0.0824	0.0871	0.0884	0.0443	0.1308	0.1512	-0.06	-0.0452	0.3171	1		
LINFL	-0.3499	-0.2637	-0.339	-0.2838	-0.369	-0.3293	0.0469	0.0196	-0.047	0.0809	1	
PF	0.1112	-0.0497	0.1369	-0.0014	0.162	0.1377	0.0344	0.2684	0.2864	-0.0744	0.0171	1
	DLCO2PC	DLYPC	DLEPC	DLOCPC	DLOECP	DLXPC	DSE	DSO	DLORPC	DLP	DLINFL	DPF
DLCO2PC	1											
DLYPC	0.3569	1										
DLEPC	0.9703	0.3501	1									
DLOCPC	0.6422	0.2548	0.5918	1								
DLOECP	0.3948	0.1367	0.5227	-0.0208	1							
DLXPC	0.0375	0.2034	0.033	-0.0239	0.0053	1						
DSE	-0.2331	0.4059	-0.2613	-0.132	-0.1939	0.2154	1					
DSO	-0.2809	0.3104	-0.2661	-0.5573	-0.0262	0.1929	0.7969	1				
DLORPC	0.0831	0.1988	0.0818	0.0481	0.0959	0.3489	0.2302	0.1869	1			
DLP	0.0956	0.1936	0.0844	0.0702	0.0376	0.2557	-0.017	-0.0206	0.8037	1		
DLINFL	-0.0254	0.1195	-0.0154	-0.0281	0.0258	0.1242	0.1724	0.1463	0.1929	0.1821	1	
DPF	-0.0436	-0.2364	-0.0293	-0.117	0.0432	-0.0231	-0.061	0.0189	-0.1523	-0.2027	-0.0654	1

Following these tests the model specifications are presented, namely the growth model in level (Eq. 1) and in first differences (Eq. 2), where LENPC represents the combination of three variables: LEPC, LOCPC and LOEPC; Furthermore, SOP embodies two variables: SE and SO.

$$LYPC_{it} = f(LCO2PC_{it}, LENPC_{it}, SOP_{it}, LORPC_{it}, LP_{it}, LINFL_{it}, PF_{it}) \quad (1)$$

$$DLYPC_{it} = f(DLCO2PC_{it}, DLENPC_{it}, DLXPC_{it}, DSOP_{it}, DLORPC_{it}, DLP_{it}, DLINFL_{it}, DPF_{it}) \quad (2)$$

The specification of CO2 model in level (Eq. 3) and in first differences (Eq. 4) is exhibited next:

$$LCO2PC_{it} = f(LYPC_{it}, LENPC_{it}, LXPC_{it}, SOP_{it}, LORPC_{it}, LP_{it}, LINFL_{it}, PF_{it}) \quad (3)$$

$$DLCO2PC_{it} = f(DLYPC_{it}, DLENPC_{it}, DLXPC_{it}, DSOP_{it}, DLORPC_{it}, DLP_{it}, DLINFL_{it}, DPF_{it}) \quad (4)$$

Scrolling down from Table 2 to Table 3, some unwished coefficients can be observed. For the matrix table, a correlation coefficient that overpasses 0.8 reveals potential multicollinearity and may lead to some concerns. The energy variables (LEPC, LOCPC, and LOEPC) are strongly correlated with CO2 (LCO2PC) and exports of goods and services (LXPC) are strongly correlated with GDP (LYPC). To overcome this problem, the variables LEPC and LOEPC from the growth model and LXPC from the CO2 will be removed of estimations.

Table 3

VIF statistics

	Dependent variable LYPC								Dependent variable LCO2PC			
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
LCO2PC	173.70	59.12	10.23	1.97	175.02	58.02	9.09	1.97				
LYPC									7.86	2.12	7.64	2.02
LEPC	166.87				168.02							
LOCPC		16.33	8.39			16.61	7.40		1.63	1.54	1.60	1.51
LOECP		21.79				19.41						
LXCP	2.88	2.83	2.69	2.69	2.89	2.83	2.72	2.72	9.33		9.30	
SE	1.42	1.93	1.62	1.42					1.64	1.59		
SO					1.63	1.73	1.63	1.62			1.80	1.76
LORPC	2.52	2.75	2.58	2.51	2.65	2.72	2.65	2.65	2.56	2.46	2.67	2.56
LP	1.29	1.28	1.28	1.28	1.29	1.28	1.28	1.27	1.37	1.32	1.35	1.30
LINFL	1.21	1.26	1.23	1.21	1.21	1.25	1.23	1.21	1.22	1.13	1.22	1.13
PF	1.31	1.26	1.25	1.19	1.29	1.27	1.27	1.17	1.50	1.28	1.37	1.20
Mean (VIF)	43.90	12.06	3.66	1.75	44.25	11.68	3.41	1.80	3.39	1.64	3.37	1.64
	Dependent variable DLYPC								Dependent variable DLCO2PC			
	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[24]
DLCO2PC	17.30	2.41	1.81	1.09	17.15	2.48	1.74	1.11				
DLYPC									1.48	1.46	1.19	1.16
DLEPC	17.66				16.98							
DLOCPC		2.03	1.73			3.00	2.48		1.17	1.16	1.09	1.08
DLOECP		1.45				1.46						
DLXPC	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.17		1.17	
DSE	1.40	1.39	1.35	1.35					1.59	1.58		
DSO					1.28	1.90	1.83	1.28				
DLORPC	3.60	3.64	3.54	3.54	3.34	3.57	3.46	3.33	3.61	3.47	3.02	2.85
DLP	3.36	3.37	3.31	3.31	3.14	3.29	3.23	3.13	3.46	3.46	2.90	2.89
DLINFL	1.08	1.07	1.07	1.07	1.07	1.07	1.07	1.06	1.07	1.07	1.06	1.05
DPF	1.06	1.07	1.07	1.06	1.05	1.07	1.07	1.05	1.10	1.10	1.10	1.10
Mean (VIF)	5.83	1.96	1.88	1.80	5.65	2.11	2.01	1.73	1.83	1.90	1.65	1.69

The estimations with the best results will be used, therefore the ARDL specifications for the growth model (Eq. 5) is shown:

$$LYPC = \alpha_{1i} + \delta_{1i} TREND_t + \sum_{j=1}^{k} \beta_{11ij} LYPC_{it-j} + \sum_{j=0}^{k} \beta_{12ij} LCO2PC_{it-j} + \sum_{j=0}^{k} \beta_{13ij} LOCPC + \sum_{j=0}^{k} \beta_{14ij} LXPC_{it-j} + \sum_{j=0}^{k} \beta_{16ij} LORPC_{it-j} +$$
$$+ \sum_{j=0}^{k} \beta_{17ij} LP_{it-j} + \sum_{j=0}^{k} \beta_{18ij} LINFL_{it-j} + \sum_{j=0}^{k} \beta_{18ij} PF_{it-j} + \varepsilon_{1it} \quad (5)$$

where α_{1i} denotes the intercept; δ_{1i}, β_{1kij}, k=1,…,m, the estimated parameters, and ε_{1i} the error term.

The Eq. 5 can be rewritten in UECM form (Eq. 6) with the proposal of decomposing the dynamic relationships in short- and long-run as follows:

$$\begin{aligned} DLYPC &= \alpha_{2i} + \delta_{2i}TREND_t + \sum_{j=1}^{k}\beta_{21ij}DLYPC_{it-j} + \sum_{j=0}^{k}\beta_{22ij}DLCO2PC_{it-j} + \sum_{j=0}^{k}\beta_{24ij}DLXPC_{it-j} + \sum_{j=0}^{k}\beta_{25ij}DSE_{it-j} + \sum_{j=0}^{k}\beta_{26ij}DLORPC_{it-j} + \sum_{j=0}^{k}\beta_{27ij}DLP_{it-j} + \\ &+ \sum_{j=0}^{k}\beta_{28ij}DLINFL_{it-j} + \sum_{j=0}^{k}\beta_{29ij}DPF_{it-j} + \gamma_{21i}LYPC_{it-1} + \gamma_{22i}LCO2PC_{it-1} + \gamma_{23i}LOCPC_{it-1} + \\ &+ \gamma_{24i}LXPC_{it-1} + \gamma_{25i}SE_{it-1} + \gamma_{26i}LORPC_{it-1} + \gamma_{27i}LP_{it-1} + + \gamma_{28i}LINFL_{it-1} + \gamma_{29i}PF_{it-1} + \varepsilon_{2it} \end{aligned} \quad (6)$$

where α_{2i} denotes the intercept; δ_{2i}, $\beta_{2kij,}$ k=1,…,m to the estimated parameters; and ε_{2i} to the error term. The ARDL specification for CO2 model (Eq. 7) is shown next:

$$\begin{aligned} LCO2PC_{it} &= \alpha_{3i} + \delta_{3i}TREND_t + \sum_{j=1}^{k}\beta_{31ij}LCO2PC_{it-j} + \sum_{j=0}^{k}\beta_{32ij}LYPC_{it-j} + \sum_{j=0}^{k}\beta_{33ij}LOCPC_{it-j} + \sum_{j=0}^{k}\beta_{34ij}SE_{it-j} + \\ &+ \sum_{j=0}^{k}\beta_{35ij}LORPC_{it-j} + \sum_{j=0}^{k}\beta_{36ij}LP_{it-j} + \sum_{j=0}^{k}\beta_{37ij}LINFL_{it-j} + \sum_{j=0}^{k}\beta_{38ij}PF_{it-j} + \varepsilon_{3it} \end{aligned} \quad (7)$$

where α_{3i} denotes the intercept; δ_{3i}, $\beta_{3kij,}$ k=1,…,m, the estimated parameters; and ε_{3i} the error term.

This equation 7 can be rewritten in UECM form (Eq. 8) with the proposal of decomposing the dynamic relationships in short- and long-run as follows:

$$\begin{aligned} DLCO2PC_{it} &= \alpha_{4i} + \delta_{4i}TREND_t + \sum_{j=1}^{k}\beta_{41ij}DLCO2PC_{it-j} + \sum_{j=0}^{k}\beta_{42ij}DLYPC_{it-j} + \sum_{j=0}^{k}\beta_{43ij}DLOCPC_{it-j} + \sum_{j=0}^{k}\beta_{44ij}DSE_{it-j} + \\ &+ \sum_{j=0}^{k}\beta_{45ij}DLORPC_{it-j} + \sum_{j=0}^{k}\beta_{46ij}DLP_{it-j} + \sum_{j=0}^{k}\beta_{47ij}DLINFL_{it-j} + \sum_{j=0}^{k}\beta_{48ij}DPF_{it-j} + \gamma_{41i}LCO2PC_{it-1} + \gamma_{42i}LYPC_{it-1} + \\ &+ \gamma_{43i}LOCPC_{it-1} + \gamma_{44i}SE_{it-1} + \gamma_{45i}LORPC_{it-1} + \gamma_{46i}LP_{it-1} + \gamma_{47i}LINFL_{it-1} + \gamma_{48i}PF_{it-1} + \varepsilon_{4it} \end{aligned} \quad (8)$$

The presence of individual effects ought to be tested against random effects. For the random effects (RE) growth model, in Eq. (9), the error assumes the form $\varepsilon_{5it}=\mu_{5i}+\omega_{5it}$, where μ_{5i} denotes the N-1 country-specific effects and ω_{5it} are the independent and identically distributed errors. In conformity, Eq. (6) is converted in Eq. (9):

$$\begin{aligned} DLYPC_{it} &= \alpha_5 + \delta_{6i}TREND_t + \sum_{j=1}^{k}\beta_{51ij}DLYPC_{it-j} + \sum_{j=0}^{k}\beta_{52ij}DLCO2PC_{it-j} + \sum_{j=0}^{k}\beta_{53ij}DLOCPC_{it-j} + \sum_{j=0}^{k}\beta_{54ij}DLXPC_{it-j} + \\ &+ \sum_{j=0}^{k}\beta_{55ij}DSE_{it-j} + \sum_{j=0}^{k}\beta_{56ij}DLORPC_{it-j} + \sum_{j=0}^{k}\beta_{57ij}DLP_{it-j} + \sum_{j=0}^{k}\beta_{58ij}DLINFL_{it-j} + \sum_{j=0}^{k}\beta_{59ij}DPF_{it-j} + \gamma_{51i}LYPC_{it-1} + \\ &+ \gamma_{52i}LCO2PC_{it-1} + \gamma_{53i}LOCPC_{it-1} + \gamma_{54i}LXPC_{it-1} + \gamma_{55i}SE_{it-1} + \gamma_{56i}LORPC_{it-1} + \gamma_{57i}LP_{it-1} + \gamma_{58i}LINFL_{it-1} + \\ &+ \gamma_{59i}PF_{it-1} + \mu_{5i} + \omega_{5it} \end{aligned} \quad (9)$$

where α_5 denotes the intercept; δ_{5i}, $\beta_{5kij,}$ k=1,…,m, e γ_{5im} the estimated parameters; and $\mu_{5i}+\omega_{5it}$ the error term. For the random effects (RE) CO2 model, in Eq. (10), the error assumes the form $\varepsilon_{6it}=\mu_{6i}+\omega_{6it}$, where μ_{6i} denotes the N-1 country-specific effects and ω_{6it} are the independent and identically distributed errors. In conformity, Eq. (8) is converted in Eq. (10):

$$DLCO2PC_{it} = \alpha_6 + \delta_{6i}TREND_t + \sum_{j=1}^{k}\beta_{61ij}DLOCPC_{it-j} + \sum_{j=0}^{k}\beta_{62ij}DLYPC_{it-j} + \sum_{j=0}^{k}\beta_{63ij}DLOPC_{it-j} + \sum_{j=0}^{k}\beta_{64ij}DSE_{it-j} +$$
$$+ \sum_{j=0}^{k}\beta_{65ij}DLORPC_{it-j} + \sum_{j=0}^{k}\beta_{66ij}DLP_{it-j} + \sum_{j=0}^{k}\beta_{67ij}DLINFL_{it-j} + \sum_{j=0}^{k}\beta_{68ij}DPF_{it-j} + \gamma_{61i}LCO2PC_{it-1} + \gamma_{62i}LOCPC_{it-1} + \quad (10)$$
$$+ \gamma_{63i}LYPC_{it-1} + \gamma_{64i}SE_{it-1} + \gamma_{65i}LORPC_{it-1} + \gamma_{66i}LP_{it-1} + \gamma_{67i}LINFL_{it-1} + \gamma_{68i}PF_{it-1} + \mu_{6i} + \omega_{6it}$$

where α_6 represents the constant term; δ_{6i}, β_{6kij}, k=1,…,m, and γ_{5im} are the estimated parameters; and $\mu_{6i} + \omega_{6it}$ corresponds for the error term.

The following step was attesting the model specifications trough the Hausman test. This test faces fixed effects (FE) with (RE). According to the Hausman test, the null hypothesis represents RE model while the alternative hypothesis indicates FE model. The FE model reveals evidence of individual correlation between countries and removes all the invariant characteristics. The Hausman test selected the FE as the most suitable estimator. Indeed this result establish the necessity of computing another tests, namely to apprise the heterogeneity. For a dynamic approach, the heterogeneity may assume two shapes: (i) short- and long-run; and (ii) short-run. To deal with this, the estimators Mean Group (MG) and (PMG) could be applied. These estimators require a large number of observations (N) and time (T) (Blackburne III and Frank, 2007). The MG model is the most flexible, by enabling the heterogeneity of the coefficients between countries. This model is effective when long- and short-run estimations are made, but ineffective against homogeneity (Pesaran et al., 1999). This model needs a long span of time and a large number of countries, 20 to 30 countries (Ciarlone, 2011). The PMG allows the existence of heterogeneity in the coefficients of short-run and homogeneity in the coefficients of long-run. If the presence of homogeneity in the coefficients of long-run is confirmed, the PMG model will be chosen as the most suitable.

4. RESULTS

The exhaustive control of the integration order of the variables is being conclusive as was shown at Annex A. As explained before, the econometric techniques must be suitable to deal with variables integrated as I(0) and I(1). To assess the presence of heterogeneity, the MG and PMG were carefully exanimated and tested against the dynamic FE estimator.

The MG, PMG and FE model estimations as the results of the Hausman test are provided at Table 4. The variables without any significance were removed from the model. Moreover, trend and LORPC from the growth model, likewise the variables LOCPC, LORPC, LP and LINFL from CO2 model are not statistically significant.

Table 4

Heterogeneous estimators, dynamic fixed effects, and Hausman tests

Growth model (Dependent variable DLYPC)			
	MG(I)	PMG(II)	FE(III)
Constant	3.6460***	1.4138***	0.8398***
LOCPC	0.5563***	0.1622***	0.2108***
LXCP	0.2822***	0.1923***	0.3873***
SO	0.6189	0.0183*	0.0626***

LORPC	0.0624	0.0334***	-0.0249
LINFL	-0.0618**	-0.0763***	-0.0467**
PF	-2.10E+07	-5.3E+07***	-7.5E+07***
ECM	-0.2484***	-0.1316***	-0.0854***
Trend	0.0020*	0.0006*	0.0003
DLCO2PC	0.2167***	0.1663*	0.1397***
DLOCPC	0.1514**	0.1815*	0.1988***
DLXPC	0.0363**	0.0389***	0.0257***
DSO	0.0850***	0.0476***	0.0340***
DLORPC	-0.0168	-0.0289**	-0.0253***
DLP	0.0261**	0.0384***	0.0332***
DPF	-2.30E+07	-1.7E+07*	-2.4E+07***
Models	MG vs PMG	PMG vs FE	MG vs FE
Hausman tests	Chi2(2)=-31,05	Chi2(2)=0,00	Chi2(2)=0,00
CO2 model (Dependent variable DLCO2PC)			
	MG(I)	PMG(II)	FE(III)
Constant	-4.7485***	-1.6993***	-0.8776***
LYPC	0.1695	0.3973***	1.5031**
LOCPC	0.3612***	0.4338***	-0.4031
SE	-0.3158*	-0.1243***	-0.2352**
LORPC	0.0588	0.1537***	0.0532
LP	-0.0268	-0.1322***	0.0899
LINFL	-0.0037	-0.0254***	-0.0598
ECM	-0.4411***	-0.1582***	-0.0272**
Trend	0.0028	-0.0001	-0.0008**
DLYPC	0.3234***	0.2974***	0.6315***
DLOCPC	0.4641***	0.5096***	0.3025***
DSE	-0.2525***	-0.3060***	-0.0456***
DLORPC	0.0660***	0.0546***	0.0280***
DLP	-0.0614***	-0.0499***	-0.0283**
DPF	1.3E+07***	7.4E+06***	1.8E+07***
Models	MG vs PMG	PMG vs FE	MG vs FE
Hausman tests	Chi2(1)= n. a.	Chi2(1)=0,00	Chi2(1)=0,00

Notes: ***, **, * denote significant at 1%, 5% and 10 % level, respectively; Hausman results (with the options sigmamore, alleqs, and constant) for H0: difference in coefficients not systematic; ECM denotes error correction mechanism; the long-run parameters are computed elasticities; the Stata command *xtpmg* was used; n. a. denote not available.

The Hausman test of MG vs PMG for the growth model presents a negative coefficient. Indeed, the negative x^2 from Hausman test although uncommon (see Dincecco, 2010) emphasizes the rejection of the first estimator (Hausman, 1984; Fuinhas et al., 2015). From Table 4 we can observe that the FE estimator is the most suitable, i.e. there is homogeneity for both models in the panel data entry. These

results sustain that oil producing countries share same coefficients and can be treated in the same way.

To reinforce the FE parameter significance, several tests were made to identify the existence of econometric violations, namely heteroskedasticity, correlations, autocorrelations and CSD. The Wald test was used to control the heteroskedasticity of the residuals. Next he Pesaran test analyses the presence of contemporaneous relationships between crosses. The null hypothesis specifies that the residuals are not correlated and follow a normal distribution. The Breusch-Pagan Lagrangian Multiplier was applied to test the cross sectional Independence and verify the correlation between errors. At last, the Wooldridge test assesses the presence of autocorrelation of first order. The results are revealed at Table 5.

Table 5

Specification tests

Tests	Growth model	CO2 model
	Statistics	
Modified Wald	chi2(13)= 383.27***	chi2(13)= 1808.14***
Pesarant	-1577	0.569
Breusch-Pagan LM	n. a.	n. a.
Wooldrige	F(1,12) = 105.952***	F(1,12) = 40.842***

Note: *** denotes significant at 1% level; results for H0 of Hausman test (with the option sigmamore) : difference in coefficients not systematic; results for H0 of Modified Wald test: sigma(i)^2 = sigma^2 for all I; results for H0 of Pesaran and: residuals are not correlated; results for H0 of Wooldrige test: no first-order autocorrelation; n. a. denote not available.

The applied tests come out as appropriate and revealed the existence of heteroskedasticity, autocorrelation of first order and contemporaneous correlation. With these phenomena the elasticities and semi-elasticities, shocks and speed adjustments for both models are presented at the Table 6. The models were re-estimated and the significance of the variables was maintained. Furthermore, the elasticities of long-run have a different way of reading them. By the reverse, the short-run elasticities have a direct reading for having equal coefficients.

To measure the long-run elasticities the ratio between the coefficient of each independent variable and the coefficient of the dependent variable (LYPC) for growth model and (LCO2PC) for CO2 model was made. Moreover, the variables had lag 1 and were multiplied by (-1).

Table 6

Elasticities, semi-elasticities, impacts, and adjustment speed

	Growth model (Dep var. DLYPC)	CO2 model (Dep var. DLCO2PC)
Short-run		
DLCO2PC	0,1367***	
DLYPC		0,6128***
DLOCPC	0,1973***	0,3086***
DLXPC	0,0283***	
DSE		-0,0448***
DSO	0,0336***	
DLORPC	-0,0266***	0,0303***
DLP	0,0343***	-0,0310***
DPF	-2,44E^7***	1,74E^7**

Long-run		
LYPC		0,5725*
LXCP	0,4565***	
SE		-0,1441*
SO	0,0559***	
LORPC	-0,0247*	
LP		0,1237**
LINFL	-0,0558**	
PF	-7,45E^7***	
Speed of adjustment		
ECM	-0,0805***	-0,0286*

Notes: ***, **, * denote significant at 1%, 5% and 10 % level, respectively; ECM denotes the coefficient of variable LYPC lagged once for the Growth model, and LCO2PC lagged once for the CO2 model; the long-run parameters are computed elasticities; and the Stata command *xtscc* with the options: fe, ase and lag(1) was used.

The results revealed Granger causal effects on both models (see Table 6).

5. DISCUSSION

The main objective of this study is highlighting the relationship between energy and CO2 among with financial development for a group of oil producer countries. Furthermore, 2 different views can be found through CO2: (1) First as a growth engine; and (2) as a dependent variable explained by his own drivers.

Preliminary tests revealed the presence of heteroskedasticity, CSD, residual correlation, first order autocorrelation and I(0) and I(1) of integration order. Moreover, the panel data entry used covers: (i) developed and developing countries; (ii) small and big oil producer countries; and (iii) to ensure a robust analysis, a large span of time was used. The dynamical panel data techniques are adequate to the study. Indeed, short- and long-run effects are detected, sustaining the former statement. The adjustment speeds are negative and statistically significant. The ECM term for the growth model is low (slightly over 8%, see table 8) while for the CO2 model is very low (under 3%). This fact suggests that a long span of time is needed when a shock is introduced. Likewise, the economic structure from the oil producer countries is weak and takes too much time to overpass possible shocks due to the lack of competitiveness.

The growth model reveals a high number of positive coefficients in the short- and long-run. Undeniably, some variables only present a short-run effect on growth, namely CO2 (CO2PC), oil consumption (OCPC) and International oil prices (P). In the main terms, the variables that have a higher impact on growth are the goods and services exportations (EXPC) at long-run and oil consumption (OCPC) at short-run. Additionally, a negative coefficient is verified at the oil rents (ORPC) and financial depth (PF) both on short- and long-run. The inflation has a negative coefficient too but only at long-run. Forward, a more detailed discussion will be provided.

At the CO2 model, variables like oil consumption (OCPC), oil rents (ORPC) and financial depth (PF) only enhances growth at the short-run. In this model, GDP (YPC) is the main propeller at short- and long-run. The relationship between oil production to consumption (SO) or primary energy consumption (SE) reveal explanation power at short- and long-run for both models. As result of this relationship, for growth have a positive impact while to CO2 as negative effect. This dissimilitude is expected. On

the one hand, when oil production increases relatively to oil consumption this impacts positively on growth. On the other hand, the negative effect of the ratio of oil production to primary energy consumption indicates the phenomenon of concentration of wealth typical of economies that are resource abundant. Indeed, wealth concentration contributes to lower CO2 *per capita* due to the specialization effect (Fuinhas et al., 2015).

Comparing both models expose interesting results. Indeed, oil prices (P) are highly significant at short- and long-run on both models. Furthermore, different signals are presented for the growth and CO2 models. A positive coefficient is revealed for the growth model and a negative one for the CO2 model. This phenomenon is consistent with the founded effect on oil rents (ORPC) and for financial depth (PF) with a negative effect on growth model and a positive effect on CO2 model. Therefore, when the oil extraction costs decrease, the local economic will all suffer the effect. The financial depth coefficient presents a negative impact on growth model and positive impact on CO2 model. In fact, this phenomenon may occur due to the recent financial crisis, a weak banking sector, and low level of finance trough the banking sector. In a different perspective, a positive impact could be in the agenda if the financial sector presents a low level of development, like the high growth rate of credit market in economies in development, originating a GDP increase. At last, inflation revealed a negative coefficient in the long-run at the growth model due to her functions, i.e. capture the economic instability. This result was expectant attending to the group of countries selected. Therefore, the instability effect dominates the excess of demand. Hence, this outcome suggests the presence of an indirect weak growth hypothesis of the oil-growth nexus. Indeed, the analyses of the two models detect causality running from CO2 to growth, and causality running from oil consumption to CO2, in the short-run. The obtained results should be considered by the policymakers in order to apply better energy policies.

6. CONCLUSION

This paper analyses the relationship between energy and CO2, highlighting the role of financial depth and inflation. For this paper, annual frequency data from 1970 to 2012 for a group of thirteen oil producer countries was used. Additionally, CO2 are studied as a growth propellant and as explained variable.

The results contribute to the literature by providing a detailed explanation to the growth-CO2 nexus. Furthermore, the introduction of a new variable, namely inflation, revealed to be a good innovation. The financial institutions in oil producer countries are weak and financial sector is undeveloped. Other factor can be provided from the excess of financial system development. In the literature, excess of finance harms growth.

The consistence of the results suggest that the *resources curse* phenomenon should not be neglected and deserve be considered in the literature. In fact, most of the studies only use rents from exploration of endogenous resources. The results are consistent as the CO2 are an important growth driver and vice-versa. Moreover, the emissions cause economic growth on the short-run. A bi-directional relationship between CO2 and growth was shown. The ratio between oil production and primary energy consumption reduce CO2 at short- and long-run. At the growth model this

ratio is a driver to growth. The oil consumption contributes for both growth and short-run CO2. Similar results are obtained with financial depth and oil rents. The inflations imply a decrease on growth at long-run while oil prices reduces CO2 in the short-run and enhance growth at short-run to. Both exportations and ratio between oil production and consumption increase the growth rate at short- and long-run. This phenomenon emphasizes that an increase in exports and surpluses promotes economic growth. Oil rents decrease the growth rate at short- and long-run, i.e. the resources curse could be considered as a blessing to these countries.

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APPENDIX – A1

Table A
Unit root tests

		LLLC			ADF-Fisher			ADF-Choi			Hadri		CIPS (Zt-bar)		CIPS (Zt-bar)	
		None	Intercep	Trend	None	Intercep	Trend	None	Intercep	Trend	Intercep	Trend	Intercep	Trend	Intercep	Trend
LCO2PC	level	-5.40389***	-2.82598 ***	-0.33883	98.5184***	34.3756	14.607	-4.92262***	0.36136	2.6613	13.491***	9.57635***	-0.385	0.054	-0.385	0.054
	1st	-10.3012***	-8.65124***	-8.87361***	184.582***	158.741***	143.404***	-10.6544***	-9.51101***	-8.76951***	4.20479***	4.4041***	-9.075***	-8.822***	-9.075***	-8.822***
LYPC	level	8.8602	-1.52555*	-0.04089	1.05374	29.8893	21.9005	9.47073	0.84629	0.98762	13.8871***	7.23567***	0.522	-0.799	0.522	-0.799
	1st	-9.29838***	-7.72128***	-7.05214***	126.818***	130.525***	119.137***	-8.49217***	-8.6203***	-7.6988***	1.42724*	5.12868***	-6.777***	-6.746***	-6.777***	-6.746***
LEPC	level	-5.82863***	-2.84825***	-0.50199	107.704***	38.1819*	14.226	-5.8066***	-0.3438	2.37429	13.6983***	9.63404***	-0.527	0.129	-0.527	0.129
	1st	-9.9481***	-6.1369***	-5.62339***	175.592***	150.796***	134.119***	-10.2965***	-9.28792***	-8.45851***	4.18029***	4.98981***	-8.525***	-8.125***	-8.525***	-8.125***
LOCPC	level	-2.51677***	-2.34598***	-1.17444	55.7993***	40.0122**	22.4714	-1.64953**	-0.61831	0.41328	8.74052***	4.79874***	-2.054**	0.441	-2.054**	0.441
	1st	-11.9149***	-10.7182***	-10.3228***	210.159***	164.362***	139.272***	-11.694***	-9.88536***	-8.62162***	2.30041**	3.88991***	-7.312***	-6.596***	-7.312***	-6.596***
LOEPC	level	-6.72875***	-3.2699***	0.85098	126.478***	41.9067**	16.0316	-7.72606***	0.20883	3.03363	13.8424***	10.3853***	1.597	0.47	1.597	0.47
	1st	-9.42561***	-5.33062***	-6.20757***	156.757***	142.908***	143.27***	-9.37357***	-8.76034***	-8.82421***	3.77112***	1.84227**	-8.448***	-7.749***	-8.448***	-7.749***
LXPC	level	6.88862	-1.92975**	-1.4955*	1.77688	22.1529	50.0769***	7.44667	0.54073	-1.65082**	13.2443***	7.7636***	1.244	0.264	1.244	0.264
	1st	-13.3799***	-12.8676***	-12.0711***	244.45***	213.128***	184.101***	-13.1366***	-12.1411***	-10.8371***	-0.22757	2.13065**	-9.422***	-8.553***	-9.422***	-8.553***
SO	level	-2.12281**	-1.47919*	-0.66867	35.0315	43.1996**	47.4739***	-0.95262	-1.7153**	-1.40184*	8.67272***	6.22707***	-0.666	-0.221	-0.666	-0.221
	1st	-13.6392***	-6.59288***	-6.18949***	241.106***	160.776***	133.048***	-12.9553***	-9.77802***	-8.39383***	1.43373*	3.53805***	-7.601***	-6.826***	-7.601***	-6.826***
SE	level	-3.14123***	-2.04977**	-1.19241	51.5549***	37.9471*	48.4041***	-2.35073***	-0.76046	-1.5481	9.28016***	7.02858***	-1.642**	-0.921	-1.642**	-0.921
	1st	-13.4992***	-7.36284***	-7.12193***	236.445***	157.226***	131.13***	-12.7403***	-9.49536***	-8.34594***	1.40201*	3.51554***	-9.112***	-8.661***	-9.112***	-8.661***
LORPC	level	1.93229	-7.72727***	-5.4438***	4.8758	104.787***	94.837***	3.69841	-6.19826***	-4.05902***	7.30727***	4.91975***	-2.926***	-1.672**	-2.926***	-1.672**
	1st	-16.3253***	-10.5519***	-8.62776***	277.475***	196.465***	159.563***	-14.5136***	-11.6857***	-10.1691***	3.2069***	7.33141***	-9.017***	-8.339***	-9.017***	-8.339***
LP	level	2.88221	-1.56254*	0.34861	3.29776	36.2499*	15.4035	4.25233	-2.45437***	0.48018	0.2662	3.78862***	16.8	16.553	16.8	16.553
	1st	-16.1024***	-11.0848***	-9.26068***	260.445***	190.082***	142.062***	-14.1268***	-11.5667***	-9.49191***	0.23023	8.41098***	16.759	16.473	16.759	16.473
LINFL	level	-2.18845*	-1.12952	-2.28181**	26.7368	43.0261**	53.8476***	-1.06173	-1.94942**	-2.89584***	5.25993***	7.00418***	-2.894***	-1.291*	-2.894***	-1.291*
	1st	-18.7531***	-11.4987***	-9.39862***	338.818***	232.754***	188.41***	-16.1442***	-12.3373***	-10.4861***	-0.05606	2.44868***	-11.842***	-10.436***	-11.842***	-10.436***
PF	level	-4.67647***	-2.60754***	-0.3575	68.048***	43.3982**	22.7478	-3.43206***	-0.98058	0.55692	4.85369***	9.78769***	5.511	7.653	5.511	7.653
	1st	-14.2601***	-8.05062***	-7.90428***	227.972***	164.302***	154.664***	-12.8418***	-10.3219***	-9.82832***	1.06308	1.27315	3.569	4.255	3.569	4.255

Notes: ***, **, * denote significant at 1%, 5% and 10% level, respectively; the null hypotheses are as follows: LLC: unit root (common unit root process); this nit root test controls for individual effects, individual linear trends, has a lag length 1, and Newey-West automatic bandwidth selection and Barttlett kernel; ADF-Fisher and ADF-Choi: unit root (individual unit root process); this unit root test controls for individual effects, individual linear trends, has a lag length 1; first generation tests follow the option "individual intercept and trend", which was decided after a visual inspection of the series; Pesaran (2007) Panel Unit Root test (CIPS): series are I(1); the EViews was used to compute LLC, ADF-Fisher, and ADF-Choi; and the Stata command multipurt was used to compute CIPS.

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CARBON EMISSION PRICES AND STOCK MARKET RETURNS OF SPANISH POWER INDUSTRY

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ABSTRACT

Long-run equilibrium relations and short-run interactions between the electricity industry stock market returns and carbon emission prices are investigated in this paper.

A cointegrated Vector Error Correction is employed for the period covering 1 January 2008 until 31 July 2014. A value-weigthed power sector stock market return is calculated by using as a weighting factor the market capitalization of each power company at year-end compared to the market capitalization of all companies of the sector. Phase II and the first year and a half of phase III of the EU ETS were compared in this study study.

In both phases a statistically significant positive long-run impact of EU ETS on power sector stock market return is found. No short-run interactions were found.

Keywords: European Union Emission trading system; Energy costs; Vector error correction analysis.

1. INTRODUCTION

The European Union launched the European Union Emission Trading System (EU ETS) aiming to reduce greenhouse gas (GHG) emissions. The sectors covered by EU ETS are: electricity industry; Oil refineries; Ferrous metallurgy; Cement clinker or lime; Glass including glass fibre; Ceramic products by firing and Pulp, paper and board. In that sense, the electricity industry is one of the

most important sectors in the scheme, accounting for 42% of the world CO2 emissions (International Energy Agency, 2014).

European Union carbon emissions allowances (EUA) price fluctuations can affect power companies' stock market values through cash flows and expected returns. Firstly, carbon dioxide prices could influence cash flows of companies as they can incorporate their carbon emission allowance costs in their sale offers. Therefore, a variation in EUA prices would be reflected in output prices as well as in costs. Secondly, Litterman (2013) and Pindyck (2013) indicate that carbon emissions generate "carbon risk" as they could lead to a climate disaster impacting the prosperity of next generations. Since polluting firms are exposed to carbon risk, they will require higher expected returns relative to non-polluting firms. Then, the final effect of EUA prices on power firms' profitability is ambiguous, as it depends how much firms can shift to consumers the increase in marginal cost through higher output prices and the uncertainty about carbon risk.

The existing empirical studies do not converge to a shared position as many of the studies are country-region specific and results also rely on the modelling, the studied EU ETS phase , the market structure and the used econometric tool, among others. Some scholars have concluded that the EU ETS has had a positive effect on power companies: Oberndorfer (2009), Veith et al. (2009), Keppler and Cruciani (2010), Mo et al. (2012) and Chan et al. (2013) found that EUA price variations and stock returns or revenue of the European electricity corporations are shown to be positively correlated. However, the particular effect of EUA price variations on electricity corporations´ stock returns might vary with country (Oberndorfer (2009) found a significantly small negative relationship for Spain), EU ETS phase (Mo et al. (2012) found a positive and negative correlation during phase I and II respectively) and power generation technology (Bode, 2006).

In the context of this debate, this paper analyses whether and to what extent the EUA prices may be linked with power sectors stock market returns in Spain. In particular we test the hypothesis that EUA price increases (decreases) affect positively (negatively) the Spanish power stock market returns.

A cointegrated Vector Error Correction Model (VECM) analysis is used allowing the estimation of long-run equilibrium relations and short-run interactions between the stock market returns and carbon emission prices. From VECM we test the following hypothesis:

Hypothesis a) EU Emission Allowances price increases (decreases) affect positively (negatively) Spanish power stock market returns in the short run.

Hypothesis b) EU Emission Allowances price increases (decreases) affect positively (negatively) Spanish power stock market returns in the long-run.

The present study contributes to the literature on this topic in four ways: (i) To contribute to the body of empirical literature in Spain on this matter, (ii) to provide useful information to policy makers about the impact of the European

Emission trading scheme on the power industry, (iii) to provide useful lessons for countries who are considering “cap and trade” systems and (iv) to provide findings that may be important for market investors.

2. METHODOLOGY

Multifactor market models are widely used to study the effect of any possible factor on corporate value change. In fact, Veith et al. (2009), Oberndorfer (2009) or Mo et al. (2012) have used multifactor market models to investigate the impact of EUA price variations on firms’ stock returns.

Many empirical results have shown that stock return is closely related to the price of oil (Lee et al. (2012) or Moya-Martínez et al. (2014) for the Spanish case) and gas (Acaravci, Ozturk, & Kandir, 2012) so other influencing factors as fuel prices are also included in the basic model. For example Veith et al. (2009) include oil and natural gas prices as control variables and Oberndorfer (2009) also includes the electricity price in the regression equation; we notice that electricity prices are very important for Spanish industry, as electricity usually represents a significant proportion of total energy cost for industry (51.7% of the total energy consumption (INE, 2013)). Additionally, other authors like Lee et al. (2012) or Moya-Martínez et al. (2014) include the long-term interest rate in order to incorporate market expectation.

Thus, the initial multifactor market model model can be specified as:

$$R_t = \alpha + \beta_1 R_{mt} + \beta_2 P_t^{EUA} + \beta_3 P_t^{oil} + \beta_4 P_t^{gas} + \beta_5 P_t^{coal} + \beta_6 P_t^{elect} + \beta_7 r_t + u_{it} \quad (1)$$

Being P_t^{oil}, P_t^{gas} and P_t^{elect}, oil, gas and electricity prices respectively and r_t the long-term interest rate.

Based on this multifactor market model, the Vector Error Cointegration model (VECM) allows for long-run equilibrium as well as short-run dynamics estimations. This system of equations model expresses each variable in the system as a function of all lagged variables, including its own lagged variable. However, VECM is only possible if the variables show the very interesting property cointegration. The cointegration concept means that a linear combination of two or more non stationary variables (with the same order of integration) may converge to a stationary process (Engle & Granger, 1987). Such process reflects the long-run equilibrium relationship, and is referred to as the cointegration equation.

If variables exhibit cointegration relations, then the VECM is specified as:

$$\Delta y_t = \prod y_{t-1} + \sum_{i=1}^{p-1} A_i \Delta y_{t-1} + \mu_t + \varepsilon_t \quad (2)$$

Where Δ is 1st difference operator, y_t represents a vector of k non-stationary endogenous variables, A_i is a matrix of unknown coefficients, p is the number of

lags included in the model, μ_t is a vector of deterministic terms (constants and trend) and ε_t is a column vector of errors $\varepsilon_t \sim \mathrm{Niid}(0,\Sigma)$. *Π* is a matrix containing information about the long-run relationship among endogenous variables and is called the error correction term. It can be decomposed as Π=*αβ´*, where *β* represents the cointegration vectors and *α* the matrix with the estimations on the adjustment speed to the equilibrium, which are also called error correction terms (EC). The rank of matrix Π (r) determines the long-run relationship. If it is zero, then there is no long-run relationship and the model above is equal to a Vector Auto-regressive (VAR) model in differences. If the matrix Π has the full rank $(r = k)$, the processes y_t is stationary I(0) and a normal VAR in levels can be used. If the rank of Π is positive and $0 < r < k$ there exists matrices *α* and *β* with dimensions $(k \times r)$ such that the equation $\Pi = \alpha \times \beta'$ holds.

The VECM provides two channels to test the considered hypothesis: a) short-run effects (estimated in the matrix Ai ; b) and the long-run effects which enter the model with the term Πy_{t-1} or $\alpha \times \beta' y_{t-1}$.

3. DATA AND VARIABLES

The daily sample period used in our analysis ranges from 2008 to July 2014. It covers the second phase of the EU ETS (1st January 2008 to 31st December 2012) and the first year and a half of the third phase of the EU ETS (1st January 2013 to 31st July 2014). We compare the obtained results under the Phase II and Phase III.

Information on daily stock price during 2008-2014 was extracted from the Datastream Database. We use the adjusted close price corrected by capital increases and splits. The power sector weighted daily return has been calculated using as a weighting factor the market capitalization of each company at year-end compared to the market capitalization of all companies at the power sector. This process allows us to obtain an aggregate daily stock market return for the power sector (R_{power}).

Table 1. Summary descriptive statistics

Variable	Units	EU ETS Phase II					EU ETS Phase III				
		Mean	Median	Min.	Max.	Std. Dev.	Mean	Median	Min.	Max.	Std. Dev.
r	%	4,77	4,54	3,62	7,50	0,84	4,12	4,22	2,58	5,43	0,73
P^{EUA}	€/ton	9,43	11,45	0,01	16,84	5,63	4,84	4,78	2,68	7,11	0,85
P^{elec}	€/MWh	47,95	48,04	3,13	82,13	12,75	43,29	46,20	0,79	91,89	16,34
P^{gas}	€/MWh gas	3,43	2,97	1,34	8,42	1,47	3,05	3,03	2,33	5,85	0,51
P^{oil}	€//BBL	67,49	68,75	24,25	99,04	17,67	81,68	81,10	75,12	90,52	3,24
P^{coal}	€/ton	75,73	73,77	43,50	142,18	19,97	59,74	59,23	53,03	69,30	4,18
R_m		1028,00	1026,70	602,56	1642,00	211,69	940,29	945,42	760,72	1143,30	105,47
R_{power}	€	9,61	9,20	6,02	14,97	2,38	11,38	10,33	8,74	16,48	2,35

The proxy for the return of the market portfolio (R_m) used is the *Índice General de la Bolsa de Madrid*, the broadest Spanish market index and the yield on 10-year Spanish Treasury bonds is used to assess the interest rate *r*. The electricity series P^{elec} (€/MWh), 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 9:00 h to 20:00 h. The natural gas price P^{gas} (€/MWh gas) is the spot price from the Zeebrugge Hub (European virtual trading point, Belgium), the coal price P^{coal} (€/ton.) is the spot index API#2 (CIF ARA Delivered to the Amsterdam/Rotterdam/Antwerp region) and the oil Crude price P^{oil} (€//BBL) is the Oil Dated Brent. The EUA price series P^{EUA} (€/ton. CO_2) is the spot price quoted at EEX – European Energy Exchange (Leipzig, Germany). We transformed the price variables into their natural logarithms to reduce variability. Table 1 summarizes the main descriptive statistics of the variables.

4. EMPIRICAL RESULTS

4.1 Long-run and short-run relationship between the power stock prices and EUA prices variations

In order to test the long-run and short-run relationship between stock and carbon emission prices, the estimation method proceeds as follows: *i*) unit root tests are conduct to test for the order of integration in individual price series, *ii*) assuming the tests conclude that the series are I(1), we explore the long run relationships between the variables by using a cointegration test and the cointegration rank is determined *iii*) a VECM for the overall power sector is estimated.

4.1.1 Unit-root-testing

Before deciding in either VAR or VECM we need to test for the presence of unit roots. All time series are tested for the presence of unit root by the Augmented Dickey-Fuller unit root test. The null hypothesis for this test is the presence of a unit root in the time series or the time series being generated by a non-stationary process. Results of the testing are presented in table 2.

Table 2. Unit root testing of variables using the Augmented Dickey-Fuller test (variables in natural logarithms except *r*)

Variable	EU ETS Phase II				EU ETS Phase III			
	Level		diff.		Level		diff.	
	Statist.	p value	Statist.	p value	Statist.	p value	Statist.	p value
r	-1,742	0,410	-10,755	0,000	-0,111	0,947	-4,363	0,000
P^{EUA}	-2,027	0,275	-37,329	0,000	-2,818	0,056	-6,172	0,000
P^{elec}	-2,613	0,090	-13,357	0,000	-2,782	0,061	-7,957	0,000
P^{gas}	-1,767	0,398	-8,073	0,000	-1,913	0,327	-5,570	0,000
P^{oil}	-1,259	0,651	-6,972	0,000	-2,240	0,192	-6,636	0,000
P^{coal}	-1,868	0,348	-6,571	0,000	-1,571	0,497	-20,083	0,000
R_m	-1,626	0,470	-9,240	0,000	-0,287	0,925	-5,032	0,000
R_{power}	-1,494	0,537	-34,996	0,000	-0,450	0,898	-5,135	0,000

The test indicates that at 1% of significance all the series contain a unit root (integrated of order 1) and therefore must be differentiated for the purposes of the current research.

Then, we obtain the growth rate of the relevant variables by their differenced logarithms.

4.1.2 Econometric model: VECM

Given the order of integration of the variables used, a general VECM specification can be formulated as:

$$\Delta y_t = \prod y_{t-1} + \sum_{i=1}^{p-1} A_i \Delta y_{t-1} + \Phi Z_t + \mu_t + \varepsilon_t \qquad (3)$$

where:

- y_t is a vector of endogenous variables measured at time t: $y_t = [r_t, R_{mt}, R_{powert}, P_t^{elec}, P_t^{oil}, P^{gas}, P_t^{coal}]$. Natural logarithms are taken of each variable except interest rate (r_t)
- α and β are matrices representing the cointegrating vectors and the estimations on the speed of adjustments to the equilibrium (EC), respectively
- A_i is a matrix with the estimations of short-run parameters relating variable changes in lagged i periods
- Φ is a matrix of coefficients associated with the vector Z_t that represents the exogenous variables. The VECM approach was been extended by Harbo et al. (1998) and Pesaran et al. (2000) to include exogenous variables in the model. In our case, we include a dummy variable taking the value of one for year 2008 and zero for the rest as during this year the price of EUA took values extremely low and price changes taking the value of zero
- μ_t is a vector of constants and ε_t is a vector of errors $\varepsilon_t \sim \mathrm{Niid}(0,\Sigma)$.

Since the unit root tests reveal that the series are integrated of order one, a need arises to check whether these time series are cointegrated (contain a common stochastic trend). The long run relationships are then explored between the variables by using the cointegration test. 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 use the asymptotic critical values provided in Mackinnon et al. (1999). The null hypothesis states that the amount of cointegrating vectors is equal to *r*; the alternative hypothesis is that the number of cointegrating vectors is greater than r. The existence of cointegration relations is showed in Table 4.

4.1.3 Cointegration testing

The lag length is determined amongst the variable series in levels VAR. Both the Schwarz information criterion (SC) and HQ (Hannan and Quinn Criterion) loss metrics suggest the appropriate VAR lag length is one[4] *p=1* (Table 3).

Table 3. Lag length in endogenous variables

	Phase II			Phase III		
Lags	AIC	SC	HQ	AIC	SC	HQ
0	-3.877	-3.812	-3.852	-13.305	-13.224	-13.273
1	-28.659	-28.338*	-28.539*	-33.162	-32.431*	-32.872*
2	-28.670	-28.092	-28.453	-33.233	-31.852	-32.685
3	-28.673*	-27.838	-28.359	-33.256*	-31.226	-32.452

[4] As the VAR is specified in first differences, the number of lags in the VECM should be (*k-1*).

Note: Model with constant and a maximum of 20 lags

Table 4. Cointegration tests EU ETS Phase II and III

	Ho:	Trace test			λ_{max} -max eigenvalue test		
Phase	r=	Statistics	Critical Value	p-values	Statistics	Critical Value	p-values
	1	0,113	125,615	0,000	0,113	46,231	0,000
II	2	0,033	95,754	0,006	0,033	40,078	0,016
	3	0,019	69,819	0,153	0,019	33,877	0,346
	1	0,137	125,615	0,000	0,137	46,231	0,002
III	2	0,128	95,754	0,000	0,128	40,078	0,001
	3	0,072	69,819	0,004	0,072	33,877	0,164

Notes: 5% significant level for critical values is. *p*-values calculated using the software in Mackinnon et al. (1999). Model with unrestricted constant, one lag in endogenous variables.

4.1.4 Power sector VECM estimation

With the cointegrated rank and the optimum number of lags determined, the parameters of the model for the power industry can be estimated. Also, the VECM estimations for Phase II and III are presented. Only the coefficients significant at 1% (***), 5% (**) or 10% (*) significant levels are reported, with the exception of the coefficients related to EUA prices that are always showed. The interpretation of the results is focused in the effect of EUA change prices on stock prices variations.

The results reported in Table 5 and 6 for the cointegrated vector β, which is normalized on lagged return on the stock index in the power sector ($R_{powert-1}$, lagged return of the market portfolio (R_{mt-1}) and lagged long-term interest rate (r_{t-1}), show that the EUA price change does not have an effect on stock market returns of the power sector in both EU ETS phases in the short run (*Hypothesis* a) is rejected). The short run parameter corresponding to EUA price for Phase II and III are 0,0003 and -0,0154, respectively and they are not significant.

Regarding the long-run parameters, the VECM estimations show that the long-run relationships between EUA price change and stock market price change for power sector are positive (but small) during both Phases (*Hypothesis* b) is not rejected). Since the coefficients can be interpreted as price elasticities, therefore, a EUA price rise of 1%, would, in equilibrium, be associated with a stock price for the sector increase of 0,0102% and 0,03% during phase II and III respectively. Thus, the stock market power is affected by the EU ETS more remarkably in phase III than in phase II. This could imply that power generation companies have passed EUA costs to electricity ratepayers, resulting in higher electricity prices and higher revenue.

The results are similar to those found by empirical literature. Oberndorfer et al. (2006) examined the impacts of the EU ETS on competitiveness in Europe and conclude that for the power sector the impacts were modest. In the same way, Chan et al. (2013) conclude that EU ETS was associated with increased material costs and revenue of the power industry during 2005–2009. By using also a Cournot representation Bonenti et al. (2013) evaluate the impact of EU ETS on the Italian electricity market profits under different allocation scenarios

of allowances (free and auctions) concluding that the generators would be expected to profit in an oligopolistic market as they are able to transfer almost all their emission costs in the final price paid by consumers. In addition, Veith et al. (2009) by using a modified multifactor market similar to Eq. 2 and 2005-2007 data of 22 electricity companies estimate a coefficient β_2 equal to 0,006.

Table 5: VECM parameter estimates for power sector- Phase II

Cointegration relationships								
$R_{power\ t-1}$	r_{t-1}	$R_{m\ t-1}$	P^{EUA}_{t-1}	P^{ELECT}_{t-1}	P^{COAL}_{t-1}	P^{OIL}_{t-1}	P^{GAS}_{t-1}	Const.
1,000	0,000	0,000	-	3,058***	-3,401***	1,258***	0,923***	-
0,000	1,000	0,000	3,317***	1,188***	-	-	0,458***	-
0,000	0,000	1,000	-1,283***	-1,070***	1,852***	-1,241***	-0,318***	-
Short run dynamics								
	$\Delta R_{power\ t}$	Δr_t	$\Delta R_{m\ t}$	ΔP^{EUA}_t	ΔP^{ELECT}_t	ΔP^{COAL}_t	ΔP^{OIL}_t	ΔP^{GAS}_t
$EC1_{t-1}$	-	-0,016***	-0,001*	0,207***	-0,089***	0,001***	-	-
$EC2_{t-1}$	-	-0,028***	-	-	-	0,005***	-	0,007***
$EC3_{t-1}$	-0.008*	-0,072***	-0,003**	0,495***	0,020***	0,011***	-	-
$\Delta R_{powert-1}$	-	0,300**	-	-	-	-	-	-
Δr_{t-1}	-	0,091***	-	-	-	-	-	-
$\Delta R_{m\ t-1}$	0,006***	-0,944***	0,033**	-	-	-	-	-
ΔP^{EUA}_{t-1}	0,0003	-	-	-0,024**	-	-	-0,008**	-
ΔP^{ELECT}_{t-1}	-	-	-	-	-0,084***	0,008**	0,008*	0,013*
ΔP^{COAL}_{t-1}	-0,048*	-	-0,081***	-	-	-		
ΔP^{OIL}_{t-1}	-0,038**	0,430***	-	-	-	-	-	0,089*
ΔP^{GAS}_{t-1}	-	-	-	-	-	-	-	0,050*
Const.	-	-	-	0,877***	-	-	-	
$DT2008_t$	-	-	-	-4,195***	-	0,028**	-	0,047*

*stands for estimates significantly different from 0 at a 10% level, ** stands for estimates significantly different from 0 at a 5% level and *** stands for estimates significantly different from 0 at a 1%

However, not all the existing empirical studies converge with our results, as some scholars have concluded that the EU ETS has a negative effect on power companies. For instance, Mo et al. (2012) indicate that positive EUA prices generated corporate value depreciation during phase II. By using a modified multifactor model similar to Eq. 2 with 2008 and 2009 data of 48 electricity companies, they estimate a coefficient β_2 equal to -0,0334. Moreover, Oberndorfer (2009) found that although EUA price variations and stock returns of the most important European electricity corporations were positively related, Spanish electricity corporations exhibit a significantly (but small as far as the size of the estimated coefficient is concerned) negative relationship. Jaraitė and Kažukauskas (2013) found that the first years of the EU ETS (2002-2010) could not be associated with excess profits for electricity producers.

We would like to point out that in the long-run, the electricity sector as a whole have modest gains from the introduction of the EU ETS instrument, but results could change if electricity sector companies were grouped according to its main generation technology. In that sense Bode (2006) remarks that plant-type specific stock price variations depend on the carbon allowances allocation rule (free or auctions).

Table 6: VECM parameter estimates for power sector- Phase III

Cointegration relationships								
$R_{power\ t-1}$	r_{t-1}	$R_{m\ t-1}$	P^{EUA}_{t-1}	P^{ELECT}_{t-1}	P^{COAL}_{t-1}	P^{OIL}_{t-1}	P^{GAS}_{t-1}	Const.
1,000	0,000	0,000	-0,809***	-0,386***	-0,702**	0,202***	-1,719***	-
0,000	1,000	0,000	1,221**	1,758***	-	-	6,955***	-
0,000	0,000	1,000	-0,677***	-0,419***	-1,109***	1,514**	-0,878***	-
Short run dynamics								
	$\Delta R_{power\ t}$	Δr_t	$\Delta R_{m\ t}$	ΔP^{EUA}_t	ΔP^{ELECT}_t	ΔP^{COAL}_t	ΔP^{OIL}_t	ΔP^{GAS}_t
$EC1_{t-1}$	-0,040***	-	-	0,105***	-	-	-	0,031***
$EC2_{t-1}$	-0,013***	-	-	0,053***	-	-	-	-0,029***
$EC3_{t-1}$	-0,020***	-	-	0,122**	0,873**	-	-	-0,131***
$\Delta R_{power\ t-1}$	-0,107***	-0,736**	-	-	-	-	-	-
Δr_{t-1}	0,025**	-0,145***	0,030***	-	-	-	-	-
$\Delta R_{m\ t-1}$	-	-1,130***	0,045*	-0,605**	-	-	-	-
ΔP^{EUA}_{t-1}	-0,0154	-	-	0,097*	-	-	-	-
ΔP^{ELECT}_{t-1}	-	-	0,002*	-	0,109**	-0,002**	-	-0,013**
ΔP^{COAL}_{t-1}	-	-	-	-	-	-	-	-0,741***
ΔP^{OIL}_{t-1}	-	-	-	-	-	-	-	-
ΔP^{GAS}_{t-1}	0,128**	-	0,022*	-	-	-	-	0,173***
Const.	0,002***	-0,005**	-	-	-	-	-	

*stands for estimates significantly different from 0 at a 10% level, ** stands for estimates significantly different from 0 at a 5% level and *** stands for estimates significantly different from 0 at a 1%

5. CONCLUSIONS AND POLICY IMPLICATIONS

This paper investigates the interactions between the stock market returns of Spanish power industry and emission rights prices during Phase II and the first year and half of Phase III.

By using daily data from January 2008 to July 2014, we have tested the hypotheses that EUA price increases (decreases) positively (negatively) affects Spanish power stock market returns in the short run and that EUA price increases (decreases) positively (negatively) affects Spanish power stock market returns in the long-run.

From a cointegrated Vector Error Correction (VECM) we have investigated both long-run equilibrium relations and short-run interactions between the stock market returns of Spanish sectors under EU ETS and emission rights prices. In general, the results indicate that the EUA price change doesn´t have short-run effect on stock market returns of the sector during both EU ETS phases (hypothesis a) is rejected). However, a statistically significant positive long-run impact of EU ETS on power sector stock market return is found for both phases (hypothesis b) is not rejected). In fact, an EUA price rise of 1%, would, in equilibrium, be associated with an stock price for the power sector increases of 0,0102% and 0,03% for Phase II and III, respectively.

It is important to note that these findings should be viewed in concert with the specific period and EU ETS phases analysed, but also in concert with the specific carbon market (the European). Regarding the period and EU ETS phases, we would like to point out that during Phase III the allocation of emission allowances are given out predominantly in auctions, starting from a

proportion of the 20% in 2013 and reaching a 70% level in 2020 (European Commission 2009). Thus, our results could vary as soon as greater proportion of auction allocation of allowances is reached. For instance, for the power sector, to switch to a higher auction proportion will leave the electricity sector as a whole better off than before the introduction of the EU ETS (Keppler & Cruciani, 2010).

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SOCIOECONOMICS IN THE ENVIRONMENTAL IMPACT ASSESSMENT: EVIDENCE IN THE HYDROELECTRIC POWER PLANTS OF THE PORTUGUESE CENTRO REGION

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ABSTRACT

The paper starts with a brief review on the various Portuguese legal systems of environmental impact assessment (EIA), focused on the relative importance of its various procedural phases and the embedding of socioeconomics on impact assessment.

Secondly, the different approaches on the EIA "socioeconomics" factor, the eventual mitigation measures on this factor, the appreciations of the presented studies and the essential outlines that arise from this assignment will be analysed. This will be done by taking into account case-studies of hydroelectric projects that were submitted to EIA, between 1992 and 2014 (i. e., covered by different legal systems). In this domain, the purpose is to recognize: (i) if the studies content integrates social and economic aspects, (ii) if the "socioeconomics" factor was considered in the monitoring programme and (iii) what is its contribution to post-evaluation processes.
Finally, a set of reflections on the relevance of the consideration of socioeconomic impacts and its incorporation in monitoring and post-evaluation of hydro exploitations will be formulated.

Keywords: socioeconomics; environmental impact assessment.

1. THE EVOLUTION OF LEGAL SYSTEMS OF ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

The environmental impact assessment (EIA) is "*one preventive instrument of environmental policy, supported by the conduction of studies and consultations, with effective public participation and analysis of possible alternatives, which is engaged in the gathering of information, identification and prediction of the environmental effects of certain projects, as well as the identification and proposal of measures to avoid, minimize or compensate for these effects,*

bearing in mind for a decision on the feasibility of implementation of such projects and respective post-assessment"[5].

The table 1 outlines a brief route by the various legal systems of EIA so far in effect in Portugal, from the perspective of the relative importance of the various procedural phases and the incorporation of socioeconomics on impact assessment.

Table 1 – The evolution of legal systems of EIA and the incorporation of socioeconomics

Legal systems	Objectives and procedures	"Socioeconomics" factor/role
Decree-Law (DL) 186/90, of June 6, modified by DL 278/97, of October 8	Creating conditions so as to avoid environmental disturbances *(preamble)* The environmental impact must always be assessed in order to, not only ensure the diversity of species and maintain the characteristics of the ecosystems as irreplaceable natural heritage, but also as a way to protect human health and promote the quality of life in communities *(preamble)* Measures to prevent, reduce and, if possible, remedy significant adverse effects and to identify and assess the main effects the project may have on the environment are foreseen *(No. 3 of Article 3)* On the appraisal, the cumulative or synergistic effects of the project over environmental components will be taken into account *(No. 5 of Article 3)*	The EIA takes into account the direct and indirect effects of projects on the following factors: a) Human being, fauna and flora; b) Soil, water, air, climate and landscape; c) The interaction of the factors mentioned in the previous subheadings; d) Material assets and the cultural heritage *(No. 2 of Article 2)* Description of the environmental elements likely to be significantly affected by the proposed project, including fauna, flora, soil, water, atmosphere, climatic factors, material assets, including the architectural and archaeological heritage, landscape, as well as the inter-relationship between the factors mentioned *(No.3 of Appendix II)*
DL 69/2000, of May 3	Promoting sustainable development by managing natural resources in a balanced manner, ensuring environmental quality protection and thus contributing to the improvement of human quality of life *(preamble)* Mandatory nature of the decision (Environmental Impact Statement – EIS) *(preamble)* Adjustment of the public participation component and the public access to information *(preamble)* Introduction to post-assessment, aimed to ensure proper monitoring of the project in stages that follow EIS *(preamble)*	Process of high complexity and large social impact, directly involving the economic side, because of the magnitude of the repercussion of its effects on public and private larger projects *(preamble)* «Environmental impact»: set of favourable and unfavourable alterations produced in environmental and social parameters *(Article 2)* Obtain an integrated information of possible direct and indirect effects on the natural and social environment of the projects *(Article 4)* Description of the local status and of the environmental factors likely to be significantly affected by the project, namely population, fauna, flora, soil, water, atmosphere, landscape, climatic factors and material assets,

(5) See Article 2 of the Decree-Law No. 69/2000, May 3 and Article 2 of the Decree-Law No. 151-B/2013, of October 31. About the preventive character of the EIA, see also José Eduardo Figueiredo Dias, *Direito Constitucional e Administrativo do Ambiente*, cadernos CEDOUA, Almedina, 2nd. edition, 2007, page 20, and Maria do Rosário Partidário and Paulo Pinho, *Guia de apoio ao novo regime de Avaliação de Impacte Ambiental*, IPAMB, 2000, page 9.

		including the architectural and archaeological heritage *(No.3 of Appendix II)*
DL 197/2005, of November 8	Greater involvement of citizens in the decision making process, ensuring public participation, the wide dissemination and availability of information, as well as access to justice. The inserted changes to the rules on public participation and dissemination of information facilitate and clarify the processing of the EIA procedure and allow a more enlightened and active citizens intervention *(preamble)*	
DL 153-B/2013, of October 31, modified by DL 47/2014, of March 24 and DL 179/2015, of August 27	Review and clarification of the various steps and procedures, including a systematic reorganization, a global reduction in the expected timeframe and a greater dematerialization of the process *(preamble)*	«Environmental impact» set of favourable and unfavourable changes in the environment on certain factors *(Article 2)*

It is however in Ordinance No. 330/2001 – which regulates the content of the documents of the various procedural stages of the EIA – that the socioeconomics is referred to as an environmental factor(6). And, although paradigmatically (since it occurs on an amendment to an ordinance that stipulates the fees for the appreciation of EIA processes(7)), socioeconomics is explicitly enshrined as an environmental factor. This issue generates some controversy. José Eduardo Figueiredo Dias, Alexandra Aragão and Maria Ana Rolla(8) argue that the concept of environment underlying the Decree-Law No. 69/2000 is too broad, acknowledging that only the environmental components of impacts should be evaluated during the EIA procedure, reserving the considerations on social and economic impacts of the project to the licensing authorities and other stakeholders in the licensing process(9).

Therefore, we can say that that the way the "environment" is perceived evolved from a restricted to a broader scope of assessment, through the inclusion of the social and economic impacts and the consideration of the population as an environmental factor. Moreover, we have been moving towards a broad, integrated and integrative impact assessment, not only concerning environmental impacts: strategic environmental assessment; cumulative

(6) See No. 3 of Appendix I, and in particular IV, a), ii) of No. 3 of Appendix II.

(7) See paragraph c) of No 7 of Ordinance No. 1067/2009, of September 18, which modifies and republishes the Ordinance No. 1102/2007, of September 7.

(8) See *Regime Jurídico da Avaliação de Impacte Ambiental em Portugal – comentário*, CEDOUA, 2002, pages 30 and 40.

(9) However, the same authors do not fail to mention that the Espoo Convention (on cross-border environmental impacts, that the Decree 59/99, of December 17 refers) defines impacts as the effects of the proposed activity on the environment, then detailing a set of factors (health, safety, flora, fauna, soil, atmosphere, water, climate, landscape, cultural or built heritage) or the interaction between them or "*the socioeconomics conditions*" resulting from its modification.

impacts; social, heritage and climate, on health, human rights, gender, sustainability, ecosystem services impacts, etc..

On the other hand, successive regimes have meliorated the methodological and groundwork requirements of the impact assessment and the requirements relating to post-assessment (monitoring/follow-up of the measures to prevent, reduce or compensate the negative impacts of projects subject to EIA). Procedures were also progressively given credibility, either by the introduction of the mandatory character of the decisions, either by growing concern on popular plebiscite.

The introduction of social assessment components of impacts in EIA procedures has been consolidating socioeconomics as an environmental factor. Indeed, despite the fact that the references to “social” and “population” are contained on the scheme approved in 2000, the know-how consolidated the presence of the “socioeconomics” factor in environmental impact assessments submitted after this date, even after the entry into effect of the 2013 regime in which such references are not included.

The environmental impact assessment should therefore consider the "environment" in a broad sense, not confined to biophysical or natural factors. The possibility of not treating the descriptor "socioeconomics" would be a “deflation” of a very relevant dimension. A social impact analysis should work on cumulative and positive impacts, “social utility” of the investment (especially when it involves public funds) and justice (social, procedural and distributive). It should also anticipate conflicts and manage interests and monitor and manage adaptively the social effects of the projects evaluated (Luísa Mendes Baptista and Paulo Pinho, 2014[(10)]). What should be involved in these assessments transcends environmental issues (in the narrow sense of the expression) because what matters is to ensure the conditions for sustainable development of the people and all the surroundings. This broad view is supported in international guidelines on impact assessment. The International Association for Impact Assessment (IAIA) (1999)[(11)] considers that the EIA corresponds to the “*process of identifying, predicting, evaluating and mitigating the biophysical effects (conjugation of physical and ecological effects), social and other relevant effects of development proposals prior to major decisions being taken and commitments being undertaken*”.

2. THE RELEVANCE OF SOCIOECONOMICS IN ENVIRONMENTAL IMPACT STUDIES REGARDING HYDROELECTRIC PLANTS

An initial note is a devoir to highlight the national and regional importance of hydroelectric exploitations in their various dimensions: i) due to the important contribution to ensure the energy production capacity and a significant part of the electricity consumption (figure 1), together with their stabilizing function of

(10) In *Poderá a Crise ser uma Oportunidade para a Componente Social da Avaliação de Impactos?*, oral presentation to the “5ª Conferência Nacional de Avaliação de Impactes” (CNAI’14), Viseu, March 2014.

(11) Quoted in Maria do Rosário Partidário, *Guia de boas práticas para Avaliação Ambiental Estratégica – Orientações Metodológicas*, APA, 2007, page 37.

other forms of energy, ii) due to the strong impacts in their phases of construction, operation and decommissioning (requiring an analysis of the respective life cycles) cause and iii) due to the multiple uses that they provide (which are often the real reason for the right decision of its implementation)[12]).

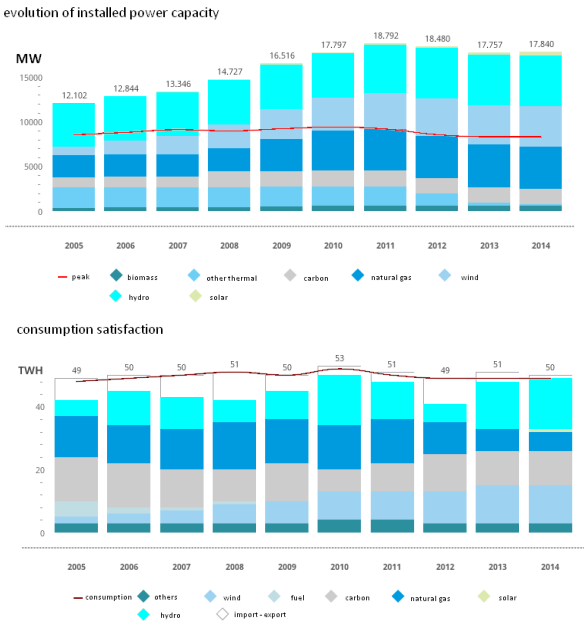

Figure 1 – The hydroelectric part on the the installed electrical power and on the consumption satisfaction (source: REN, Relatório e Contas 2014)

The Portuguese hydroelectric power plants are concentrated in the North and Centro regions[13]. On the other hand, the European Union advocates for Portugal a slight increase in installed hydroelectric capacity by 2050[14].

2.1. On selected case studies

The selection of case studies (table 2 and figure 2) had into account the following aspects: focus on hydroelectric plants for energy or multiple purposes in Centro Region; diversification of the typology (large and medium dams and mini-hydro), of location (extended territorial coverage) and of the presentation and construction dates (so the analysis could cover periods when various legal systems were effective and cases that were built and not built).

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(12) On its *Reflexão preliminar sobre o Relatório Ambiental do Programa Nacional de Barragens com Elevado Potencial Hidroelétrico (PNBEPH)*, 2007, the National Council for Environment and Sustainable Development (CNADS) referred: "*one of the main criteria of the (…)sustainability [of hydropower projects] is the ability to integrate in a compatible way multiple purposes and uses, involving both direct economic services and biodiversity*". Apropos, is noted that the Strategic Environmental Assessment (SEA) of PNBEPH (a national dam program with high hydropower potential) considered two critical factors in the decision which were related to socioeconomics (human desvelopment and competitiveness), in a set of six factors (see COBA/PROCESL, *Relatório Ambiental da AAE do PNBEPH*, 2007).

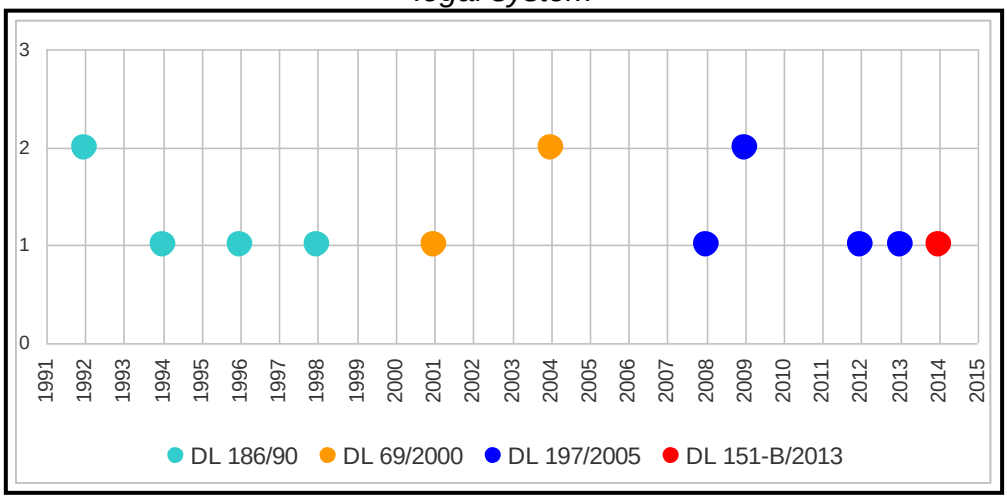
(13) Indeed, in a publication of a company that owns the majority of the ventures in operation (EDP, *New hydroelectric projets*, 2013), 35 cases in North, 31 cases in Centro and only 6 in Alentejo are listed.

(14) See https://ec.europa.eu/energy/sites/ener/files/documents/trends_to_2050_update_2013.pdf.

Table 2 – Brief characterization of the evaluated ventures

Hydroelectric project (HP)	Annual energy production (GWh)	Municipalities	Current state	Goal(s) of the project
HP "Rio Côa – Escalão de Foz Côa"	298.00	Fig.ª de Castelo Rodrigo, Pinhel and Meda	Not built	Electric power production
HP "Janeiro de Cima – Rio Zêzere"	15.60	Pampilhosa da Serra and Fundão	Operating since 1995	Electric power production
HP "Oliveira de Frades"	19.55	Oliveira de Frades	Not built	Electric power production
Mini-hydro "Avô – Rio Alva"	4.20	Oliveira do Hospital	Operating since 2001	Electric power production
HP "Penacova"	23.69	Penacova	Operating since 2001	Electric power production
HP "Pinhel"	16.52	Pinhel	Operating since 2004	Electric power production
HP "Palhais"	12.41	Sertã	In design/construction	Electric power production
HP "Pereira, Rib.ª da Carvalhosa"	5.50	Castro Daire	Operating since 2006	Electric power production
HP "Ribeiradio – Ermida"	139.00	Vale de Cambra, Sever do Vouga, Oliveira de Frades and S. Pedro do Sul	In design/construction	Hydric regulation; electric power production; availability of a strategic water reserve; tourism development
HP "Alvito"	70.00	Castelo Branco and Vila Velha de Ródão	In design/construction (until 2020)	Electricity production with pumping; water plan for tourism and recreation
HP "Janeiro de Baixo"	1.20	Fundão, Pampilhosa da Serra and Oleiros	In design/construction	Electric power production
HP "Girabolhos"	871.00	Gouveia, Seia, Fornos de Algodres, Mangualde and Nelas	In design/construction (until 2020)	Electricity production with pumping; water plan for tourism and recreation
Hydroelectric power plant "Vale das Botas"	6.12	Arganil and Tábua	Not built	Electricity production with pumping; water plan for tourism and recreation
HP "Penacova e Poiares"	22.30	Penacova and Poiares	Not built	Electric power production

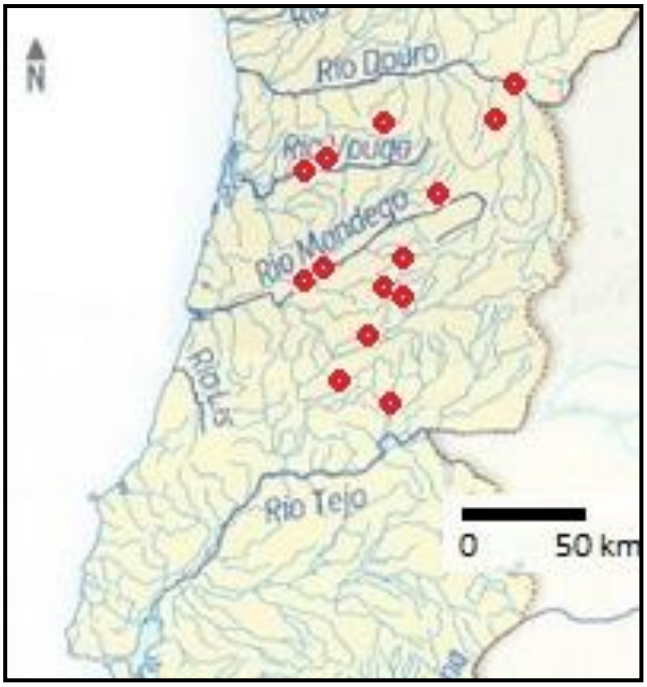
Figure 2 – Environmental Impact studies analysed, per year and per applicable legal system



Much of the information analysed was accessed through SIAIA (Portuguese environmental impact assessment information system) available at http://siaia.apambiente.pt, which is a valuable analytical tool, complemented by the files of the Centro Coordination and Regional Development Commission (CCDRC).

The Figure 3 shows the approximate location of the 14 projects considered.

Figure 3 – Location of the assessed projects



2.2. The socioeconomics content of the studies

In the 14 cases analysed, there is some disparity in the depth and breadth of treatment of the subject "socioeconomics". Therefore, the following topics were highlighted:

Demographic aspects: there are 10 cases in which surrounding population and effects of the project on the local labour market are studied;

Economic activities emerging from hydroelectric exploitations: this is a dimension which is covered in nine cases, however, addressing very different issues (use of water resources for purposes not related to energy production, potential recreation and leisure use, effects on the creation of direct and indirect jobs during the construction and exploitation, reduction in agricultural and forestry activity and concomitant loss of income, power generation, etc.);

Impacts for the surrounding populations, acceptance of the project by the population and effects generated by the projects: in six cases, there are concerns related to mobility/accessibility, allocation of road infrastructures or road disruption and need for re-establishment, in addition to a case of reduced river navigability; in four cases, negative impacts or nuisance in terms of noise

and air quality during the construction phase (due to dust emission) are referred/analysed; in two cases each, the degree of project acceptance by the target population and the land valuation of the reservoir surrounding are discussed; in one case each, the effects on the housing, the community improvements that the project can generate (as counterparts for its construction) and the allocation of non-road infrastructure and equipment are analysed;

Effects on the environment: in the context of socioeconomics, environmental issues are presented and discussed, examples of which are: (i) the impracticability of a river beach, in four cases, (ii) the decrease in circulation of some fish species as lamprey and shad, in one case; (iii) the reduction of water quality, in one case, and (iv) the reduction of external energy dependency on fossil fuels and atmospheric emissions, in one case.

Reference to the use of endogenous resources: socioeconomics is intended in four cases to the call for incorporation of domestic materials and equipment and/or the use of local manpower, aspects we know that contradict the laws of competition and of the movement of persons and goods and services in Europe, but are merely non-binding recommendations.

We can group the main concerns relating to the factor "socioeconomics" in accordance with the following table:

Table 3 – The most common issues on the socioeconomics factor

Social aspects	Economical aspects
Employment, population and settlement Labour market/recruitment Social inclusion/social cohesion/poverty Social rights Health, safety and hygiene at work Education/training and qualification Associated technological risks Governance Social monitoring of the project's effects	Competitiveness and markets Investment Microeconomics (effects on the local or sectoral economics) Macroeconomics (effects on the regional or national economics) Regions/territorial cohesion Effects on the labour market Accessibility, mobility and transport Energy and raw materials (resource utilization) Governance

There is thus a tendency to “pigeonhole” on socioeconomics themes that do not fit within the other factors of greater or lesser environmental bent. The most striking example is associated with accessibility and transport, which is often treated in the factor “socioeconomics” (either in the sample considered, either in environmental impact studies for other types of projects).

Regarding the analysis that the Commissions assessment (CA) of environmental impact assessments (EIA) conducted on the socioeconomics content, only three more severe critics were detected: in one case, it was considered that the “*EIA is a superficial analysis of socioeconomics aspects, since it assumes that the project will have few negative impacts*”, in another case, it was noted that “*there was no evidence of the link between the baseline and the identification and assessment of socioeconomic impacts*” and that “*the*

impacts on local populations resulting from flooding and destruction of agricultural land were evaluated" on an insufficient way.

The complexity of socioeconomic aspects advise that the Assessment Committees (mostly comprised by representatives of national public entities, with reduced presence of representatives of regional organizations(15) and absence of representatives of local authorities) and the EIA teams of hydroelectric exploitations should contain experts in socioeconomics.
From a methodological point of view of the impact analysis, three cases of reference to the matrix recommended by the International Commission on Large Dams (1980) were detected and the most recent case already used the Index of Weighted Evaluation of Impacts (Portuguese IAP)(16) advocated in the current legal system of EIA(17).

2.3. Socioeconomics on monitoring programs

Since in the case studies it was not always given due relevance to socioeconomic impacts, a great densification of measures on socioeconomics in the monitoring programs should not be expected.

In the 14 projects analysed, the socioeconomic conditions of the Environmental Impact Statement (EIS) or – in the cases of environmental impact studies in a previous study phase – the socioeconomic elements to deliver at a later stage (a total of six cases) concerned only the aspects related to access, except for a case in which the EIS "imposes" (in terms that we had already considered at least debatable) the "*recruitment of local manpower (during the construction phase) and local operators*" (for the exploitation phase).

In what concerns the measures envisaged, it can be summarized as follows:
Protective measures of the surrounding populations: (i) minimizing noise impacts of the hydroelectric plant in existing housing; (ii) displacing the construction site to the farthest location from human settlements; (iii) planning measures to avoid the crossing of human settlements with the generated traffic (three cases) during the construction or to reduce the construction machines speed (two cases); (iv) ensuring access to farm and forest land during the phases of construction and operation (two cases); (v) preferential use of local labour (two cases), providing appropriate professional training (one case); (vi) adequate financial compensation of the owners of the affected land during construction and installation of the structures associated with the hydroelectric exploitation, the land flooded by the reservoir or the land damaged by rising water levels in the river tributaries in which the reservoir is created; (vii) supporting the population to be displaced from permanent housing; (viii) financial compensation of operators of affected economic activities, "namely linked to rural tourism"; (ix) procurement of goods and services at local level;

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(15) Between 14,3% and 40% of the members in the 14 cases analyzed, with an average of 24.7%.14,3% e 40%.

(16) The very significant negative impacts and significant positive impacts in socioeconomic terms were evaluated; ergo, the socioeconomics has been considered a relevant descriptor, with decisive influence over the value of the IAP. In this case, a unfavourable EIS was issued to the project.

(17) See No. 1 of the Article 18 of the Decree-Law No. 153-B/2013.

Measures of information and involvement of affected populations (for example, the divulgation of the "*implementation program of construction works to the interested population, namely the population living in the surrounding area*" including "*the purpose, the nature, the location of the site, the main actions to be taken, respective timing and eventual affectations to the population, particularly the allocation of accessibility*" and the implementation of "*a customer service mechanism to clarify questions and to answer eventual complaints*", in five cases, whereas in one of them it is still planned to provide the "*information about expected benefits following the exploitation start of the project*";

Natural resource protection measures, affecting the local economy: for example, the guarantee of an ecological flow (with action in maintaining fish stocks) or reducing the risk of ignition in land clearing, deforestation and stripping of land to flood.

Three more monitoring programs were analysed, which predict the following goals on the field of socioeconomics:

One defined as objectives "*1) Establish a diagnosis of the conditions in respect to the parameters considered and propose effective measures to solve the problems encountered; 2) Assess the implications of development on local social and economic structure, including the respective territorial implications during the phases of construction and exploitation*", predicted the monitoring of the "*actual circumstances in which the expropriations and relocations were executed*" and advocated an annual sampling frequency ("*from the beginning of the expropriations and until two years after the filling"* of the reservoir). This program is intended to assess "*the state of evolution and adaptation of the affected communities to the new prevailing*", recommending the annual proposal of "*mitigation measures of any detected malfunctions*";

Two other programs (very similar between them) were titled "*Plan of Human Development and Competitiveness Monitoring*" and "*Plan of Regional Development Monitoringl*" and intend to monitor (i) the "*effective contribution of hydroelectric projects (HP) on the quality of life increment*", focusing on the following parameters: jobs and benefit of the families; population growth, economic activities and municipal public investment and (ii) the "*effective contribution of the HP for the economic activity increment*", focussing on the following monitoring parameters: tourism, production and trade of local agricultural products of exception and activities such as crafts. They advocate biannual monitoring (judging that they intend that it is made biennially).

2.4. The contribution of socioeconomics in the post-evaluation

According to the current EIA system since 2000, the post-evaluation of goals, which are the responsibility of the EIA authority and should cover the conditions of the licensing or authorization, construction, operation, exploitation and decommissioning of the project are as follows:

"*a) Evaluation of the conformity of the execution project with the EIS, in particular the compliance with the terms and conditions set out therein;*

b) Determination of the effectiveness of the measures envisaged to prevent, minimize or compensate the negative impacts and maximize the positive effects as well as, if necessary, the adoption of new measures;

c) Analysis of the efficacy of the EIA procedure performed".

Partidário and Pinho (2000) further refer the objective of the monitoring the environmental system response to the effects produced by the project, explaining that the post-assessment can match the project of execution and the verification of its compatibility with EIS (when it was issued in a previous study phase or draft), or to the phases of construction, operation and decommissioning of the project (through monitoring or audits)[(18)].

Now whether socioeconomics presents mostly positive impacts on the surrounding environment of a given hydroelectric plant (when such impacts can mitigate, reverse or even overcome the negative effects of adverse impacts in terms of other factors) or not, the post-evaluation is always convenient and should cover the social and economic aspects.

Since the evaluation period of the 14 studies of environmental impact is between 1992 and 2014 and that only 5 exploitations are in operation, there is still no clear evidence that can be drawn from monitoring reports. In these 14 cases examined, only three of them had evidence of post-evaluation results (monitoring and Environmental Compliance Report of the Final Design with the EIS –Portuguese 'RECAPE'), which are summarized as follows:

In one of them, the interconnection between environmental components and their relationship with the social component (for example, interactions between noise levels and air quality and the welfare of the people) is very interesting and the concerns about accessibility and the social effects of expropriation and relocation are once again very prominent;

In another case (one 'RECAPE'), an interesting complementary study about the possibility of building a bridge is held, since "*the currently existing connection will be unviable with the creation of the reservoir*". The study shows that the construction of the bridge "*although being technically feasible, does not show up as solution with relevant socioeconomic interest*". The Parish Council was heard, "*in order to perceive this entity in what concerns the relevance of this crossing or the existence of other more interesting compensatory alternatives*", and the final choice was to perform "*projects of valorisation and development of the parish"*" to the detriment of a new bridge;

In this case, the Evaluation Committee compliments the "*reporting on complaints and/or requests for clarification to be submitted to the EIA authority*" and considers that the "*implementation methodology of this measure is appropriate, given the diverse use of means of communication to the involvement and commitment of the population (general and comprehensive channels in the area and information sessions)*". On the monitoring program,

(18) Quoted work, pages 34 and 35.

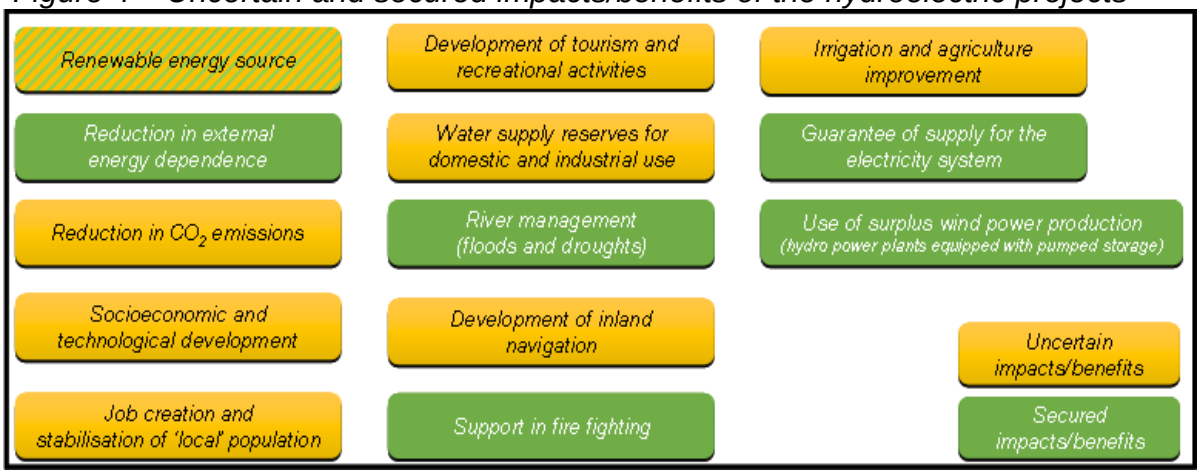
the Evaluation Committee highlights the "*complexity underlying, given the qualitative characteristics of the concepts in question, considering that the displayed operation fits well the situation"*, emphasizes the relationship with an integrated action of economic and social development to be established under the hydroelectric project and alerts to the possible need for, under monitoring, reviewing the recommended indicators;

Finally, in another case, the monitoring program enables a contribution as "*orientation to the studies and proposals to be implemented in the future development plan of the reservoir and as gauge instrument of expected impacts*", identifying and evaluating "*impacts that were not foreseen*", defining "*new measures*" and assessing the "*effectiveness of minimizing measures planned aiming to their possible amendment*".

We can then say that the post-evaluation is a path that now is being crossed, in which there is not the possibility of reverse gear.

Socioeconomics may allow monitoring and post-evaluation of very relevant impacts of hydroelectric projects, including by monitoring the maximization of benefits of multiple uses in reservoirs created (see Figure 4[19]).

Figure 4 – Uncertain and secured impacts/benefits of the hydroelectric projects



3. SOME CONCLUSIONS

From the assignment we have been done, we can extract the following concluding summary:

Proven the difficulty on in collecting retrospective information on environmental impact studies it is pertinent that the loading of historical data in SIAIA

(19) The scheme illustrates a doubt, for further discussion: is the "large hydro" a completely renewable source, since it induces significant impacts that may cause substantial changes (climate change, changes in tributaries flow rates, etc.)? On the other hand, reduction in greenhouse gas emissions is not evident (since the reservoirs generate some eutrophication).

(Portuguese system of information of environmental impact assessment) is concluded;

There is an increasing densification of the objectives of hydroelectric exploitations, which leads to a greater development of the characterization of the socioeconomic baseline on environmental impact studies and to a progressive significance of considering and analysing of the respective socioeconomic impacts. Indeed, on the analysed cases, it was found that between 1992 and 2014 there was a growing awareness of the importance of this factor in the decision and in the consideration of the impacts of these projects;

Through time, socioeconomics has been understood in a broad manner as a cross factor that is related to the themes that are classically considered environmental factors;

Simultaneously, there is a greater anchoring to supranational objectives, taking into account international contexts and targets in the use of renewable energy;
Procedurally, there is a reinforcement of the legal power of the decision following the environmental impact assessments, which has also the most profound consequences regarding monitoring and post-evaluation;

The Assessment Committees (mostly comprised by representatives of national public entities, with reduced presence of representatives of regional organizations and absence of representatives of local authorities) and the EIA teams of hydroelectric exploitations should contain experts in socioeconomics;

The constraints of the EIS and the elements to present at later stages of the EIA procedure (for example, environmental compliance report – ‘RECAPE’ – or monitoring reports) are, regarding socioeconomics, excessively focused on issues related to accessibility. It looks like the guidelines relating to the effects of projects on employability, on the social effects of projects, on territorial cohesion and on local economic development should be reinforced;

Still, more measures and deeper measures (to minimize but also to potentiate or reward other negative impacts) in recent projects evince the growing importance of the "socioeconomics" factor, in particular for the post-assessment phase of the impacts generated by hydroelectric projects.

RENEWABLE ENERGY IS CAUSING ECONOMIC GROWTH? AN EMPIRICAL STUDY UPON COUNTRIES WITH A BARRIER TO DIVERSIFY ENERGY SOURCES

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ABSTRACT

This paper is focused on the relationship between economic activity, renewable and non-renewable energy consumption for the set of countries with the largest share of usage of each energy source. Accordingly, a panel of 28 countries, using data with annual frequency, for the time span 1995-2013 was studied. The dominance of one type of energy source was the single criterion for selecting them. ARDL approach was used to capture the short- and long-run effects. The results show great consistency. After leaving the possibility of heterogeneity of the panel and with the application of specification test, the Driscoll-Kraay estimator was used to obtain robust results. According with the results non-renewable energy consumption has a positive contribute to the economic growth. In the other hand, in the long-run renewable energy consumption degraded economic activity, contrary to the non-renewable energy which is not statistically significant.

Keywords: renewable energy; non-renewable energy; dominant sources; ARDL

1. INTRODUCTION

Fossil fuels remain the main source in the global energy mix, there are associated with the increase carbon dioxide emissions. The deployment of renewable energy sources can play a crucial role to reduce carbon dioxide emissions and fossil fuels dependency (Lind et al., 2013).

Several countries have implemented renewable energy sources, so there is a growing global trend in this kind of source. This diversification of energy sources is verified due to the enforcement carbon dioxide emission reduction targets, as the Kyoto protocol, or others international and national programs. Renewable energy production targets concerted between countries, like us the European Union, also causes a diversification of energy sources.

Entry barriers are vastly analyzed in the industrial economy (McGowan, 2014; Mukoyama & Popov, 2014). There are several types of entry barriers such as: initial investment, inelastic demand, restrictive practices and research and development. Barriers to diversification of sources in energy mix, particularly renewable energy sources, are also common (Runko Luttenberger, 2015).

This analysis is focused on a countries panel where there is at least one dominant source. The country's presence in the top ten of world electricity production share in 2012, was chosen criteria in selecting countries, as well as data availability.

Panel data with 28 countries that are dominant in the energy production in some kind of source was used in this study. Estonia, Iceland, Israel, Luxembourg, Slovenia and Turkey were excluded from the analysis due to data unavailability. Annual data is used in this study, for the period 1995 to 2013. The period was chosen according to the availability of data for selected countries, for the greatest possible time span. Energy variables (nonrenewable and renewable energy consumption), economic variables (gross fixed capital formation, exports of goods and services and employment) and an environmental variable (dioxide carbon emissions) were used to explain economic growth.

The ARDL approach in panel data was used to detect short- and long effects. In the short-run the DLNREC has a positive impact, while in the long-run the LREPC has a negative impact in the DLGDP. Gross fixed capital formation has a positive effect for both short- and long-run.

2. LITERATURE REVIEW

The purpose of this article is to study how economic activity reacts to the diversification of energy sources, in countries that are dominant in the energy production in some kind of source. The causal relationship between economic activity and energy consumption is strongly present in the literature. In the energy growth nexus four traditional hypotheses are tested (Ozturk, 2010; Payne, 2010). The *growth hypothesis* predicts a unidirectional causality, running from energy consumption to economic growth. The *feedback hypothesis* predicts a bidirectional causality between economic growth and energy consumption. The *neutrality hypothesis* which implies non-causality between economic growth and energy consumption. Finally, the conservation hypothesis implies a relationship from economic growth to energy consumption.

Although the literature is abundant, there is no consensus in the results. Different samples and econometric techniques can explain this lack of consensus (Ozturk, 2010). A positive relationship between renewable energy consumption and economic growth was founded by Al-mulali, Fereidouni, & Lee (2014). While then non-existence of the relationship between renewable energy consumption and economic growth was confirmed by Chang, Huang, & Lee (2009). There are several forms of nexus: energy aggregate consumption-growth nexus (Alshehry & Belloumi, 2015), natural gas-growth nexus (Adebola & Shahbaz, 2015), nuclear energy-growth nexus (Chu & Chang, 2012), electricity consumption-growth nexus (Sun & Anwar, 2015) and electricity

consumption-growth nexus by source (Ohler & Fetters, 2014). The interaction between electricity generation sources and economic activity was studied by Marques & Fuinhas (2015). Summary results of the energy-growth nexus can be seen in Ozturk (2010) and Payne (2010).

This research does not focus specifically on the energy-growth nexus analysis, but in the diversification of energy sources, the study sample is composed by countries with high energy production in a source type.

Different types of renewable integration barriers are presented by Nalan, Murat and Nuri (2009). Economic barriers are the main obstacle to the renewable deployment, initial costs are relatively high and the energy production is low, which increase the risk of financing. Scientific and technical barriers are another type, hare included geographical issues and the fact that renewable energy technology is not as developed as fossil fuel tecnhology. Legal and institutional barriers must be considered (Morales et al., 2015). Obstacles and ways to overcome to renewables integration in the European Union are synthesized by DeLlano-Paz, et al. (2015).

3. DATA AND VARIABLES

To achieve the aim of this study the countries sample, for the period 1995 to 2013, was chosen following a single criterion: the country's presence in the top ten of world electricity production share in 2012. According with the data availability the following countries were selected: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, South Korea, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, United Kingdom and United States of America.

The source of the variables was the World Bank Data, for gross domestic product (constant 2005 US$); exports of goods and services (constant 2005 US$), population (in number of people); unemployment (% of total labor force); labor force (total) and gross fixed capital formation (constant 2005 US$); and BP Statistical Review of World Energy, June 2015, for oil consumption (in tones), gas consumption; coal consumption; nuclear energy consumption, Hydroelectricity consumption; solar consumption; wind consumption; geothermal, biomass and others renewables sources; and carbon dioxide emissions. All variables obtained by BP Statistical Review of World Energy, June 2015 are in million tones oil equivalent, except oil consumption and carbon dioxide emissions. The variables gross fixed capital formation, exports of goods and services, dioxide carbon emissions and employment were are used as control variables (Azam et al., 2015; Cai, Mu, Wang, & Chen, 2014; Özbuğday & Erbas, 2015). The variables used in the estimated models are:

GDPPC (Gross Domestic Product *per capita*) – this variable was obtained by dividing de gross domestic product by the total population.

NREPC (nonrenewable energy consumption *per capita)* – this variable was computed in two steps. The first one consists of the sum of oil consumption, gas

consumption, coal consumption and nuclear energy consumption. The second step consists in dividing the above sum by the total population.

REPC (renewable energy consumption *per capita*) – this variable also was computed in two steps. The first one consists of the sum of hydroelectricity consumption, solar consumption, wind consumption and geothermal, biomass and other renewables sources consumption. The second step consists in dividing the above sum by the total population.

EXPPC (exports of goods and services *per capita*) – This variable was obtained by dividing the exports of goods and services by the total population.

GFCFPC (gross fixed capital formation *per capita*) – This variable was obtained by dividing the gross fixed capital formation by the total population.

CO2PC (carbon dioxide emissions *per capita*) - This variable was obtained by dividing the carbon dioxide emissions by the total population.

EMP (employment) – This was obtained in three steps. The first one consists of dividing unemployment by 100. In second step the former result is multiplied by labor force, in order to obtain unemployment absolute value. In the third step the subtraction of labor by unemployment was computed, in order to obtain the employment.

4. METHOD

To study the relationship between economic growth, renewable and non-renewable energy consumption in countries with a dominant source, it is useful analyze the dynamic effects of short- and long-run. The Autoregressive Distributed Lag (ARDL) (Shin & Pesaran, 1999) model allows analyzing this effects. It also allows different independent variables, different integration order of variables, I(0) and I(1), different lag-lengths within the model and it is less restrictive. The dependent variable is DLGDPPC. The specification of the ARDL model is following:

$$LGDPPC_{it} = \alpha_i + \beta_{i1} + \beta_{i2}LNREPC_{it} + \beta_{i3}LREPC + \beta_{i4}LGFCFPC_{it} + \beta_{i5}LCO2PC_{it} + \beta_{i6}LEXPPC_{it} + \beta_{i7}LEMP_{it} + \varepsilon_{it} \quad (1)$$

Where the prefixes “L” and “D” denote natural logarithm and first differences of the variables, α denotes the intercept, β_i and γ_i the estimated parameters, and ε_i the error term. In the equation (2) can be observed the dynamics of short- and long-run.

$$DLGDPPC_{it} = \alpha_i + \beta_{i1}DLNREPC_{it} + \beta_{i2}DLREPC_{it} + \beta_{i3}DLGFCF_{it} + \beta_{i4}DLCO2PC_{it} + \beta_{i5}DLEXPPC_{it} + \beta_{i6}DLEMP_{it} + \lambda_{i1}LGDPPC_{it-1} + \lambda_{i2}LNREPC_{it-1} + \lambda_{i3}LREPC_{it-a} + \lambda_{i4}LGFCF_{it-1} + \lambda_{i5}LCO2PC_{it-1} + \lambda_{i6}LEXPPC_{it-1} + \lambda_{i7}LEMP_{it-1} + \varepsilon_{it} \quad (2)$$

In studies with analysis on panel data it is required to analyze the characteristics of the series and cross sections. It is important to note the nature of the variables, cross section dependence and the stationary properties. Table 1 shows the descriptive statistics and CD-test to test the cross section dependence.

Table 1. Descriptive statistics and cross section dependence

Descriptive statistics						Cross Section dependence (CD)		
Variables	**Obs**	**Mean**	**S.D.**	**Min**	**Max**	**CD-test**	**corr**	**abs(corr)**
LGDPPC	532	10.1555	0.6230	8.5632	11.1432	75.73***	0.894	0.894
LNREPC	532	-12.5661	0.4732	-13.8810	-11.1235	29.57***	0.349	0.566
LREPC	532	-15.2415	1.4954	-19.4802	-11.8437	32.46***	0.383	0.451
LGFCFPC	532	8.6554	0.6281	6.6992	9.70179	45.64***	0.540	0.640
LCO2PCC	530	-11.8161	1.4055	-22.7427	-10.6975	26.65***	0.313	0.565
LEXPPC	532	9.0810	0.8261	7.0242	10.7430	74.16***	0.878	0.881
LEMP	532	15.9674	1.1581	14.0704	18.8171	47.70***	0.565	0.678
DLGDPPC	504	0.0172	0.0265	-0.0911	0.10119	49.01***	0.594	0.595
DLNREPC	504	-0.00131	0.0424	-0.1472	0.17212	25.18***	0.305	0.346
DLREPC	504	0.05238	0.1684	-0.5248	1.10107	3.31***	0.040	0.236
DLGFCFPC	504	0.01779	0.0710	-0.3350	0.24032	34.99***	0.426	0.449
DLCO2PCC	502	0.00764	0.1766	-1.5992	2.52067	21.43***	0.260	0.321
DLEXPPC	504	0.04519	0.0700	-0.2769	0.25992	52.00***	0.633	0.636
DLEMP	504	0.00895	0.0192	-0.0892	0.07699	21.20***	0.258	0.304

Notes: CD-test has N(0,1) distribution, under H0: cross-section independence. *** represents significance level of 1%. All variables are in natural logarithms.

Cross section dependence was detected. There are two kind of dependence between crosses (Moscone & Tosetti, 2010). The first one is related with the geographical proximity. Dependence of countries sharing common shocks (Eberhardt, 2011) is the second type.

Variance Inflation Factor (VIF) was performed (table 2), to check the multi-collinearity between variables. The absence of multi-collinearity is verified by low VIF statistics values.

Table 2. VIF statistics

Variables	VIF	Variables	VIF
LGFCFPC	5.07	**DLGFCGFPC**	2.23
LEXPPC	3.98	**DLEMP**	1.93
LEMP	1.79	**DLNREPC**	1.39
LNREPC	1.78	**DLEXPPC**	1.35
LREPC	1.51	**DLREPC**	1.13
LCO2PC	1.23	**DLCO2PC**	1.07
Mean VIF	2.56	Mean VIF	1.51

To check the stationary properties of the variables first and second generation tests were made. The traditional first generation teste are: LLC (Levin, Lin, & Chu, 2002), where H0: unit root (common unit root process); ADF-Fisher

(Maddala & Wu, 1999) and ADF-Choi (Choi, 2001), where H0: unit root (individual unit root process). The second generation unit root test CIPS (Pesaran, 2007) was made, this unit root test is robust to heterogeneity and H0: series are I(1). Table 3 shows the results of unit root test.

Table 3. Unit roots test

1st generation				2nd generation	
	LLC	ADF-Fisher	ADF-Choi	CIPS	
	Individual intercept			No trend	With trend
LGDPPC	-7.0333***	80.9601**	-2.4486***	0.928	1.537
LNREPC	2.0566	23.4639	4.6104	2.176	2.128
LREPC	0.4459	60.6490	1.9415	1.831	1.909
LGFCFPC	-4.3517***	70.9475*	-1.9769**	0.394	-0.031
LCO2PCC	3.2564	21.3007	4.9496	9.155	7.015
LEXPPC	-8.1914***	80.5933**	-2.5461***	0.458	1.348
LEMP	-3.7223***	55.6038	0.2155	2.039	2.619
DLGDPPC	-8.0073***	116.174***	-5.3309	-4.675***	-2.926***
DLNREPC	-5.3582***	168.046***	-7.1222***	-13.693***	-11.426***
DLREPC	-7.9846***	215.347***	-9.9715***	-15.408***	-12.603***
DLGFCFPC	-8.2607***	147.156***	-6.9178***	-7.275***	-5.551***
DLCO2PCC	-6.5208***	159.320***	-6.8733***	-10.839***	-10.069***
DLEXPPC	-11.0871***	165.524***	-8.2675***	-7.919***	-5.784***
DLEMP	-5.6475***	119.796***	-5.3481***	-4.453***	-3.560***

Notes: *** and ** represents significance level of 1% and 5%, respectively. CIPS test assumes cross-section dependence is in form of a single unobserved common factor.

Different integration order of the variables was detected. Accordingly with the first generation tests the variables LGDPPC, LGFCFPC and LEXPPC are integrated in order 0,and the remaining variables are I(1). According with the second generation unit root test all variables are I(1). As such, considering that the variables are not I(2), then the use of the ARDL model shows to be appropriate.

The presence of individual effects was tested. Fixed effects (FE) against random effects (RE) was tested using Hausman test, where H0: random effect model is appropriate. The null hypothesis is rejected (Chi-squared = 95.64) at significance level of 1%, it supports the fixed effects model is adequate.

Considering the stationary properties of the second generation unit root test, the heterogeneous panel data, the presence of dynamic effects and cross-section dependence, the second generation co-integration test developed by Westerlund (2007) was performed, using bootstrapping to obtain robust critical values. The results of Westerlund co-integration test can be seen in the table 4.

Table 4. Westerlund co-integration test

Statistic	Value	Z-value	P-value
Gt	-1.624	4.159	0.600
Ga	-2.713	7.069	0.300
Pt	-3.840	3.840	0.580
Pa	-2.465	4.558	0.320

The null hypothesis of Westerlund co-integration test is: no co-integration. Statistics Gt and Ga test the hypothesis of at least one cross having all the variables co-integrated, and Pt and Pa statistics test the co-integration as a whole. The results show no co-integration in both statistics.

5. RESULTS

Considering the sample under analysis and taking into account the dominance of one type of energy source which could be diverse between sources, the possibility of panel heterogeneity should be considered. In this case the Mean group (MG) and the Pooled Mean Group (PMG) estimators can be used. The MG estimator is more flexible than PMG (Shin, Pesaran, & Smith, 1999), this estimator is efficient when the long-run coefficients are heterogeneous. The PMG estimator allows short-run coefficients heterogeneous and long-run coefficients homogeneous.

The Hausman test was performed, in order to test the adequacy of PMG and MG estimator against FE estimator. The FE estimator is less flexible than PMG and MG estimators. These models only allow the homogeneity in both short- and long-run coefficients. The PMG, MG and FE models, as well as the results of the Hausman test can be observed in table 5.

Table 5.Heterogeneous estimators and Hausman test

Models	**PMG(I)**	**MG(II)**	**FE(III)**
Constant	1.2913***	3.0724**	0.9459***
DLNREPC	-0.0098	0.0358	0.0469***
DLREPC	-0.0054*	-0.0075	0.0002
DLGFCFPC	0.1968***	-0.1751***	0.1818***
DLCO2PCC	0.0453	0.0010	0.0012
DLEXPPC	0.1708***	0.2171***	0.1555***
DLEMP	0.1425**	0.1135	0.1773***
ECM	-0.1737***	-0.6928***	-0.1603***
LNREPC	-0.0103	0.0921	0.0628
LREPC	-0.0115**	-0.0449	-0.0326***
LGFCFPC	0.3520***	-0.6540	0.2476***
LCO2PCC	0.0371***	1.7041	0.0324***
LEXPPC	0.2150***	0.3142	0.2773***
LEMP	-0.1384***	0.9896	0.0189
Models	**PMG vs FE**	**MG vs PMG**	**MG vs FE**

Hausman tests	Chi2(7)=0.00	Chi2(7)=0.61***	Chi2(7)=0.00

Notes: *** and ** represents significance level of 1% and 5%, respectively. ECM denotes error correction mechanism; Hausman test including constant and H0: differences in coefficients not systematic.

The results show the FE model is the suitable model. Therefore the predominance of a homogeneous panel is verified, it is appropriate consider the crosses as a group sharing common coefficients.

Taking into account the previous results and in other to select the most robust estimator specification tests were made. It was tested the presence of heteroscedasticity, autocorrelation and contemporaneous correlation among crosses. To check the heteroscedasticity modified Wald test was performed. It has H0: homoscedasticity. The second is Wooldridge test to verify the existence of serial correlation, where the H0: no first-order autocorrelation. Pesaran test was performed to appraise the contemporaneous correlation among crosses, the null hypothesis is cross section independence. The specification test results are presented in the table 6.

Table 6. Specification tests

	statistics
Modified Wald test	491.23***
Wooldridge test	75.911***
Pesaran test	5.417***

Note: *** denote significance at 1%; Modified Wald test results, Wooldridge test and Pesaran test are based in Chi-squared distribution, F distribution and standard normal distribution, respectively.

The specification tests results show the rejection of the Null hypothesis of the modified Wald test. The data have first order autocorrelation according with Wooldridge test. The existence of contemporaneous correlation was confirmed in the Pesaran test.

Following the results of the specification tests, the Driscoll and Kraay (1998) estimator was used. The standard errors of this estimator presented are robust in the presence of temporal dependence. The error structure assumed to be heteroskedastic and auto correlated. It was also estimated the FE model and FE model with robust standard errors to control the heteroscedasticity. The results can be observed in table 7.

Table 7. Estimation results

Models	FE(III)	FE Robust (IV)	FE D.K. (V)
Constant	0.9460***	0.9460***	0.9460***
DLNREPC	0.0469***	0.0469***	0.0469***
DLREPC	0.0002	0.0002	0.0002
DLEXPPC	0.1555***	0.1555***	0.1555***
DLGFCFPC	0.1818***	0.1818***	0.1818***
DLCO2PC	0.0012	0.0012	0.0012
DLEMP	0.1773***	0.1773**	0.1773***
LGDP(-1)	-0.1603***	-0.1603***	-0.1603***
LNREPC(-1)	0.0101	0.0101	0.0101
LREPC(-1)	-0.0052***	-0.0052***	-0.0052**
LEXPPC(-1)	0.0444***	0.0444***	0.0444***
LGFCFPC(-1)	0.0397***	0.0397***	0.0397***
LCO2PC(-1)	0.0052***	0.0052***	0.0052***
LEMP(-1)	0.0030	0.0030	0.0030
Diagnostic statistics			
N	502	502	502
R^2	0.8632	0.8632	0.8632
R^2_a	0.8513	0.8595	
F	F(13.461)=223.74***	F(13.27)=272.86***	F(13.17)=17792.94***

Notes: *** and ** represents significance level of 1% and 5%, respectively

The results show great consistency, only there two changes were detected in the models. The variable DLEMP loses significance in IV, from 1% to 5%, and the variable LREPC lagged once loses significance in model V, from 1% to 5%. Following the parsimonious principle, the reduced form of the models III, IV and V was estimated. The results can be seen in table 8, as well as, specification tests.

Table 8. Estimation results and specification

Models	FE(VI)	FE Robust (VII)	FE D.K. (VIII)
Constant	0.8232***	0.8232***	0.8232***
DLNREPC	0.0427***	0.0427***	0.0427***
DLEXPPC	0.1558***	0.1558***	0.1558***
DLGFCFPC	0.1850***	0.1850***	0.1850***
DLEMP	0.1732***	0.1732***	0.1732***
LGDP(-1)	-0.1599***	-0.1599***	-0.1599***
LREPC(-1)	-0.0059***	-0.0059***	-0.0059***
LEXPPC(-1)	0.0446***	0.0446***	0.0446***
LGFCFPC(-1)	0.0429***	0.0429***	0.0429***
LCO2PC(-1)	0.0050***	0.0050***	0.0050*
Diagnostic statistics			
N	502	502	502
R^2	0.8625	0.8625	0.8632
R^2_a	0.8518	0.8599	

F	F(9.465)=323.99***	F(9.27)=168.31***	F(9.177)=2072.46***

Specification tests	
	statistics
Modified Wald test	486.57***
Wooldridge test	75.911***
Pesaran test	5.417***

Note: *** and * represents significance level of 1% and 10%, respectively; Modified Wald test results, Wooldridge test and Pesaran test are based in Chi-squared distribution, F distribution and standard normal distribution, respectively.

The results reveal great consistency, except the variable LCO2PC lagged once in the model VIII. The specification tests outcomes have not changed. Thus the presence of heteroscedasticity, serial correlation and contemporaneous correlation among crosses is checked. Therefore the use of the Driscoll and Kraay estimator proved to be adequate.

Table 9. Semi-elasticities, elasticities and adjustment speed

Models	FE(VI)	FE Robust (VII)	FE D.K. (VIII)
Semi-elasticities			
Constant	0.8232***	0.8232***	0.8232***
DLNREPC	0.0427***	0.0427***	0.0427***
DLEXPPC	0.1558***	0.1558***	0.1558***
DLGFCFPC	0.1850***	0.1850***	0.1850***
DLEMP	0.1732***	0.1732***	0.1732***
Elasticities			
LREPC(-1)	-0.0366***	-0.0366***	-0.0366***
LEXPPC(-1)	0.2788***	0.2788***	0.2788***
LGFCFPC(-1)	0.2683***	0.2683***	0.2683***
LCO2PC(-1)	0.0313***	0.0313***	0.0313**
ECM	-0.1599***	-0.1599***	-0.1599***

Notes: *** and ** represents significance level of 1% and 5%, respectively; ECM means Error correction Mechanism.

In table 9 are presented semi-elasticities and elasticities. When the ECM is highly significant, the series have long memory, there a certain adjustment speed from short to long-run equilibrium.

6. DISCUSSION

This paper analyses the relationship between economic growth, non-renewable energy consumption and renewable energy consumption, using exports, gross fixed capital formation, employment and carbon dioxide emissions as control variables in line with the literature. Considering that the countries under analysis are those where there is a dominant energy source, then the existence of potential barriers to diversify production sources (mix) deserves particular attention.

The results obtained show great consistency. Different estimators were used and, in general, the results remain. Due to the characteristics of the countries, the presence of heterogeneity in the countries was tested. The Hausman test was used to test PMG, MG and FE estimators, and the best estimator is FE. Specification tests were used to detect heteroscedasticity, first-order autocorrelation and cross section dependence. Fixed Effects robust estimator was used to correct the heteroscedasticity and the result remains the same. In order to obtain more robust significance of the coefficient Driscoll-Kraay estimator was used. This estimator is efficient in the presence of serial correlation and contemporaneous correlation among the crosses. Thus, it produces more robust standard errors. The estimation of the dynamic model appears to be appropriate to observe effects of short- and long-run. The results must be analyzed taking into account the specific characteristics of the sample, high share in the energy production from a specific source.

As expected the gross fixed capital formation and exports of goods and services are statistically significant in both short- and long. In the short-run the gross fixed capital formation effect is biggest than exports of goods and service effect. While in long run the opposite is verified. The other control variable, employment, has a positive effect in the economic activity, however in long run the variable is not statistically significant.

Non-renewable energy consumption is highly statistical significant in the short-run. Although non-renewable is not statistically significant in the long-run, but renewable energy consumption is highly significant in the long-run with a negative sign. The fact that the fossil does not appear in the long run, further reinforces the negatives effected caused by renewable energy consumption in the economic activity. Un increase of 1% in the renewable energy consumption provoke a decrease of 3,66% in the GDP.

Regarding the environmental variable, the carbon dioxide emissions, it has a positive effect in the long run. This result is common in the literature. Fossil fuels are the main source of dioxide carbon emissions. The productive structure is still very dependent of the fossil fuels consumption. To generate wealth countries need to emit carbon dioxide.

7. CONCLUSION

A data panel of countries with high energy production levels by one source type was analyzed. Accordingly, the countries are facing obstacles to the diversification of sources, namely the high dependency from a specific one. Time span goes from 1995 to 2013, and the panel is constituted by 28 countries.

Recent panel econometric technics were used. The presence of individual effects was extensively tested, as well as the potential heterogeneity in the panel data. After that one tests the heteroscedasticity, serial correlation and contemporaneous correlation. Following the specification tests, the Driscoll-Kraay estimator was used as the reference estimator. The ARDL approach was used due the stationarity properties of the variable, and to capture the short-

and long-run effects. Moreover, both semi-elasticities and elasticities were performed. The ECM is highly statistically significant, and there is a low adjustment speed of the variables to the long-run equilibrium. This paper provides an overview of the impact of renewable and non-renewable energy consumption in economic activity, in countries with high share in the energy production from a specific source. Therefore, in countries with potential barriers to diversification in production sources, in the long the renewable energy consumption has a negative effect in economic activity.

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THE GLOBE ENERGY-GROWTH NEXUS: A SHORT AND LONG-RUN ANALYSIS.

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ABSTRACT

The research on energy-growth nexus is plenty of individual country and panels of countries studies, but no at globe dimension. This paper examines the globe nexus by using annual time series from 1965 to 2013.The interactions between the variables lead to an endogeneity phenomenon analyzed by n Autoregressive Distributed Lag (ARDL) as well as Vector Error Correction (VEC) model. The results suggest cointegration between the variables, as evidenced by an ARDL bounds test and reinforced by the Johansen cointegration test. The results suggest that there is bi-directional causality between energy consumption and economic growth, both on the short and on the long-run. Nevertheless, it is proven that the globe nexus is stronger on long-run. Accordingly, changes on energy consumption can impact the globe economic growth as well as the reverse. Moreover, it was concluded that innovations on energy consumption have permanent positive impacts on the nexus. These findings provide a globe perspective of the energy-growth nexus that encourage globe policymakers, to design policies based on energy efficiency improvement. In this way it is possible to reduce energy consumption without constrict economic growth.

Keywords: Globe energy-growth nexus; ARDL bounds test; Johansen cointegration; VEC model; Primary energy consumption

1. INTRODUCTION

The world energy consumption is experiencing a period of changes that are expected to continue. Accordingly to BP (2014), primary energy consumption will increase 41% between 2012 and 2035. In addition, energy demand growth moves towards emerging economies. As a result, changes on globe economic growth can occur and the literature on globe energy consumption and economic

growth nexus is not able to handle with those impacts. Here arises the interest in a new energy policy insight based on globe energy-growth nexus.

The energy-growth nexus literature focused on individual and panels of countries studies led to the existence of conflicting results. Moreover the energy markets are increasingly global, for instance: (i) there are increasingly global energy goals, namely universal access to modern energy and improve energy efficiency; (ii) the movements of Crude and Brent prices evidence correlation between the markets. For those reasons the globe nexus research can provide interesting information in the future. A causality relationship running from energy to growth is *a priori* expected due to the energy function as production factor. The presence of bi-directional causality between globe energy consumption and economic growth is also a hypothesis, thus leading to an endogeneity phenomenon. For this reason the main research question is: Is a bi-directional causality between energy consumption and economic growth present at globe level?

To analyse the globe energy-growth nexus and their stability, long time span series are needed. This study uses a yearly sample, from 1965 to 2013. Structural breaks are expected due to well-known episodes of crises in the studied period, for instance: (i) the 1970s crises with the oil shocks of 1973 and 1979; (ii) the 2008 financial crisis; and (iii) the 2009 European debt crisis. To handle with our variables both Autoregressive Distributed Lag (ARDL) and Vector Error Correction (VEC) models are performed. The use of the ARDL and VEC models is justified by endogenous nature of the variables. Moreover, these approaches allow both short and long run analysis. The results confirm the used approaches as suitable and allowed us to conclude that at globe level, bi-directional causality (*feedback hypothesis*) is verified both, on the short and on the long-run.

This paper evolves as follows. Section 2 presents a debate on the energy-growth nexus. Section 3 presents the data and the methodology. Section 4 presents the results. Section 5 discusses the results. Section 6 concludes.

2. DEBATE ON ENERGY-GROWTH NEXUS

The research on energy-growth nexus started when Kraft and Kraft (1978) examined that causality relationship for USA. For decades the energy-growth nexus research has been divided into two main groups: (i) individual country studies (e.g. Fallahi, 2011; Han et al., 2004; Lee & Chang, 2007; Shahbaz et al., 2012); (ii) and panels of countries studies (e.g. Ajide et al., 2013; Akinlo, 2008; Fuinhas & Marques, 2012; Ozturk & Acaravci, 2011). However the results of existent literature are not consensual.

The nexus literature is usually divided in four relationship types: (i) neutrality hypothesis (e.g. Śmiech & Papież, 2014; Yıldırım et al., 2014); (ii) feedback hypothesis (e.g. Apergis & Payne, 2009; Dagher & Yacoubian, 2012); (iii) conservation hypothesis (e.g. Al-mulali et al., 2013; Pao & Fu, 2013); and (iv) growth hypothesis (e.g. Apergis & Payne, 2010; Borozan, 2013). The term neutrality hypothesis represents the non-existence causality between energy

consumption and economic growth is found. On contrary, the feedback hypothesis denotes a bi-directional causality between energy and growth. Regarding to the uni-directional causalities, the conservation hypothesis defines a uni-directional causality running from economic growth to energy consumption, on contrary a unidirectional causality running from energy to growth is known as the growth hypothesis. Most recently, Fuinhas and Marques (2013) report the possibility of atypical relationships in the nexus due to the non-inclusion of crucial parameters that characterize an economy.

To define the nature of the energy-growth relationships, four generations of methodologies have been used (e.g. Mehrara, 2007): (i) studies based on VAR methodology (e.g. Sims, 1972) and Granger causality, assuming stationarity (e.g. Kraft & Kraft, 1978; Yu & Hwang, 1984); (ii) studies based on non-stationary series and Granger (1988) cointegration theory using correction model to test for causality (e.g. Cheng & Lai, 1997; Glasure & Lee, 1998); (iii) studies using multivariate approaches with more than two variables in the cointegration relationship (e.g. Acaravci & Ozturk, 2010; Lee & Chang, 2005; Oh & Lee, 2004; Pao & Fu, 2013; Stern, 2000); and (iv) studies based on panel cointegration and panel error correction models (e.g. Al-Iriani, 2006; Ciarreta & Zarraga, 2010; Damette & Seghir, 2013; Mohammadi & Parvaresh, 2014; Sadorsky, 2011). The nexus can be studied using three approaches: (i) a supply approach; (ii) a demand approach; and (iii) a neutral approach with a bivariate energy-growth model. The neutral approach is the only one which allows study individual effects between energy consumption and economic growth. A multivariate model is only preferred when a robust bivariate model cannot be achieved. Indeed the use of bivariate models is frequent in recent literature (e.g. Fuinhas & Marques, 2012; Odhiambo, 2009; Ozturk et al., 2010). The changes on energy supply and consumption are a current issue. Projections show that primary energy consumption will increase, at least until 2035 (BP, 2014), as stated early. Energy consumption is moving from the OECD to the non-OECD countries, namely China and India (IEA, 2013). Moreover there are high amounts of investment in energy development. In 2013, more than $1600 billion was invested to provide energy all over the world and $130 billion to improve energy efficiency (BP, 2014). In short the energy markets: (i) are experiencing huge changes; (ii) require a high investment level; and (iii) are increasingly global, as evidenced by the similar movements of Crude and Brent. Beyond it understand the globe nexus is relevant.

3. DATA AND METHODOLOGY

Given that it is expected that energy and growth interacts each other namely on long-run, the use of and ARDL model could be appropriate, as well as a VAR model. Thus, the use of the two approaches can lead to robust conclusions. The nexus research recurring to ARDL models (e.g. Bildirici & Bakirtas, 2014; Fuinhas & Marques, 2013) and to VAR approaches (e.g. Lee, 2005; Marques et al., 2014; Masih & Masih, 1996) is far from new in the literature. To handle with these models the econometric software Eviews 9 was used.

3.1 Data

The study uses 49 observations covering an annual time span from 1965 to 2013. The used time span was determined by data availability. This research uses the real world gross domestic product (LY), extracted from World Bank – World Development Indicators, and total world primary energy consumption (LE) extracted from BP Statistical Review of World Energy, June 2014. Let L denote the natural logarithms and D denote the first difference of the variables. Table 1 shows definitions and summary statistics.

Table 1
Descriptive statistics.

Variable	Descriptive statistics				
	Obs.	Mean	S.D.	Min.	Max.
LY	49	30.993	0.4278	30.1734	31.6554
LE	49	22.7641	0.3065	22.1012	23.2673
DLY	48	0.0321	0.0156	-0.0212	0.0618
DLE	48	0.0254	0.0196	-0.0123	0.064

A first appraisal of the variables reveals a strong correlation (0.9946) between LE and LY, as well as, between DLY and DLE (0.8566). The presence of high correlation does not mean that cointegration exists. As a consequence the order of integration of those variables will be tested. To do so we will work upon: (i) graphical analyses of the level variables and their first differences (not shown to preserve space); (ii) autocorrelations and partial autocorrelations; and (iii) Augmented Dick Fuller (ADF), Phillips Perron (PP) and Kwiatkowski Phillips Schmidt Shin (KPSS) tests.

The visual inspection of the variables as well as their correlograms (not shown to preserve space) shown patterns that support that the variables are I(1). Then three test are performed in order to confirm the patterns (see table 2): (i) ADF; (ii) PP; and (iii) KPSS. The PP test is, similarly to ADF test, work upon the null hypothesis that the variable has a unit root, i.e. the variable is non-stationary. However, the PP test is non-parametric. The KPSS test is performed as a confirmation test, with the null hypothesis of stationarity. The Schwarz criterion is used in the ADF test with a maximum of 11 lags. In the PP test, the Bartlett kernel spectral estimation method and Newey–West Bandwidth were used, as well as in the KPSS test. The use of three tests allows us to achieve a robust assessment of the order of integration of the series.

Table 2
Integration order tests.

	ADF			PP			KPSS	
	a)	b)	c)	a)	b)	c)	a)	b)
LY	-2.9824	-3.5059**	14.0312	-3.7771**	-3.4997**	11.1301	0.1899**	0.9254***
LE	-3.4790*	-3.1743**	8.8723	-3.8178**	-2.583	6.0813	0.1516**	0.9179***
DLY	-5.3446***	-4.8143***	-2.0650**	-5.2056***	-4.6805***	-1.8436*	0.102	0.5970**
DLE	-4.4574***	-4.2601***	-2.5601**	-4.4574***	-4.2601***	-2.5601**	0.1636**	0.3651*

Notes: a) represents the test statistic with trend and constant; b) represents the test statistic with

constant; c) represents the test statistic without tendency and constant; ***, ** and * denotes statistical significance at 1%, 5% and 10% level, respectively.

The Table 2 shows the results of the energy and growth variables in levels and in their first differences. The non-existence of a unit root in the variables LY and LE is rejected by the KPSS test. However, the results of the ADF and PP tests for LY and LE are not clear. Nevertheless, DLY and DLE have shown that the series are stationary. These results confirm the initial suggestion of the non-stationarity variables in levels, provided by visual inspection of the variables and their correlograms. Moreover, the Zivot and Andrews (1992) and Perron (1997) unit root tests were performed and confirmed the former results. Both Zivot and Andrews (1992) and Perron (1997) unit root tests detected the effect of the 1970s oil crises on the series. It is worthwhile to note that these unit root tests are not suitable to handle with structural breaks at the beginning and at the end of the series which is expected to happen, namely at the end of the series, due to the use of globe variables.

3.2 Model

To analyse the short and the long run relationships between globe energy consumption and economic growth and given that the variables are I(1) or near I(1), an ARDL bounds test approach (Pesaran & Shin, 1999; Pesaran et al., 2001) is performed. The ARDL equations are:

$$\mathrm{LY_t} = \gamma_0 + \gamma_1 t + \sum_{i=1}^{k} \gamma_{2i}\mathrm{LY_{t-i}} + \sum_{i=0}^{k} \gamma_{3i}\mathrm{LE_{t-i}} + \mu_{3t} \qquad ((1),$$

and

$$\mathrm{LE_t} = \delta_0 + \delta_1 t + \sum_{i=1}^{k} \delta_{2i}\mathrm{LE_{t-i}} + \sum_{i=0}^{k} \delta_{3i}\mathrm{LY_{t-i}} + \mu_{4t} \qquad ((2),$$

where, k represents the number of lags defined by empirical knowledge of the variables. If the variables are cointegrated, the ARDL could be transformed into a UECM. Eqs. (3) and (4) (hereinafter model 1 and model 2, respectively) which represents the general UECM in its equivalent ARDL bounds test:

$$\mathrm{DLY_t} = \alpha_0 + \alpha_1 t + \sum_{i=1}^{k} \alpha_{2i}\mathrm{DLY_{t-i}} + \sum_{i=0}^{k} \alpha_{3i}\mathrm{DLE_{t-i}} + \alpha_4\mathrm{LY_{t-1}} + \alpha_5\mathrm{LE_{t-1}} + \mu_{5t}, \qquad ((3),$$

where the signs of parameters expected are $\alpha_0 \neq 0$, $\alpha_1 \neq 0$, $\alpha_{2i} \neq 0$, $\alpha_{3i} \neq 0$, $\alpha_4 < 0$, $\alpha_5 < 0$. The parameters α_{2i}, α_{3i} explain the short-run dynamic coefficients, while α_4, α_5 explain the long-run multipliers.

$$\mathrm{DLE_t} = \beta_0 + \beta_1 t + \sum_{i=1}^{k} \beta_{2i}\mathrm{DLE_{t-i}} + \sum_{i=0}^{k} \beta_{3i}\mathrm{DLY_{t-i}} + \beta_4\mathrm{LE_{t-1}} + \beta_5\mathrm{LY_{t-1}} + \mu_{6t}, \qquad ((4),$$

where the signs of parameters expected are $\beta_0 \neq 0$, $\beta_1 \neq 0$, $\beta_{2i} \neq 0$, $\beta_{3i} \neq 0$, $\beta_4 < 0$, $\beta_5 < 0$. The parameters β_{2i}, β_{3i} explain the short-run dynamic coefficients, while β_4, β_5 explain the long-run multipliers.

Cointegration is also evaluated by the Johansen procedure and the extraction of the long-run cointegration relationships is performed. This approach allows comparing the results with the previous obtained by the ARDL models, thus providing robustness to the research. Moreover, if the performed tests confirm the cointegration, a Vector Error Correction Model (VECM) with k lags will be performed as shown (hereinafter model 3):

$$X_t = \sum_{i=1}^{k} \Gamma_i X_{t-i} + \prod X_{t-k} + CD_t + \varepsilon_t \qquad ((5)$$

where X_t is the vector of endogenous variables; D_t is the vector of exogenous variables; Γ is the coefficient matrix of endogenous variables, C is the coefficient matrix of exogenous, and k is the optimal lag number. While Γ_i captures the short-run dynamics of the model, the $\prod$ captures the long-run relationships. The residuals are denoted by ε_t, $X_t = [DLY, DLE]$ and $D_t = [Constant, SD_y]$, where SD_y represents the shift dummies that controls for the y years on the nexus. The need to include shift dummies to the model was expected due to possible structural breaks occurring from well-known historical crises such as the 1970s oil crises which their impacts on the series were early identified, the 2008 financial crisis and the 2009 European debt crisis, such as stated above.

4. RESULTS

This section encompasses the results of cointegration tests and both short and long-run analysis. To do so we initially carried out a general UECM version of ARDL with constant and trend (model 1), as Pesaran et al. (2001). The model 2 becomes highly significant excluding the trend. In presence of structural breaks the lag selection using level of information, such Akaike Information Criterion, Hannan-Quinn or Bayesian Information Criterion should not be pursued. In fact the residuals analysis revealed the presence of structural breaks and their effects were controlled by introducing a shift dummy from 2009 onwards on model 1 and from 2008 onwards on model 2. The principle of parsimony was followed and one lag was the optimal number. Globally, the battery of diagnostic tests indicates that the two models have the desired econometric proprieties of no normally distributed errors, no serial correlation in the residuals and no auto-regressive conditional heteroskedasticity. All coefficients are statistically significant. The ECM in model 1 (coefficient of LY_{t-1}) has a magnitude of -0.4812 revealing a fast speed of adjustment from a short-run disequilibrium to the long-run equilibrium. In model 2 the ECM (coefficient of LE_{t-1}) has a magnitude of -0.1296 revealing a moderate speed of adjustment. With regard to the 2008/2009 crises it was observed that the shift dummies are both statistically significant. For model 1 the SD0913 variable has a negative impact of -0.0298 and for model 2 the SD0813 variables has a positive impact of 0.011.

To the VEC model (model 3), once more the principle of parsimony was followed. The 2 lags were achieved as optimal number. This is consistent with the optimal ARDL models above obtained (one lag) given that the ARDL approach uses lagged variables. Once again, the SD0913 variable was

introduced as an exogenous variable. In addition, there was no need to introduce shift dummies to correct the 1970s oil crises whose effects were previously identified by the Zivot and Andrews (1992) and Perron (1997) unit root tests. The introduced shift dummies, to correct these effects, revealed to be not statistically significant. The validity of the estimated VEC model was evaluated for three problems: (i) violation of normality, by using the Jarque Bera test; (ii) autocorrelation by the Langrage Multiplier (LM) test; and (iii) heteroskedasticity by performing the White test (without cross terms). All statistics are not significant. The VEC model shown highly significant negative error correction terms, as expected, revealing that the system converges to a long-run equilibrium after some disturbance. Moreover the error correction term revealed that any disequilibrium is corrected within approximately two years. Some coefficients of VEC lagged variables are not statistically significant. This could mean that, on the short-run, the effects between the variables are weak. However this result should be analysed with caution due to potential overfitting in the VECM. A first overview indicates that cointegration may be present.

4.1 Cointegration analysis

In order to identify cointegration, the ARDL bounds test was performed (see table 2).

Table 2
Bounds test.

	Model 1	Model 2
F-statistic	10.6025***	7.4385**
K	1	1

Notes: k represents number of independent variables in equation estimated. Critical values obtained from Pesaran et al. (2001), tables CI(iii) and CI(v). Critical values for unrestricted intercept and no trend for bottom and top are, respectively, 6.84 and 7.84, for 1%; 4.94 and 5.73, for 5%; and 4.04 and 4.78 for 10%. Critical values for unrestricted intercept and unrestricted trend for bottom and top are, respectively, 8.74 and 9.63, for 1%; 6.56 and 7.3, for 5%; and 5.59 and 6.26 for 10%. ***and ** denotes significance at 1% and 5% level, respectively.

The bounds test proofs that there exists a long-run relationship between energy and growth by rejecting the null hypothesis of non-cointegration. In model 1 the null hypothesis is rejected at the significance of 1% and in model 2 rejection of the null hypothesis occurs at the significance of 5%.

To confirm the presence of cointegration the Johansen Cointegration methodology was also followed. To achieve the optimal lag number selection in presence of variables with outliers, the Schwarz and the Hannan-Quinn are suitable criterions. Both criterions set 2 lags as optimal. The table 3 shows the Johansen cointegration tests results. The order of the exogenous variables is LY followed LE. Once again, the shift dummy SD0913 was introduced as exogenous after the model residuals observation.

Table 3
Johansen Cointegration Tests.

Eigenvalue	H0:	Trace	Max-Eigen
0.4526	0	41.1138***	27.722***
0.2526	1	13.3918**	13.3918**

Notes: r indicates the number of cointegrating relationships. *** and ** denotes statistical significance at 1 % and 5% level, respectively. MacKinnon-Haug-Michelis (1999) p-values. Deterministic trend assumption of test: Intercept and trend in cointegration equation and no intercept in VAR.

The Johansen cointegration test revealed the existence of two cointegrating vectors between DLY and DLE. Both Trace statistic and Max-Eigenvalue statistic are highly significant.

4.2 Short-run analysis

Given that cointegration was observed, we aim to distinguish the short-run effects from the long-run effects. To analyse the short-run effects, the ARDL partial short-run elasticities were extracted from model 1 and 2 (see table 4). Both models have shown statistically significant short-run elasticities.

Table 4
ARDL Short-run elasticities.

	Model 1	Model 2
Short-run (DLE+DLE(-1))	0.3907***	
Short-run (DLY+DLY(-1))		0.3872*

Notes: ***and * denotes statistical significance at 1% and 10% level, respectively

The short-run elasticities are calculated by adding the coefficients of a differenced variable and of their respective one lagged variable. The joint significance is tested by recurring to the Wald coefficient test. Both elasticities have the expected signs. The model 1 shows that in the short-run the energy exerts a positive impact on growth. A 1% increase in energy leads to an economic growth of 0.391%. In model 2 it is also observed that in the short-run, a 1% increase in economic growth leads to an energy growth of 0.387%.
Recurring to the VEC model (model3), the short-run behaviours are analysed by Granger causality/Block exogeneity Wald tests (see table 5).

Table 5
Granger causality/Block exogeneity Wald tests.

Dependent variable:	DLY	DLE
Excluded	Chi Square	Chi Square
DLY	-	5.6958*
DLE	5.8623*	-

Notes: * denotes statistical significance at 10% level.

Granger causality was detected, at the statistical significance of 10%, and its direction is LY↔LE. Both ARDL and VEC models points towards the existence of endogenous short-run behaviour between the variables.

4.3 Long-run analysis

Finally the long-run effects were observed by the ARDL elasticities (using model 1 and 2) as well as the Johansen Cointegration elasticities (using model 3). The ARDL long-run elasticities are shown on table 6.

Table 6
ARDL long-run elasticities.

	Model 1	Model 2
Long-run (LE)	0.5848***	
Long-run (LY)		0.6483***

Notes: ***and * denotes statistical significance at 1% and 10% level, respectively

The ARDL long-run elasticities are calculated by the dividing the coefficient of one lagged independent variable by the coefficient of one lagged dependent variable, multiplied by -1. All the elasticities have the expected signs and are highly significant. The model 1 shows that both in short and long-run the energy exerts a positive impact on growth. A 1% increase in energy leads to an economic growth 0.585% on the long-run. In model 2 it is also observed that on the long-run the economic growth exerts a positive impact on energy. A 1% increase in economic growth leads to an energy growth of 0 0.648% in the long-run.

To confirm the endogenous long-run behaviours we extract the long-run elasticities from the following Johansen normalized long-run cointegration equations:

$$\mathrm{LY} = 0.0252\mathrm{trend} + 0.2363\mathrm{LE}, \qquad 6)$$

And

$$\mathrm{LE} = -0.1068\mathrm{trend} + 4.2326\mathrm{LY}. \qquad 7)$$

The two normalized long-run cointegration vectors are consistent with what was expected. In Eq. (6) the coefficient of LE is positive. In Eq. (7) the coefficient of LY is positive. Eqs. (6) and (7) reveal a bi-directional positive long-run relationship between energy consumption and economic growth. Given the variables are on their logarithms, the coefficients can be interpreted as long-run elasticities. We observe that the impacts of economic growth on energy consumption are higher than the impacts of energy consumption on economic growth, on the long-run.

5. DISCUSSION

The nexus research on the globe can provide an important tool to understand the impacts of the changes occurring in the energy consumption and therefore improve world growth. Our research adds to the literature the globe nexus dynamics analysis by revealing the existence of stable relationships between energy and growth, from 1965 to 2013. The application of UECM version of

ARDL model as well as the VEC model proved to be adequate and allow observing that the feedback hypothesis is present at globe level both on the short and on the long-run.

It should be noted that the 2008 crises impacted at globe nexus. It was needed to control for the crises by introducing shift dummies from 2008 and 2009 onwards. This is far from unexpected. The 2008 crisis impacted on nexus due to the bankruptcy of financial companies and produced instability in financial markets by the impacts in sovereign debts of some countries. Moreover, at this period a collapse on international global trades was experienced which negatively impacted at the transportation sector. In consequence, energy consumption decreased. In fact tests to add control variables shown that there was no need to add dummies for other crises such as 70s oil crises which allow us to conclude that the 2008 crises had higher impacts on the globe nexus, than any other previous crisis. On one hand in model 1 the effects of 2008 and 2009 crises needed to be controlled by a shift dummy from 2009 to 2013. On the other hand the model 2 needed to be controlled from 2008 onwards. The models reveals different speeds until the crisis shocks are experienced by the dependent variable. Economic growth decelerated faster than the energy consumption, which explains the positive coefficient dummy in model 2. This behaviour is against what was expected, given that the energy is one of the most essential good and one of the last choices in the consumers' savings. Moreover in model 3 there was also the need to introduce a dummy from 2009 to 2013.

The ARDL bounds test as well as the Johansen cointegration test evidences the presence of long-run relationships between energy consumption and economic growth. Moreover the Johansen cointegration test reveals a strong endogenous system with two cointegrating vectors. On the short-run, the energy consumption and economic growth exhibit an endogenous nature and similar responses to the shocks. The partial short-run elasticities show the endogeneity between the variables where energy consumption leads to economic growth and the reverse is also true. Despite the endogeneity presence, when an ARDL framework is free of correlation the endogeneity is not a problem (Pesaran & Shin, 1999) which contributes to robust results. The Granger causality tests reinforced the results. Despite these results the elasticities lower than 0.4 and the statistically significance of the Granger causality testes only at 10% could mean that the short-run endogeneity is weak. With regard to the long-run the ARDL elasticities superior that 0.5 revealed a stronger nexus. As expected an increase on energy consumption promotes economic growth. Moreover, regarding to the Johansen cointegration equations it was observed that when economic growth raises, the energy consumption raise four times more. That was unexpected huge effect. It should be noted that the long-run equations are almost reversed equations with a coefficient of determination near 1. These results are also compatible with the presence of two cointegrating vectors as shown by our results. The different long-run elasticities are justified by the use of two distinct methodologies. However the results evidence that the nexus exists and is stronger on the long-run.

If primary energy consumption increases, as expected by BP (2014), that will most likely lead to a world economic growth, increasing energy consumption once again and thus inducing inefficient consumption. Energy efficiency policies are required. In fact, any energy consumption reduction should be made by an efficiency increase. Otherwise, the attempts to apply globe energy policies that lead to a sustained world growth could fail. The energy efficiency improvement should be done by recurring to more efficient products. For instance: (i) encouraging building that fulfils efficient norms; (ii) promote technological development, for example by implementing renewables. The European 2020 energy strategy is consistent with these finding. However promote energy efficiency in countries that suffers from energy poverty it is hard and can be a future research focus. Despite the globe inequalities on energy consumption, the globe nexus is stable and therefore an encouragement to the energy equality access can promote the globe sustainable growth.

6. CONCLUSION

The research on energy-growth nexus focused on the globe level is absent. Given the increasingly globalization of the energy markets, understand the relationships between energy consumption and economic growth on globe can afford a new insight on energy policy. This study provides the results of globe energy-growth interactions. To do so, the UECM version of ARDL models as well as a VEC model were performed with globe energy consumption and economic growth, from 1965 to 2013, and proved to be suitable tools.

The results proved the presence of feedback hypothesis at globe level allowing the observation of the nexus both in short and long-run. The former results shown that the dynamic effects on both ways are huge. Moreover, the long-run elasticities larger than short-run suggest that the nexus is stronger on long-run. The impacts of energy consumption on economic growth were expected, however the reverse were not so easy to conclude. The results also revealed that 2008 and 2009 crises negatively impacted on energy consumption and economic growth and consequently impacted on the nexus. The obtained results at the maximum macroeconomic level could provide a basis for further disaggregated researches and to understand the inconsistent results on nexus literature.

Overall, the globe energy-growth nexus proved to follow a feedback relationship over a long time span. This globe nexus perspective could help the energy policymakers in their decisions. Given that on the globe there is a *feedback hypothesis*, an inefficient energy consumption can be induced over the next years, namely by non-productive activities. Moreover, some caution on constrain politics is required. Although in short-run a reduction on energy consumption has small effects on economic growth, in long-run it will cause a huge slow down. Future policies should promote the energy consumption reduction without hampering economic growth. Any energy reduction should always be done by recurring to efficiency gains and therefore fostering the globe economic growth.

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