Proceedings of the 3rd Annual Meeting of the Portuguese Association of Energy Economics & 5th Meeting of Environmental and Energy Economics

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Proceedings of the 3rd Annual Meeting of the Portuguese Association of Energy Economics & 5th Meeting of Environmental and Energy Economics

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MESSAGE FROM THE PROGRAMME COMMITTEE CHAIR

The 3rd Annual Conference of the Portuguese Association of Energy Economics – APEEN and the International Meeting on Energy and Environmental Economics – ME3 took place on the 18-19 October 2018 in Braga, Portugal. The event was hosted by the Universidade do Minho and gathered the contributions of specialists in Energy and Environmental Economics to enrich the debate about the many issues raised by the management of resources and waste. The main topic was Managing Resources and Waste: challenges for Energy and Environmental Economics beyond 2030.

Natural resources are the keystone in environmental and energy economics. Nowadays, resource management cannot ignore waste, traditionally seen as a by-product of consumption and production decisions, but increasingly recognized as a source of energy or as new type of resource

The APEEN & ME3 joint conference had over 50 presentations from researchers from all over the world and lively discussions. Some of these presentations are summarized in the short papers compiled in this Book of Proceedings.

We are grateful to have had the presence and contribution of the keynote speakers: Maria L. Loureiro (Universidade de Santiago de Compostela) and Martin Brocklehurst (Kempley Green Consultants). Their speeches challenged us now to think of new research and business opportunities beyond 2030.

On behalf of the organizing committee, I thank our sponsor, LIPOR, and all presenters for their academic excellence and lively participation.

Lígia Pinto, Universidade do Minho

Conference website: http://apeen-me3.eeg.uminho.pt

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FINAL CONFERENCE PROGRAMME

Thursday, October 18

Welcome and registration, hall of EEG (from 9h30)

Thursday, October 18, 10:30-11:00

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Opening Ceremony

Isabel Soares, President of APEEN

Jorge Vasconcelos, President of the General Assembly of APEEN

Ana Carvalho, Vice-Presidente da EEG-UMinho

Odd Straume, Diretor of NIPE

Lígia Pinto, Chair of the Organizing Committee

Thursday, October 18, 11:00-12:30

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Maria L. Loureiro (Universidade de Santiago de Compostela)

Chair: Isabel Soares (FEP)

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Chair: António Cardoso Marques

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Susana Silva, Carlos Pinho, Isabel Soares

> *Gasoline and diesel elasticities in Portugal: an aggregate approach*

Judit Mendoza Aguilar, Francisco Javier Ramos-Real, Alfredo J. Ramírez-Díaz

> *Measuring energy poverty in special circumstances. The case of the Canary Islands*

Michael Chessera, **Jim Hanlya**, Damien Cassellsa, Nicholas Apergisb

Is empowering energy citizens working? The case of a small European economy

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Chair: Marta Ferreira Dias

Konstantinos Ninikas, George Ntalos, Michael Skarvelis

Commercial possibilities, and energy gain potentials of exploiting waste, tree bark and hemp residues to construct insulation boards.

Alfiado Victorino, João Nildo de Souza Vianna, Izabel Zaneti, Suzi Huff Theodoro

Waste to energy as part of the urban solid waste management strategy

***Isabel das Mercês Costa,** Marta Ferreira Dias, Denilton Salomão Souza Dos Santos

Management of solid urban waste in Brazil: a brief overview

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Chair: Mara Madaleno

Sílvia Coelho, ***Michael Russo**, Ruben Oliveira, Alexandra Monteiro, Myriam Lopes, Carlos Borrego

Sustainable energy action plans at city level: a Portuguese experience

***Manuel Villa-Arrieta**, Andreas Sumper

Global cost and cost-optimal of nearly zero energy cities

***Manuela Novais Moreira**, Margarita Robaina, Myriam Lopes

Covenant of mayors for climate and energy study area: northern region of Portugal

Mara Madaleno, Margarita Robaina, Marta Ferreira Dias

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Chair: Lígia Pinto

Marco Persichina

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António Cardoso Marques, José Alberto Fuinhas, ***Fábio Valente De Almeida***

Is the inequality driven environmental degradation? Evidence from developed and developing countries

Tatiana Costa, **Lígia M. Costa Pinto**, Marieta Valente

Package or no package – do consumers care?

Marieta Valente, Sara Gomes, Cristina Chaves

Exploratory study on consumer demand for organic personal care products

Thursday, October 18, 18:00-19:00

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Round-table: Managing Resources and Waste: Challenges for Energy and Environmental Economics beyond 2030.

Chairperson: Carlos Borrego, University of Aveiro

Leonel Nunes, Member of the Board of Directors at AFS - Advanced Fuel Solutions SA

Teresa Franqueira, DECA, UA, projecto Katch_e

Maria Lurdes Lopes, (FEUP), SmartWaste Portugal

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***Renato Santiago**, José Alberto Fuinhas, António Cardoso Marques

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Raquel Figueiredo, **Pedro Nunes**, Miguel C. Brito

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Chair: Nuno Figueiredo

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***Yvonne Vogt Gwerder,** Nuno Carvalho Figueiredo, Patrícia Pereira da Silva

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***Humberto António Ferreira Carlos**

Impacts, public policies, regulation related with transition to electrical mobility

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Martin Brocklehurst (Kempley Green Consultants)

Chair: Lígia Pinto (EEG, UM)

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Chair: Marieta Valente

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Paula Ferreira, Angela Lopes, **Jorge Cunha**

Renewable electricity planning for Cape Verde

***Susana Gonçalves**, Mara Madaleno

Energy consumption, macroeconomic and financial effects over CO2 emissions: a European approach

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Chairs of the organizing committee (Lígia Pinto and Marieta Valente, NIPE-UMINHO; Marta Ferreira Dias and Margarita Robaina, GOVCOPP-UAveiro)

Notes:

*Student presentations

In **bold**: presenting author

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Wagd Ajeeb[1]

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Abstract

On our planet, the traditional energy source is limited thus inefficiency of fossil fuel energy and ecological damage made by heat and nuclear power engineering make it extremely important to develop alternative energy sources, for instance, solar. This article provides tendencies of solar energy use, analyses problems of substituting conventional types of energy for solar, talk about Nearly Zero Energy Buildings (nZEB), present the nanofluid technology to enhance the thermal energy efficiency and an economic analysis to build up a solar thermal plant using Greenius software.

KEYWORDS
Nanofluids, Solar, nZEB, Greenius.

1. Introduction

Simple techniques for concentrating sunlight to generate heat date back thousands of years. Solar thermal can fulfil a substantial amount of heat demand in industrial and agricultural food processes within any given country and irrespective of the geographical location. In developed economies, solar thermal can provide technically about half of this energy consumption by supplying hot water and steam in a temperature range of up to 400°C. In developing countries, especially in those where agriculture, the textile, brick and food processing industries are important sub-sectors, solar thermal energy can provide hot air and hot water needed for curing, drying, dyeing, washing, boiling, pasteurisation and sterilisation. It can be built locally, and its cost depends on local building materials and labour. Conventional solar water systems, like flat-plate collectors or evacuated tube collectors, are primarily used in residential applications. Deployment levels are mainly determined by the economic competitiveness of solar thermal systems. Key challenges for solar thermal heat in industrial applications are the short pay-back times, the relatively low fossil fuel prices charged in the industrial sector and the integration into existing industrial processes. Although solar thermal energy could save costs, in the long run, the complexities of integrating new heat sources into existing processes create possible risks that the bulk producing industries try to avoid. Furthermore, in order to achieve higher market penetration, policy options are: create more awareness of the benefits of solar process heating, especially in industrial clusters of small- and medium-size enterprises; provide financing mechanisms to cover upfront costs; and consider whether support for solar thermal could be an alternative to fossil fuel price subsidies to national industries.

Moreover, this study have referred to the Nanofluid which is a mixture of a thermal fluid with carbon nanoparticles has an enhanced properties of the thermal fluid and can be used in a heat or cooling systems. The nanofluid has higher thermal conductivity (+18%) and excellent thermo-physical properties, unlike commonly used coolant fluids. Furthermore, nanofluid can be customizable to detain a higher rate of heat transfer (16%), according to the customer needs and/or applications. The applications of the nanofluid are diverse, however, it will be directed to the automotive industry, more specifically to commercial vehicles, like logistics and transportation vehicles, since it can produce savings from 1% to 2% on fuel consumption.

2. Nearly zero energy buildings requires

The implementation of energy efficiency measures, as well as the integration of renewable energy systems, is challenging tasks on the road towards the Low or Zero Energy Buildings (ZEB). when considering intensively energy consuming buildings, amongst them hotels and touristic lodgings. when applying the fundamentals of energy efficient design of buildings to a hotel, like the implementation of sound sun-protection schemes, the use of thermal insulation, and the use of efficient heating ventilating air conditioning systems, there is a significant demand for sanitary hot water, as well as for warm water for purposes like swimming pools that has to be covered. This can be ideally done by means of Renewable Energy Sources (RES) with solar thermal systems being a primary candidate, as they meet the range of temperature requirements and feature a proven efficiency, reliability and durability. The EU legal frame asks for a sustainable built environment and introduces the concept of Nearly Zero Energy Buildings (nZEB) that should be developed for any public investment starting with January 1st, 2018 and for any new building starting with 2021 (Visa & Duta, 2016). A major study on principles for nearly zero-energy buildings has been conducted by Ecofys for the Buildings Performance Institute Europe (BPIE) (Hermelink et al., 2013). In their report, they identify ten major challenges related to setting a practical nearly zero-energy building definition, derive implications and propose principles for a suitable nearly zero-energy building definition. Flexibility should be also allowed for different climates, building types, building traditions and the existing building stock. The BPIE study suggests that a nearly zero-energy building definition should include a threshold for household electricity (plug load) used for integrated building equipment (e.g. lifts and fire-protection systems) going beyond the building services (heating, cooling, ventilation and lighting) included under the current EPBD (Hermelink et al., 2013).

Also, it has applied some new energy efficiency laws EU countries in buildings, for example, in the European market, Domestic Solar Hot Water Systems (DSHWS) are a mature technology.

Bulgaria: ''The definition for nZEB in Bulgaria has been published within the state gazette on 14/04/2015 NZEB buildings need to simultaneously satisfy the following two conditions:

1. The energy consumption of the building, defined as primary energy, needs to meet energy efficiency Class A of the scale of energy consumption classes for the type of the buildings.

2. Not less than 55% renewable energy from the energy consumption for heating, cooling, ventilation, DHW and lighting.

Based on the new energy efficiency law, a sports building wanting to be at least class A, its primary energy demand has to be below 175 kWh/m^2 (Union & Commission, 2015).

In Portugal; ''Directive 2010/31/EU was transposed by the Decree Law n. 118/2013, which defines the System for Energy Certification of Buildings (SCE) and sets out minimum requirements for improving energy efficiency before 2015 in residential and, commerce and service buildings. In general, the requirements for new buildings were more tightened, promoting more efficient envelops and introducing technical systems requirements and a general nZEB definition. This law represents a first step to pave the way towards nZEB. Minimum energy class for air handling units, pumps and fans are some examples of the kind of requirements established by the national law. Nevertheless, the numerical indicator of primary energy and the minimum share of renewable energies have not been defined yet for any building typology. ADENE, the Portuguese energy agency, is currently developing the nZEB definition" (Union & Commission, 2015).

3. Economic analysis of solar thermal system with greenius software

Greenius software is one of the leading simulation tools used for simulating renewable energy systems, especially concentrating solar power systems. The software is developed by German Aerospace Center (DLR) and is still subject for further developments. In this study, a parabolic trough with storage will be simulated, optimized, and adapted for both dry and wet cooling('greenius Manual', 2015). One should be able to deal with the large number of input variables and different outputs. Here in this section, the procedure is described based on its manual and self-learning through program interface; see Fig. (1).

Fig. 1: Process for Greenius simulation (Mastny, Moravek, & Pitron, n.d.).

3.1. The elements and boundary conditions of the analysis:

In order to analysis the solar thermal flat plate system (Process heat with non-concentrating collectors), the following input masks are available at the technology tab sheet in Greenius software: Solar Collector, Collector Field, Thermal Storage, Auxiliary Boiler. In this article, a solar flat collector (non-concentrate) will be used. Also, the location has been chosen in Spain – Almeria, the programme will load the datasets related with the climatic of the location: Amb, temperature, Humidity, GHI, Diffuse Irradiation, DNI.

3.2. Design the solar thermal plant:

By choosing (CPC Thermo max - SOLAMAX 20.gpa) type of solar collector. The collector has total area of 3.02 m^2 and an aperture of 2.14 m^2 and the optical efficiency is 75.4 %.

The values of solar collector design are as following:

- Total length and total width. (2.015 m * 1.500 m)

- Total area (automatically calculated from length and width)

- Aperture Area A collector, aperture (2.140 m^2)

- Collector empty weight (55.0 kg)

- Specific collector heat capacity (10.828 kJ/m^2. k)

- Heat transfer fluid :(water).

- Conversion factor 0.754.

- Conversion factor of direct irradiance F' (0.767).

- Loss coefficient 1 (heat transfer coefficient) (k_1=1.595 w/ m^2. $k^{2)}$.

- Loss coefficient 2 (temperature dependent heat transfer coefficient) (k_2 = 0.0010) w/m^2.k^2).

The incidence angle modifier (IAM) of a solar thermal collector for diffuse irradiance is usually determined under the simplifying assumption of isotropic sky and ground radiance (0.890).

The collector field

It can be chosen 10 collectors with total aperture area of 21.40 m^2. The collectors have an elevation of 1000.0^o and azimuth angle of 40.0^o. Here it can be change properties of HTF fluid. Also, the properties of pipes have been chosen (length, Diameter, specific mass, heat capacity, insulation thickness, heat conductivity), Fig. 2.

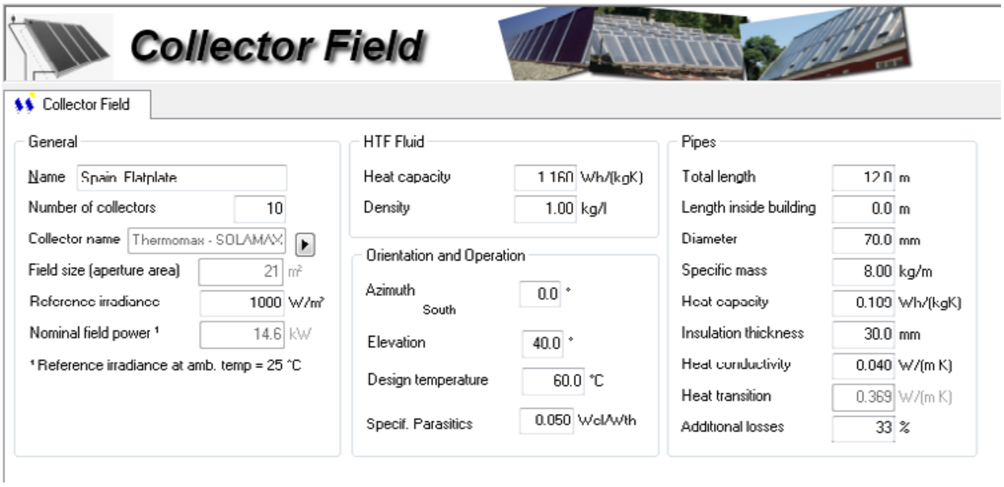

Fig. 2: The required values of the designed Field.

The properties of the thermal storage tank (losses, temperatures, ...) have been chosen as 400 kWh Net-capacity.

3.3. Calculate the Costs:

There are two types of the costs, the conventional and the non-conventional. At solar thermal power plants, the solar field is the non-conventional component and the power block is the conventional. The costs are subdivided into: Investment costs and Operating and maintenance costs (O&M) (General O&M, Replacement costs, Insurance costs).

Further costs are land costs that are calculated from specific land costs and the area demand and absolute costs for infrastructure. Costs for project development, insurance during construction, supervision and setup and contingencies can be defined as well. The sum of the costs is calculated automatically and is the base for all further simulations.

The costs of contents system (The field, land, the storage system, Operating and maintenance (O&M) cost....) were found from the companies that sell these elements. Furthermore, the start of the project was suggested in 2018 for 25 years operation period. The end of operation and the start of construction are calculated automatically.

The cost of traditional energy in Spain:

The cost of each (kw) for heat/ cool and electricity have been obtained.

The total investment requirements are approx. 2 770 228 €.

The costs can be broken down into:

- Total costs of non - conventional components: 6420 €.
- Total costs of conventional components: 2400000€.
- Total costs of thermal storage system: 14000 €.
- Total other costs (incl. land costs, etc..): 217893 €.

Each 1 m^2 from this solar thermal field will give (10.828 kw/m^2) heat energy so we have about 210 kw from this energy field when it works. The program shows in the results that will reduce the cost of fossil fuel that was used for heat water. The total cost of this energy field can be taken in about 15 years, so still 10 years of free heat energy. After 25 years of working it will be old and not good for use, thus it should be change the collectors and other parts of the solar plant.

3.4 Use Nanofluid instead of water in solar system

The current collectors in recent studies possess low energy conversion efficiencies. The efficiency depends on the performance of the absorber in capturing the solar energy and also the performance of heat transfer process of the working fluid. Solar thermal collector is defined as a heat exchanger that converts solar radiation to thermal energy within the working fluid filled in the solar thermal system.

An efficient solar thermal collector must be coupled with fluids which possess superior thermal and optical properties. New generation of heat transfer fluid such as nanofluid is proven to have good prospect to be utilized in the solar collector. Although water is shown to be the best absorber of solar energy of the four fluids (water, ethylene glycol, propylene glycol, and Therminol VP-1), but it is still a weak absorber, only absorbing 13% of the energy while the Therminol VP-1 heat transfer fluid is the weakest absorber examined, only absorbing 2% (Leong et al., 2016; Otanicar, Phelan, & Golden, 2009; Sarsam, Kazi, & Badarudin, 2015). Furthermore, Nanofluid allow to use the direct absorb solar collector DASC, which with nanofluid can performe with 10% higher efficiency compared to a conventional flat plat collector with pure water (Muhammad et al., 2016), In addition, the presence of nanoparticles yielded the absorption of irradiation by more than nine time over that of pure water (Leong et al., 2016), Some researches show that gold coated SiO2 nanoparticle in water can absorbing by 70% of the sun energy as a heat another kind of nanofluid can absorb 40% (Gorji & Ranjbar, 2015) provides a promising alternative to conventional solar collectors. Most of the previous numerical and experimental studies evaluated the effect of various nanofluids on the thermal performance of a pre-designed collector, and did not consider the effect of varying collector dimensions on its overall performance. In this study, a numerical model of nanofluid flow and temperature distribution in a DASC is proposed by solving the radiative transfer equations of particulate media and combining conduction and convection heat transfer equations. Response surface methodology (RSM. Also, Nanofluid increase the collector efficiency, for example $Al_2O_3-H_2O$ (13 nm) nanofluid with 0.1% volume fraction and at a flow rate of 1.5 kg/min showed the highest energy efficiency of about 73.7% (Said, Saidur, & Rahim, 2016) and (Gupta, Agrawal, & Mathur, 2015). the efficiency of solar collector was enhanced by 23.83% with using Cu–H2O nanofluids (25 nm, 0.1 wt%) (Gupta et al., 2015). All the last ideas and steady show that it can enhance the solar collector efficiency, thus all the solar system can be enhanced in term of the elements weight and the spaces, so that reach an important point in this technology.

4. CONCLUSIONS

Solar processes are generally known to have high initial cost and low operating cost. Other factors to consider are the interest on money, borrowed, property and income taxes, resale of equipment, maintenance, insurance, fuel, and other operating expenses. The objective of the economic analysis can be viewed as the determination of the least costly method of meeting the energy need. Several economic criteria have been used for evaluating and optimizing solar energy systems. From the environmental point of view, the performance of solar collectors presents clean, renewable, and available energy, which is essential for sustainable development. Solar collectors as a kind of solar energy devices are clean energy producers during their operation. Solar energy technologies such as solar collectors provide significant environmental advantages due to reducing fossil fuel consumption and as a result reducing global warming, greenhouse effect, climate change, Ozone layer depletion, and acid rains (Tsoutsos, Frantzeskaki, & Gekas, 2005).

The design of the solar thermal system has been done in this paper. The results showed that if the project starts of construction in 2018, in construction period three years, so that first operation year will be 2021, and it still works for 25 years until 2046, so the cost of the total investment requirements is approx. 2 770 228 €. we have about 210 kw per sec from this energy plant when it works. Moreover, the total cost of this energy field can be taken in in about 15 years, so still 10 years of free heat energy. After 25 years of working it will be old and not good for use, it should change the collectors and other parts. The paper also referred to the challenges of nanofluids for solar devices and other applications which are mostly related to the high cost of nanofluid due to production limitations, instability and agglomeration of nanoparticles, pumping power and pressure drop. Therefore, for application of nanofluid in solar collectors, there is a need to restructure the design for most of the collectors to meet practical utilization for water-heating systems used both domestically and industrially. The operation cost of nanofluids operated solar collector will definitely be higher, but it can be good if the improving efficiency of solar collector is much higher than operation cost.

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Impacts on Grid Integration Electric Vehicles – Definition of Regulatory and Policy Solutions

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Abstract

The purpose of this study is to review regulations and policy solutions regarding Electric Vehicles Grid Integration, also known as Vehicle to Grid (V2G). The methodology is based on literature review and assessment of the referred research fields. Main results have demonstrated the incipient characteristics of V2G, the lack of standardizations regarding V2Gs models, types and modes, lack of awareness from sectors' specialists towards V2G technology, and poor public policies and regulations that hinder rather than support EV owners on a Grid Integration scenario. Furthermore, EV owners do not have much incentives to integrate EVs onto a Smart Grid given that the rewards hardly cover energy expenses and overall costs from the wholesale.

KEYWORDS
EV, Grid Integrated EV, EV history, EV regulations, EV policies

1. Introduction

Business models are rising with the recent advancements of electric vehicles (EVs), following a technological development and cost reductions in battery technology and management systems (Kester *et al.*, 2018). One such model is known as vehicle to grid (V2G), capable of retrieving stored electricity in electric vehicles for the benefit of the electricity networks (Kempton, Tomic, 2005).

Despite the infancy of V2G technology, the research and development incentives on the sector are vast. Nevertheless, given EVs intermittent history and recent outcomes, the policies, regulations and mandates regarding EVs Grid Integration through V2G do not boast economic benefits for the final consumer, hindering EVs full integration and use as energy storage for energy fluctuations (IEA, 2017; Kester *et al.*, 2018; Matulka, 2014).

Therefore, this research aims at describing different regulations and public policies aimed at making V2G technology concept economic viable, both through the consumer perspective as well as authorities' perspective. The results have shown that V2G is not well disseminated amongst sector specialists and lacks interest on policy recommendations due to lack of awareness and incentives. Moreover, current policies do not take into account complex methodologies to accurately depict the overall energy expenditure and overall energy intake throughout the wholesale cycle, let alone the role of EV owners. Even on a virtual model with the use of Virtual Power Plant modelling, EV owners would still be penalized for owning and using an EV as a V2G component.

In order to proceed, this research has been dived into 5 sections: a brief introduction on Section 1; a history, types and V2G concept presentation on Section 2; Most noticeable regulations and public policies regarding V2G on Section 3; overall conclusions on Section 4; and references on Section 5.

2. Introduction to Electric Vehicles – Brief History, Types and the Vehicle to Grid

Electric vehicle (EV) uses one or more electric motors or traction motors as means of propulsion. It may also be powered through a collector system by electricity from off-vehicle sources, as well as being self-contained with a battery, solar panels or an electric generator aimed at fuel to electricity conversion (Faiz *et al.*, 1996). EVs range from road and rail vehicles, to surface and underwater vessels, as well as electric aircraft and electric spacecraft. For the purpose of this research, the range will be restricted to road vehicles. Although EVs history has been intermittent, recent initiatives from governments across European Union (EU) and developed nations to increase EVs adoption have provided new basis for EVs resurgence, especially given the technological developments and increased focus on renewable energy (EC 2016a; 2017).

2.1. Brief History

The EV history dates to the 19th Century when, in 1827, Hungarian priest Ányos Jedlik built the first crude yet viable electric motor with stator, rotor and commutator, and which powered a tiny car on 1828 (Guarnieri, 2012). From this moment on, the invention of the electric car would take place not by a single inventor or group of inventors, but through a series of breakthroughs ranging from the battery to the electric motor, all of which have taken place in the 1800s (Matulka, 2014). The first successful electric car was introduced in 1890 by the American chemist William Morrison, which was a six-opassenger vehicle capable of a top speed of 14 miles per hour (Hirshland, 2016; Matulka, 2014; Westbrook, 2011). Despite being rather unconventional and somewhat unsuccessful, this first step was important to promote the growth of the electric vehicles. By the early 1900, electric cars accounted for approximately one third of all vehicles on the road, with automakers springing across the United States, and receiving illustrious contributions from Thomas Edison and Henry Ford, whom have worked together in order to develop superior electric vehicle technologies (Matulka, 2014; Westbrook, 2011).

Although the early stages of development and sales were seen as successful, eventually the gasoline powered car took over the market. This happened despite the electric car advantages of being quiet, easy to drive and emitted no pollution. The mass production of Ford's Model T was one of the overturning events that have made gasoline powered cars the preferred choice of transportation, especially on the promising U. S. Moreover, the price of a gas-powered vehicle was half of that of an electric vehicle by 1912, further contributing to the EVs demise at this first stage (Hirshland 2016; Matulka, 2014).

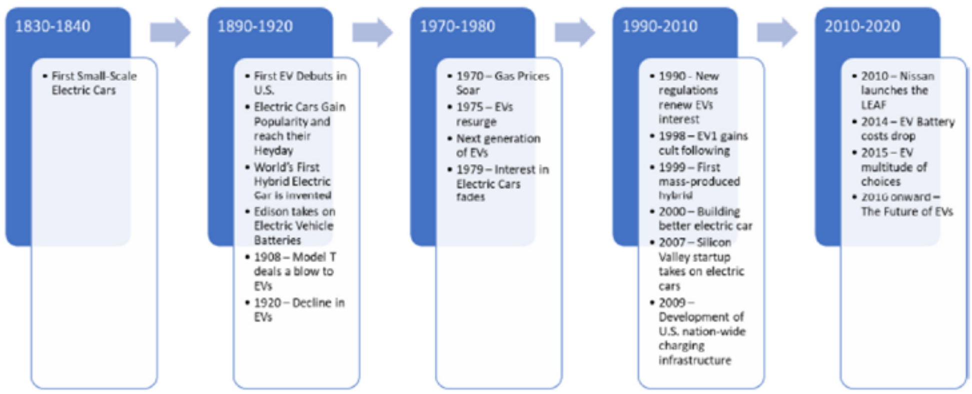
Despite seeing a comeback on the 1970s due to new legislations and the oil crises, it was not until the early 2000s that electric vehicles would see a true revival. This resurgence on current trends is mainly due to the increasing environmental concerns, especially on regulations terms. On the 1990s, the Clear Air Act Amendment and the Energy Policy act, combined with new transportation emissions regulations issued by the California Air Resources Board, EVs finally got a new chance to thrive, especially with the rise of Silicon Valley companies bearing environmental and technological objectives in mind (Hirshland 2016).

The release of Toyota Prius in 1997 was also a turn-point, considered to be the first hybrid electric vehicle which was mass-produced. Prius technology uses nickel metal hybride battery, which was supported by U.S. Energy Department's research at the time, boasting incentives towards a global hybrid EV market (Matulka 2014). In the late 2010 both the Chevy Volt and the Nissan LEAF were released bearing interesting characteristics. The Chevy Volt was the first commercially available plug-in hybrid, whereas the LEAF is an all-electric vehicle (or a batteryelectric vehicle) (Matulka 2014).

More importantly was the incentive provided by the Recovery Act, where the U.S. Energy Department invested more than $115 million to help develop a nation-wide charging infrastructure, with more than 18,000 residential, commercial and public chargers across the country. The current statistics bear astonishing 8,000 different charging locations with over 20,000 charging outlets on U.S. soil (Matulka, 2014). The U. S. Energy Department also made investments for the development of new battery technology through the Vehicle Technologies Office, improving the plug-in EVs range as well as developing the lithium-ion battery technology currently widespread.

Current figures suggest that there are 23 plug-in electric and 36 hybrid models available in a variety of sizes and objectives, resulting in over 234,000 plug-in EVs and 3.3 million hybrids being driven currently solely on U.S. soil (Hirshland 2016; Matulka, 2014). Globally, EVs account for over 2 million vehicles in 2016, with Norway leading the market share boasting impressive 29% of EV on total vehicle market share (IEA, 2017). A comprehensive timeline for the EVs history is demonstrated on **Figure 1** (Hirshland 2016; Matulka, 2014).

Figure 1
Electric Vehicle timeline



Source: Adapted from Hirshland, 2016; Matulka, 2014.

2.2. Types of Electric Vehicles

The different EV types distinguish themselves based on the electrification use of the drive train coupled with the electric power & electric driving range, also known as the integrated functions (IEC 2017). There are five major classes of EVs, as described below (IEC, 2017; Matulka, 2014; Smolinka, 2009):

1 – Electric Vehicle: Based on pure electric driving, it has a low electric & power driving range, and low electrification of the drive train;

2 – Plug-In Hybrid: characterized by its charging with sockets, it has more electric power & electric driving range when compared to pure EVs, and moderate electrification of the drive train;

3 – Full Hybrid: designed with an integrated motor assist and limited electric driving, it boasts moderate electric power & electric driving range and moderate electrification of the drive train;

4 – Mild Hybrid: Displaying braking energy recuperation systems and acceleration assistance which provides a slide boost of performance and range, it has moderate to high electric power & electric driving range, as well as moderate to high electrification of the drive train;

5 – Micro Hybrid: Characterized by its start-stop system, this type of Hybrid Electric Vehicle has the highest electric power & electric driving range as well as the highest electrification of the drive train.

For demonstration purposes, **Figure 2** below displays the integrated functions of these five classes of EVs (IEC, 2017; Matulka, 2014; Smolinka, 2009). Despite this first description, more types of EVs exist on the market currently, being accommodate under these classes according to their respective characteristics, such as: fuel cell electric passenger light-duty vehicles (PLDVs or FCEVs), electric two-wheelers (mainly motorcycles and bicycles), low-speed electric vehicles (LSEVs) and electric buses (IEA, 2017). Predictions point out that EVs could reach 200 million units in the vehicle stock by 2030, thus fulfilling the Paris Agreement range of ambition, which corresponds to an average increase in the global temperature by 1.75°C (ACEA, 2017a, 2017b; EAFO, 2017; EEA, 2017; IEA, 2017; IHS Polk, 2016; MarkLines, 2017).

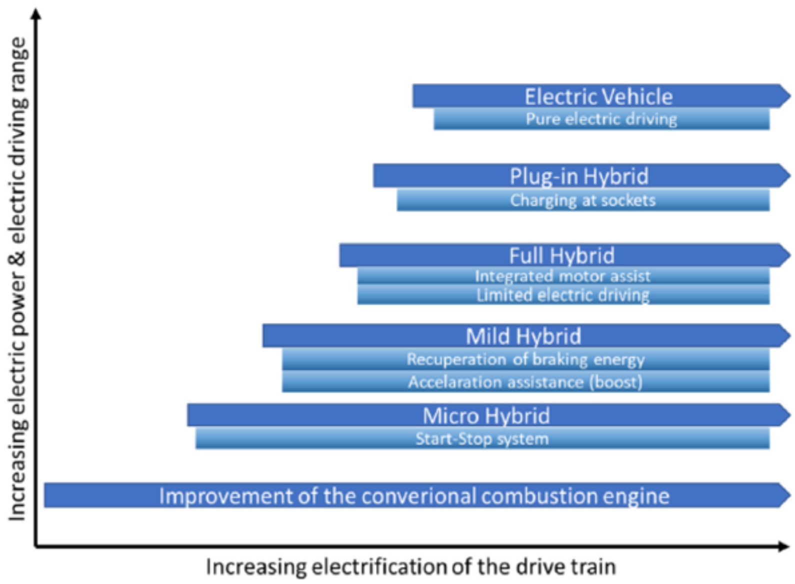


Figure 2
Hybrid classes sorted by electrical power and functional range, against stage of development

Source: Adapted from IEC, 2017; Matulka, 2014; Smolinka, 2009.

It is also important to stress the differences between hybrid and electric vehicles' power trains with respect to the specifications of the electric motor, the batteries' capacities, the range for electrical driving and the potential in fuel savings, described by Smolinka (2009), as shown on **Table 1** below:

Table 1
Differences between hybrid and electric vehicles' power trains

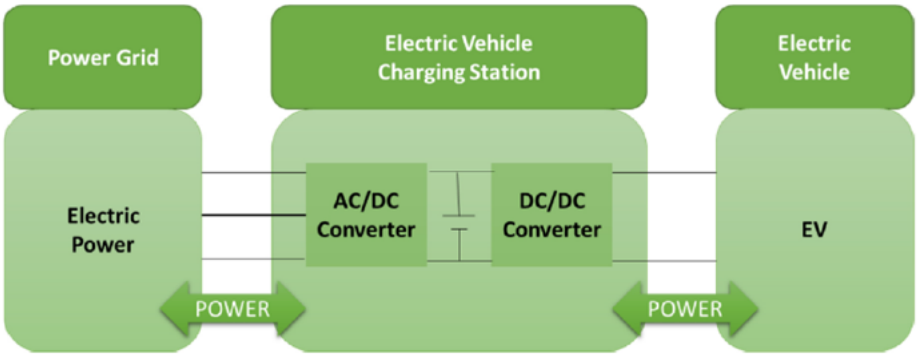
Specifications	Micro Hybrid (Lead Acid, NiMH, Li-Ion)	Mild Hybrid (NiMH, Li-Ion)	Full Hybrid (NiMH, Li-Ion)	Plug-In Hybrid (Li-Ion)	Electric Vehicle (Li-Ion, NaNiCl)
Electric Motor (Power kW)	2 - 8	10 - 20	20 - 100	20 - 100	< 100
Batteries Cap. (kWh)	< 1	< 2	< 5	5 - 15	15 - 40
Electrical driving range (km)	--	< 3	20 – 60	100	100 - 250
Fuel Saving Potential (%)	-8	-15	-20	-20	--

Source: Adapted from Smolinka, 2009.

2.3 Vehicle to Grid

The introduction of the smart grid concept has brought modernization features to the power system with additional communication features, amongst which is the Vehicle to Grid (V2G) concept (De Ridder et al., 2013; Shi et al., 2012). V2G involves the EV aimed at improving the power system operation, allowing an energy exchange between EVs and the power grid. This new business model is appealing both to EV owners as well as grid users, since power efficiency and supply would increase while EV owners might enjoy appealing revenues for their participation in V2G services (Tan et al., 2016).

V2G technology can be either unidirectional of bidirectional, where the unidirectional V2G uses the communication between the power grid operator and the EV to boost the charging rate of each EV, therefore having the capability of preventing grid overloading, system instability and voltage drop issues (Fasugba, Krein, 2011; Sortomme, 2012; Yilmaz, Krein, 2012, 2013). On the other hand, bidirectional V2G is based on the concept that an EV battery is both an electric load as well as an energy storage, this enabling energy exchange between the EV battery and the power grid for EV charging or grid support. Moreover, it provides greater flexibility for the power utility to control the EV battery energy bearing in mind the need to improve the reliability and sustainability of the power system (Gallardo-Lozano et al., 2012; Pinto et al., 2013). It is noteworthy that unidirectional V2G services are limited by the ability to provide ancillary services to the power grid. On this sense, functions such as peak load shaving, reactive power support, voltage regulation and frequency regulation can only be achieved through bidirectional V2G services (Tan et al., 2016). A very simple diagram of bidirectional V2G service can be seen on **Figure 3** below (Tan et al., 2016).



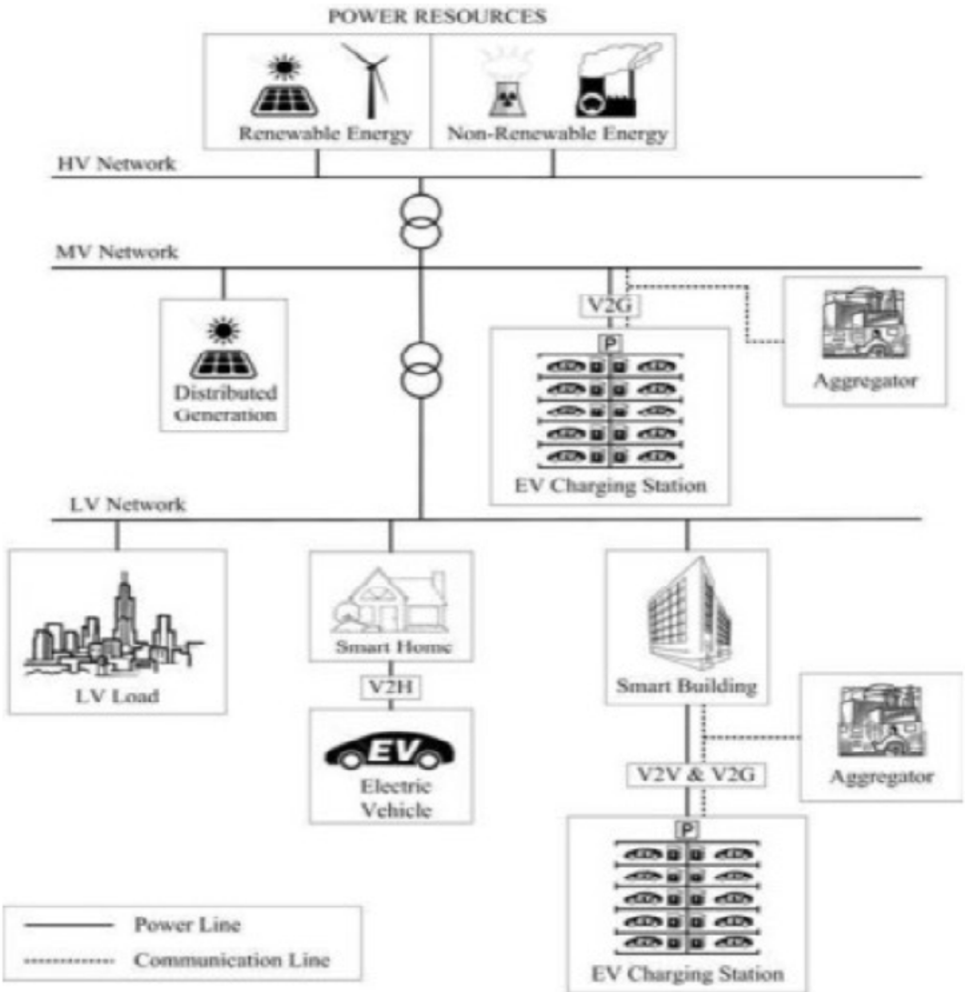
Source: Adapted from Tan *et al.*, 2016.

Figure 3
Power flow diagram for bidirectional V2G Tan *et al.,* 2016

Currently, bidirectional V2G implementation faces several issues, ranging from battery degradation due to frequent charging/discharging cycles, to the additional hardware and leads required for extra investment, as well as social barriers such as safety concerns that directs EV owners to acquire high battery state of charge for unexpected travelling use (Dogger *et al.*, 2011; Fasugba, Krein, 2011)

The emerging concepts of grid-connected EV technologies are the Vehicle to Home (V2H), Vehicle to Vehicle (V2V) and Vehicle to Grid (V2G) concepts (Liu et al., 2013; Tan *et al.*, 2016). Briefly, V2H is aimed at describing the power exchange between the EV battery and a home power network, whereas V2V is a local EV community that can charge/discharge EV battery energy among themselves. Lastly, V2G uses the energy from the local EV community and trades it with the power grid through the control and management of local aggregators (Wu et al., 2010). A typical V2G system framework is demonstrated on Figure 4 below (Tan *et al.*, 2016).

Figure 4
V2H, V2V and V2G framework according to Tan et al., 2016



Source: Adapted from Tan *et al.,* 2016.

According to a recent German government forecast, there will be over one million EVs estimated by 2020 on the EU (BMWI, BMU, 2010). An IEA study (2009) has shown that EV batteries may be used for time shift and smoothing of short-term fluctuations through the use of V2G technology, which would decrease the required Electricity Energy Systems (EES) by 8.19% to 54.9%, depending on the scenario (IEA 2009).

3. Regulatory and Policy Review

Still proving to be crucial for electric vehicles market deployment, policy support is required in order to lower barriers of EVs adoption. In this sense, policy support mechanisms can be grouped into four major categories: R&D of innovative technologies; targets, mandates and regulations; financial incentives; other instruments primarily enforced in cities which will allow for EVs value proposition to increase (IEA, 2017).

Regarding R&D support of innovative technologies, regulations and policies are key to achieve cost reductions and performance improvements, being best conceived when coupled with other instruments that allow the scale-up of production. RD&D over battery cost and performance, combined with mass production prospects, are leading towards a rapid cost decline and performance enhancements, which is confirmed by the research applied to the gap between commercial applications and new batteries' technologies, but also by the increase production volumes due to electric vehicles market growth, larger pack sizes and cost reductions expected for all families of battery technologies (IEA, 2017; US DOE, 2017). Current technologies in the R&D stage have better performance than those available on the market, with projections for lar battery costs on a continuous decline (IEA, 2017; US DOE, 2017).

Concerning mandates and regulations, which are built on the definition of regulatory targets to provide a clear signal to manufacturers and customers as medium- to long-term visions are being settled, are directed at producing zero-emission vehicles (ZEVs) and fuel economy regulations. ZEV mandates are regulatory requirements for automakers with objective to sell a set portion of ultra-low or zero-emission vehicles, while promoting RD&D efforts for marketing such portfolio. ZEV mandates were initially taken on California (CARB, 2017) and further enforced on several U.S. States, as well as Canada and China (Lambert, 2016; UCS, 2016). On this sense, the Global Fuel Economy Initiative, which helped ensure fuel economy regulations would cover 80% of the global vehicle market, is seen as an example of the focus resulted in measurable progress towards the achievement of policy goals (GFEI, 2016).

More important for this research are the policies aimed at electric vehicle supply equipment (EVSEs), which involve charging infrastructure for EVs (whether at home, work or public/private locations) (IEA, 2017). Communication between EVSE and the distribution systems operator (DSO), also known as EVSE-grid communication, and the use of cables and connectors are within the requirements to effectively perform EV charging operations on different environments (IEA, 2017). Therefore, a suitable EVSE for electric vehicles has three main characteristics: level (which refers to the power output of an EVSE outlet); type (the socket and connecter being used for charging); and the mode (also known as the communication protocol between EV and charger). To provide a standardized market and development of EVSE, key entities are involved: International Organization for Standardization (ISO); the International Electrotechnical Commission (IEC); the U. S. Society of Automotive Engineers (SAE); and the Standardization Administration of China (SAC) (IEA, 2017). Table 2 below provides an overview of the level and type of EVSE used in China, Europe, Japan and the U. S. (AFDC, 2017; Bohn, 2011; CHAdeMO, 2012, 2016; CharIN, 2017a, 2017b; EC, 2014; Electric Vehicle Institute, 2017; HK EMSD, 2015; State Grid Corporation of China, 2013).

Table 2
Overview of the level and type of EVSE used in China, Europe, Japan and the U. S.

Level	Current	Power	Type			
			China	Europe	Japan	U. S.
Level 1	AC	≤ 3.7 kW	Devices installed in private households			SAE J1772 Type 1
Level 2	AC	> 3.7 kW and ≤ 22 kW	GB/T 20234 AC	IEC 62196 Type 2	SAE J1772 Type 1	SAE J1772 Type 1
Level 2	AC	≤ 22 kW	Tesla Connector			
Level 3	AC triphase	> 22 kW and ≤ 43.5 kW	--	IEC 62196 Type 2	--	SAE J3068 (Under Development)
Level 3	DC	Currently < 200 kW	GB/T 20234 DC	CCS Combo 2 Connector (IEC 62196 Type 2 & DC)	CHAdeMO	CCS Combo 1 Connector (SAE J1772 Type 1 & DC)
Level 3	DC	Currently < 150 kW	Tesla and CHAdeMO Connectors			

Source: Adapted from AFDC, 2017; Bohn, 2011; CHAdeMO, 2012, 2016; CharIN, 2017a, 2017b; EC, 2014; Electric Vehicle Institute, 2017; HK EMSD, 2015; State Grid Corporation of China, 2013.

On the specific topic of EV grid integration, V2G technology can provide ancillary services to the power grid, both through unidirectional and bidirectional forms. Unidirectional V2G can provide power grid regulation and spinning reserve (Guille, Gross, 2009; Akhtar et al., 2013). However, the implementation of unidirectional V2G requires an attractive energy trading policy between the EV owners and the power utility (O'Connell *et al.*, 2012; Sousa *et al.*, 2012). This policy should guarantee revenues to EV owners if they charge their EVs during off peak hours and limit the EV charging during on peak periods, while also guaranteeing that power utility would avoid overloading during on peak hours (Kempton, Tomic, 2005; Quinn *et al.*, 2010; Tan *et al.*, 2016; Tomic, Kempton, 2007).

Tan *et al.* (2016) have proposed an optimization algorithm for V2G control strategy which includes the type (unidirectional, bidirectional), the service, optimization objectives, constraints (power system and electric vehicle) and optimization methods applied (Genetic algorithm, convex optimization, linear programming, particle swarm optimization, quadratic programming and ant colony optimization) (Tan et al., 2016). Their optimization objectives involved: operation cost, carbon dioxide emission, profit, support for renewable energy generation, target load curve and power loss; while the constraints were: power system (power balance, generation limit, voltage limit, line thermal limit), and electric vehicle (battery energy exchange rate limit, battery SOC limit, EV availability). Authors have concluded that the optimization technique and methodologies are necessary for V2G energy management since it can comply with complex power system constraints and achieve multiple objectives, as required by policies and regulations on the sector (Tan *et al.*, 2016). Moreover, authors attribute great importance for participation and collaboration between government, power utilities, V2G aggregators and EV owners in order to accomplish

V2G technology on large scale. These would be achieved mainly through incentive-based policies capable of catalysing successful V2G technology implementation (Tan *et al.*, 2016).

On another study, Bhandari et al. (2018) investigate the implications of battery costs and different market rules on the rewards of a V2G to participants. This objective would be achieved through the development of a centralized V2G system model and application on case study of Texas electricity market. On the centralized system, EVs act as micro-generators and participate in the wholesale market through a Virtual Power Plant (VPP), either through an aggregator or a parking lot. Authors discussed and applied three different compensation scenarios for EV owners: EVs were paid based on a fixed retail market price (traditional); EVs were paid through time-varying retail prices based on changes of wholesale market conditions; or the VPP shares 50% of its total reward with participating EVs. Authors concluded that V2G system is always financially profitable for the VPP and the system operator acquired grid services. However, more often than not EVs owners tend to be the losing side. Moreover, cheaper EVs (based on lower per unit output-battery cost $/kWh) would lose more by participating due to extensive battery over-use and insufficient reward. Authors argue that policy makers could invest in reducing battery costs, spur the introduction of newer market products such as peak-shaving product or a renewable consuming/flexibility product. Moreover, EVs could get extra revenue for discharging during peak hours and charging during off-peak hours. Also, the introduction of policies aimed at providing additional subsidies such as Production Tax Credits, would incentivize EVs to participate in the V2G system (Bhandari *et al.*, 2018).

Lastly, the research of Kester et al. (2018) is noteworthy, since it carried out interviews with 227 experts related to electric mobility and its reflection on policy suggestions for EVs and V2G in the Nordic countries. Their results and conclusion suggest that there is a lack of awareness and deep understanding of V2G concept which directs advices for public policy towards electricity sector primarily, disregarding mostly the vehicle sector and consumers. More importantly, their research confirms multiple themes offered in policy literature, affirming the need for policies targeting aggregators, the position of DSOs, the organization of electricity markets, the need for standardization and guidelines, and the requirement for information for both consumers and V2G associated industries (Kester et al., 2018). Nonetheless, the scale and scope of regulation is just as important as the actors crafting and supporting them (that is, if it is on a given industry, charging companies, DSOs, local governments, regulators, companies, consumers and/or research institutions). Main policy recommendations identified on this research were regulatory or financial in nature, which can be observed on **Table 3** below (public policies and regulations suggestions) (Kester *et al.*, 2018).

Table 3
Public policies and regulations suggestions (Kester et al., 2018)

Party	Policy Suggestions
Authorities (national governments, energy regulators, TSOs	• V2G capable chargers are part of the consumer market or the wholesale market; • Existence of double taxation on flexible electricity storage; • Formulate role and responsibilities of aggregators.
Governments	• Support pilot projects/start-ups on V2G and other flexible storage solutions; • Create energy strategy;
	• Support the sector in generating appropriate aggregation frameworks; • Consider building regulations; • Set up (aid or invest in) technical/pragmatic guidelines; • Support research; • Support EV and Renewable Energy Sources uptake.
General	• Clearly differentiate between controlled charging and V2G.

Source: Adapted from Kester et al., 2018.

4. Conclusions

Despite being a prominent factor for the future, especially regarding sustainability scenarios, EVs are still lacking economic viability when it comes to the final consumer. Thevast amount of research on EV topics suggests that policy makers should take into account the complex system involving both EVs and Smart Grid integration concerning regulations and mandates. Nonetheless, what has been observed on specialized literature is a lack of interest and knowledge both from policy makers and sector specialists alike, which majorly contribute for poor decision making, thus providing lacking policy frameworks for companies and consumers to rely upon.

The results have shown that V2G is not well disseminated amongst sector specialists and lacks interest on policy recommendations due to lack of awareness and incentives. Moreover, current policies do not take into account complex methodologies to accurately depict the overall energy expenditure and overall energy intake throughout the wholesale cycle, let alone the role of EV owners. Even on a virtual model with the use of Virtual Power Plant modelling, EV owners would still be penalized for owning and using an EV as a V2G component.

In conclusion, the vast amount of literature on the topic and policies which exist on different scopes and scales did not solve the main issues regarding V2G technology constraints and do not benefit the final consumer with respect to EV Grid Integration. Clearly, policies concerning users' adherence to controlled EV charging schemes, energy scenarios and plans, EV aggregators roles and responsibilities, and lower price energy provision are lacking and are not seen as an urgent concern.

Future research on this matter should be aimed towards applying known methodologies (such as optimization) to public policy regarding V2G and energy prices, as well as other methodologies already explored in literature. Moreover, future works may concern different countries strategies and provide a roadmap for standardizations regarding V2G technology.

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Review and Development of Regulatory Solutions for Battery Energy Storage Systems (BESS)

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Abstract

The purpose of this study is to review and describe the characteristics and development of Electricity Energy Systems (EES) and Battery Energy Storage Systems (BESS), as well as their regulations and policies. The methodology is based on literature review and assessment of the referred research fields. Main results have demonstrated the incipient characteristics of new storage technologies and the lack of standardizations for general purpose regarding BESS. Moreover, technical and economical characteristics are rarely taken into account when concerning regulations and policy making for the sector.

KEYWORDS
EES, BESS, BMS, BESS regulatory solutions.

1. Introduction to electricity sector and electricity storage

Due to a disconnection between the amount of energy consumers require and the amount of energy produced from generation sources, a clear inefficiency can be seen on current electric grid systems, which causes significant amount of wastes of generated electricity (Lawder et al 2014). Electricity demand is variable in nature, being different regarding daily and seasonal aspects, boasting a challenge for generator operational needs in order to match loads with broad peak-to-base spreads (Kassakin et al 2011). Therefore, electricity providers must manage and have availability of installed power capacity to match peak demand while

On the European electricity sector there is a rising evolution, challenging in nature, which will see an increase on primary energy consumption being supplied by renewable energy sources (RES) between 2005 and 2030 (Ferreira *et al* 2013). In order to better understand the electricity role in the European Union, the International Electrotechnical Commission – Market Strategy Board (IEC-MSB) established a project team on October 2010 aimed at investigating the current situation and future orientation upon electrical energy storage (EES) technologies, roles, markets and perspectives. Germany is leading on the introduction of renewable energies sources into its electricity energy systems, having set targets to increase allocation in installed storage capacity from the current 20% to 60-80% until 2030. To achieve this goal, the methodology is to increase penetration capacity of renewable energies through optimum exploitation of wind and solar energies, the former presenting almost twice percentage contribution than solar to Germany's energy profile (IEC 2017).

Energy storage is considered a key element in diversifying energy sources and adding more renewable energy sources into the energy market. Through its use, generation sources can operate at optimal efficiency while energy storage will account for variations in demand, optimizing the hole system. In this sense, electrochemical energy storage devices, such as batteries, offer capacity, siting and rapid response flexibilities, all of which are required to meet application demands from a vast range of functions (Lawder *et al* 2014).

Therefore, this research is aimed at reviewing most common Battery Energy Storage Systems (BESSs), their management solutions, communication fluxes, types of provided services (such as energy arbitrage and ancillary services provision) and overall regulations, in order to provide a background for development of regulatory solutions.

2. Battery energy storage systems (BESS)

2.1. Definition and types

Battery Energy Storage Systems (BESS) are a sub-set of Energy Storage Systems (ESS), which is a general term for the situation where a system is able to store energy using thermal, electro-mechanical or electro-chemical solutions (BESS focuses on the latter) (AIG 2018).BESSs currently account for a small portion of energy storage within the grid. Nevertheless, they have seen great growth from R&D and market perspectives due to their versatility, high energy density and overall efficiency (Divya, Ostergaard 2009). While displaying the ability to react almost instantaneously to grid demands, BESS also boast the capacity to function over longer durations and have a wide range of storage and power capacities.

BESSs can be categorized into three different sets according to the constitution of the batteries themselves and their methods of discharging the energy contained: chemical batteries, flow batteries and metal-air batteries. Electrochemical batteries, such as lead-acid based, are also known as rechargeable battery comprised of three major components: the positive electrode (cathode), the negative electrode (anode) and the electrolyte (either solid or liquid). Both electrodes are immersed on the electrolyte producing a voltage of up to 2V in general for each cell, and these cells can be connected in series providing higher energy outputs. The main concern with such batteries are their durability, which is directly linked to the depth of discharge. Flow batteries are also electrochemical devices, whereas their distinction from chemical batteries lies on the energy being stored in the solution (electrolyte) containing dissolved electroactive species. Therefore, redox flow batteries use electrolyte solutions that can be stored in external tanks, providing benefits in the form of the system capacity now being dependent on the size of said tanks and the system power being determined by the size of the cell stacks. The main benefit from these types is an independent scaling of power and energy capacities, with high energy flexibility since the energy output is proportional to the amount of electrolyte used. The main drawbacks of redox flow batteries are their low power density, the high level of toxicity from the required materials and insufficient deployment at commercial level (despite vanadium redox – VRB - and zinc bromide - ZnBr – batteries being available at market). The final set (metal-air batteries) is the most incipient from these technologies, being researched only in recent years. It is characterized by the use of metal as the fuel to supply electricity. As an incipient technology, the low efficiency and low power output are still the most prominent barriers to be overcome (Ferreira *et al* 2013; AIG 2018). A brief overview of characteristics of each set can be seen on Table 1 below.

Table 1
BESS general technologies and characteristics

Major Cat.	Type	Description	Power Rating (MW)	Efficiency (%)	Durability (years)	Capital Cost ($/kWh)	Tech. Maturity	Availability	References
Chemical	Lead-acid	Traditional rechargeable batteries, inexpensive compared to newer types.	0.001 - 50	70 - 92%	6 - 15 (~10)	200 - 400	5	99.997%	AIG 2018; Ferreira *et al* 2013; Hale Jr, Arno 1999; IEC 2017; Pedersen, Dong 2010.
	Ni-Cd	Nickel-cadmium - robustness to deep discharges; long life cycle; temperature tolerance; higher energy density compared to lead-acid. Deployed at appliance level.	0 - 46	60 - 70%	5 - 20	800 - 1500	4	99%+	Ferreira *et al* 2013; Makarov *et al* 2008; Pedersen, Dong 2010.
	NiMH	Nickel-metal Hybride - Variant of Ni-Cd; Higher energy density; environmently friendly; Drawbacks: high self-discharge and dependency on limited supply of rare earth materials; Used in consumer electronics and electric vehicles.	0.01 - ~MW	60 - 66%	3 - 15	N/A	4	99%+	Ferreira et al 2013; IEC 2017; Makarov *et al* 2008; Zelinsky 2010.
	Li-ion	Lithium-ion - Good energy storage; Many recharges through lifecycle; Used in variety of consumer electronics: Smartphones, tablets, laptops, digital cameras, electric cars and some aircraft	0.1 - 50	85 - 90%	5 - 20	600 - 2500	4	97%+	AIG 2018; Ferreira *et al* 2013; IEC 2017; Lippert 2010; Miller 2002; Pedersen, Dong 2010.
	NaS	Sodium-sulphur - High-temperature; Quick reversibility between charging and discharging; efficient operation; low maintenance; long life; good scale production potential; Drawback: high operating temperature; Economic option for power quality and peak shaving; Corrosion problems impair reliability; Used for renewable energy storage such as solar and wind	0.05 - 34	75 - 90%	15	300 - 500	4	Up to 99.98%	AIG 2018; Ferreira *et al* 2013; IEC 2017; Makorov *et al* 2008; Pedersen, Dong 2010; Sandia National Laboratories 2007.
	Zebra	Sodium-nickel-chloride - Small and light; Fast response, robustness at full discharge, very high energy density; Drawbacks: high cost and self-discharge; Mostly been used in electric vehicles and submarines	0.001 - 1	~90%	8 - 14	100 - 200	4	99.9%+	Connoly, Leahy 2007; Crugnola, Sonick 2010; Ferreira *et al* 2013; IEC 2017; Pedersen, Dong 2010.
Redox-Flow	VRB	Vanadium redox - highly flexible; High efficiency, short response times, symmetrical charge and discharge; quick cycle inversion Drawbacks: Low power density, toxicity, insufficient deployment at commercial level	0.005 - 1.5	65 - 85%	10 - 20	150 - 1000	3	96-99%	Ferreira *et al* 2013; IEC 2017; Li *et al* 2011; Pedersen, Dong 2010.
	ZnBr	Zinc Bromide - highly flexible; High efficiency, short response times, symmetrical charge and discharge; quick cycle inversion Drawbacks: Low power density, toxicity, insufficient deployment at commercial level; Used for renewable energy storage from solar and wind.	0.025 - 1	75 - 80%	5 - 20	150 - 1000	2	94%	AIG 2018; Ferreira *et al* 2013; Pedersen, Dong 2010.
Metal-air	Zinc-air	High-potential - still under research; Environmentaly friendly; Low efficiency and low power output	0.02 - 10	40 - 60%	N/A	10 - 60	1	N/A	Ferreira *et al* 2013; Inage 2009; IEC 2017; Pedersen, Dong 2010.

Source: Many, structure and data adopted from Ferreira *et al* 2013

In the revised literature, the most efficient EES technologies are those designed in order to support high power ratings with relatively small energy content, thus making them appropriate for power quality and reliability, which is the case with BESS. Furthermore, BESS were seen as technologies with high energy density (Ferreira *et al* 2013; Gonzáles *et al* 2015; Hameer, van Niekerk 2015). Also, it is worth noting that small-medium batteries may sustain short discharge times (ranging from seconds to minutes), making them useful for ensuring the quality and continuity of power delivered when switching from one source to another. On the other hand, large-scale batteries will sustain energy management applications that require large power and energy capacity, providing long discharge times (ranging from days to weeks). Cycle efficiencies from electrochemical batteries and flow batteries are higher than 60%, especially when compared to other EES technologies (Gonzáles *et al* 2015; Hameer, van Niekerk 2015).

Existing research on batteries revealed that Li-ion batteries poses promising technology forecasts for the future large-scale storage systems, whereas Na-S batteries are already being commercialized in Japan. It brings the conclusion that batteries are proven attractive EES technologies due to flexible adaptability at various geographical regions, power and energy density, efficiency, weight and mobility (Cho *et al* 2015; Hameer, van Niekerk 2015). On this sense, the requirement of detailed techno-economic evaluation, the lack of multiple manufactures (stagnating growth) and the achievement of economy of scales in the near future are the key-issues for future development of large-scale applications' batteries technology. Similarly, stationary batteries present other key-issues for future development and commercial launch, such as the capital cost (cost per unit energy/cycle life) and the long cycle performance of batteries (Cho *et al* 2015).

When considering the BESS technologies operation, determining parameters are: storage capacity and duration, available power, depth of discharge or power transmission rate, discharge time, energy and exergy efficiencies, life cycle and lifetime, autonomy, costs, feasibility, self-discharge, reliability, safety and environmental impact (including recyclability) and technical maturity.

On the applicability point-of-view, the following applications can be outlined when regarding (Ferreira *et al* 2013; Hameer, van Niekerk 2015; Schoenung, Hassenzahl 2003):

a. Bulk energy storage:

- Load leveling (effective scheduling between charging off-peak power and discharge power at peak hours – uniform load for generation, transmission, distributions systems and maximized efficiency)
- Flow batteries may be potential future technology;
- Peak shaving/valley filling (effective minimization of peak power / process of increasing efficiency of base plants by increasing load) – Lead-acid is a mature technology, with Flow batteries seen as potential future technology;
- Contingency service and Area control – NiCd is a mature technology, with Flow batteries seen as potential future technology;

b. Distributed storage:

- Peak shaving/valley filling – Flow battery is a potential future technology;
- Demand side management – Metal-air batteries are potential future technologies;
- Area control – Lead-acid, NaS, NiCd are mature technologies;

c. Power quality (voltage and frequency synchronization):

- Intermittency mitigation – Lead-acid is a mature technology with NiMH being a potential future technology;
- Black start (end-use application) – NaS is a mature technology with Zebra being a potential future technology.

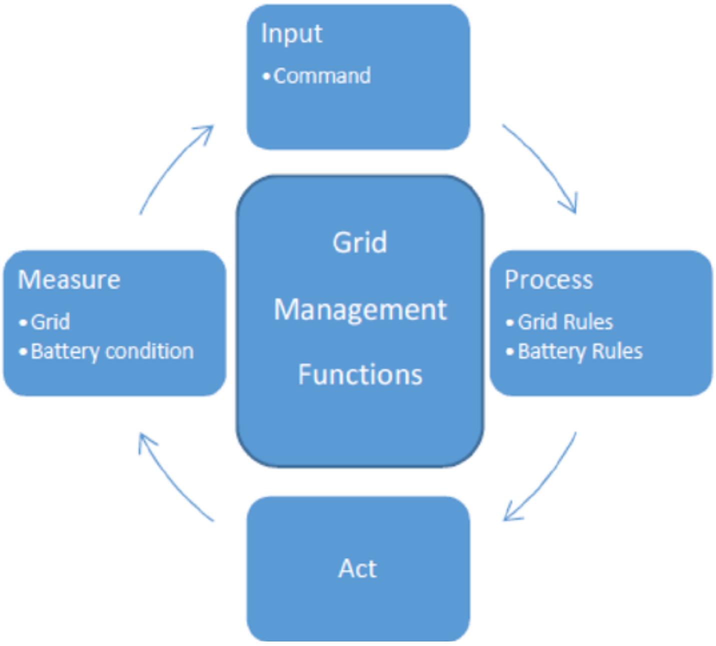
On forecast studies aimed at the 2030 scenario regarding BESS applications, conventional stabilization, Island/off-grid storage and balancing energy are the most feasible (implementation wise) and pose the most attractive profitability rate (IRR between 10% and 30%). On the other hand, price arbitrage and residential storage are seen as unprofitable (less 10% IRR or even negative IRR) despite being easy to justify their feasibility (from an implementation point-of-view) The total market potential for the eight groups of the present market study is 330 GW (BCG 2011). Panasonic Group has also estimated BESS market forecasts for 2030, especially regarding Li-ion batteries. They divided the applications into 5 different groups: UPS, EV Charger, Industrial, Residential and Utility. Also, results have shown that Li-ion battery market has a growing potential with fast increase of the residential market (Sanyo 2011).

2.2. Battery Management Systems (BMS), Communication fluxes and Types of services to be provided

Regardless of the chemistry, each BESS requires management solutions for monitoring and safekeeping the systems within optimal operation of each battery pack, as well as a system supervisory control (SSC) to manage the entire energy system (Cho *et al* 2015; Lawder et al 2014). Also, in order to provide large-scale energy storage applications to thrive, a set of parameters are needed, such as: cost, lifetime, efficiency, power and energy density (a brief summary of some of these parameters can be seen on Table 1 for the BESS). For this purpose, a Battery Management System (BMS) is required.

Basic BMSs are used only to control battery packs aimed at meeting the power demand. More complex BMSs (smarter model-based) can reduce the causes of degradation and improve the performance of the system. For this purpose, predictive and adaptive BMSs based on models are especially important for large battery packs and for applications such as electric vehicles and grid integration (Verbrugge 2009; Verbrugge, Koch 2006; Verbrugge, Connel 2002). By using physics-based models, BMSs can accurately estimate many internal variables that allow it to gain a thorough understanding of battery state of charge (SOC) and state of health (SOH). In this sense, the details of the physics involved, scale involved, time constants and other variables will determine the numerical challenges and opportunities for faster numerical algorithms and control schemes aimed at improving efficiency A conceptual illustration of BMS control cycle may be seen on **Figure 1** below (Lawder **et al** 2014).

Figure 1
Conceptual illustration of BMS control cycle



Source: Adapted from Lawder *et al* 2014

The Li-ion modeling is based on the single-particle model (SPM) that represents each electrode as a single particle. This model considers the effects of transport phenomena inside the solid phase of a Li-ion cell, despite neglecting the concentration and potential effects in the solution phase between particles. It can be quickly simulated to estimate SOC and remaining cycle behavior, while also being used to predict capacity fade due to growth of the solid electrolyte interface (SEI) layer (Guo *et al* 2011; Pinson, Bazant 2013; Santhanagopalan *et al* 2006; Zhang *et al* 2000). Whenever multiple stacks of cells are used, a poorly designed BMS will incur on overcharging individual cells due to wrong readings from the pack, whilst a well-designed BMS with tiered architecture will be able to predict such mismatches and take correction steps (Lawder *et al* 2014). Simplified coupled thermal electrochemical models applied to a single particle for stacks in parallel and series configurations have also been researched, as well as fully coupled battery stack models with limited number of cells (analyzed through use of reformulation techniques to improve the efficiency of simulation) (Guo, White 2011; Northrop *et al* 2011).

Redox-Flow detailed modeling, considered novel electrochemical storage approach with use of decoupled electrolyte, requires much different approach when compared to conventional Li-ion battery. The major difference is the inclusion of electrolyte flow within the system. The advanced models enable higher fidelity simulation to be used by BMSs. Analyticalbased models can be used to develop control-oriented dynamic unit cell model that employs mass and charge balances, providing accuracy similar to empirical models (Shah *et a*l 2011). Isothermal models and 1-D flow models are capable of adding detail to simulation of the system (Fedkiw, Watts 1984; Scamman *et al* 2009a; 2009b). Nevertheless, 2-D electrochemical flow (2-DE) model provides accuracy for many different BMS tasks (Shah et al 2011; You *et al* 2009; Al-Fetlawi *et a*l 2009; Al-Fetlawi *et al* 2010; Shah *et al* 2010). Beyond 2-D flows, 3-D coupled species/charge/fluid transport models studying pore scale felt electrodes may be employed to obtain a better understanding of the flow on the pore level (Qiu *et al* 2012a; Qiu *et al* 2012b). A known and used model of this categorization is the Lattice Boltzmann method which is used for the flow across the pore space. Also, for a broader and deeper understanding, kinetic Monte Carlo methods may be employed, which can be coupled with the continuum scale models in order to establish very accurate and powerful multiscale models for RFBs.

Reformulation of battery models' approach allows for more detailed physics-based models used when simulating battery cycling, while also allowing for simulations and optimizations to be run in real time, updating the model with changes in system dynamics. For energy storage at grid scale, optimization schemes can be used to produce charging patterns for microgrids or solar tied energy storage systems, among other possibilities (Lawder *et al* 2014).

On literature there are several examples of connecting energy storage devices to the network, which depend on application. For instance, when aimed at providing services such as peak shaving or frequency regulation, a conventional generator may be connected to the network, whereas frequency regulation can also be provided using DC/AC interfaces that connect storage units to the grid, which are capable of emulating behavior of a synchronous machine together with its frequency regulation loops. When concerning uninterruptible power, the connection may be done through standby, line-interactive or online, depending on switching speed, quality of service and rating (Ferreira *et al* 2013).

3. Regulatory solutions

Electrochemical energy storage systems have a wide spectrum of energy densities, ranging from 10s of W h/kg (VRB and Lead-acid) up to 1350 W h/kg (Zinc-air and Lithium-air – metal-air batteries) (Cho *et al* 2015). It is also important to note that none of the existing single battery technologies satisfy all of EES requirements, thus making the case for a more general policy and regulations' perspective (Kyriakopoulos, Arabatzis 2016). In the short-term, already developed battery technologies must be further improved in order to achieve capital costs lower than $ 250/kWh and a system efficiency greater than 75%. From policy making point-of-view, new battery technologies should be facilitated with advanced systems and electroactive materials to be developed with a capital cost lower than $150/kWh and efficiency greater than 80% (Cho *et al* 2015). Therefore, it is paramount that decrease on high costs and increase of electrochemical performances are of utmost importance to accomplish successful large-scale stationary BESS for use in renewable energy systems.

On another note, differentiating between single round trip efficiency and constant system's operational energy efficiency is also a key point on policy making roadmapping. The main problems encountered on this aspect refer to the use through several cycles within a given period, such as annual operation of the battery system (Kyriakopoulos, Arabatzis 2016). When considering Balance of Plant (BoP) loads on the efficiency calculation aimed at providing background for policy making agendas, it is important to understand the efficiency drops associated with BoP inclusion on the calculation and without its inclusion. In this sense, BoP is the cost associated with the facility and control systems which house the equipment, environmental controls, electrical connectors between power conversion systems and the electrical grid, as well as the cost related to heating, air conditioning, auxiliary power, utility system protection, control and safety systems. On the studied literature it was possible to establish a correlation between the BoP (pricing in terms of energy storage capacity or power) and the determining costs for each BESS, presented on **Table 2** below (Kyriakopoulos, Arabatzis 2016; Sundararagavan, Baker 2012).

Table 2
Determining cost data of BESS, highest and lowest priorities for total storage cost

BESS Tech	Energy cost ($/kWh)	Power Cost ($/kWh)	BoP cost ($/kW)	Operation/ Maintenance Costs ($/kW)	Efficiency (%)	Lifetime (years)	Highest Priority Factor	Lowest Priority Factor
Lead-acid	300	450	100	10	75	6	Lifetime	Power Cost
Ni-Cd	1197	600	100	15	65	20	Interest rate	Lifetime
Li-ion	1500	1500	100	10	93	15	Power Cost	Interest rate
NaS	534	3000	100	14	85	15	Power Cost	Lifetime
VRB	630	3200	100	28	80	10	Power Cost	Interest rate
ZnBr	400	2000	100	26	75	10	Interest rate	Lifetime

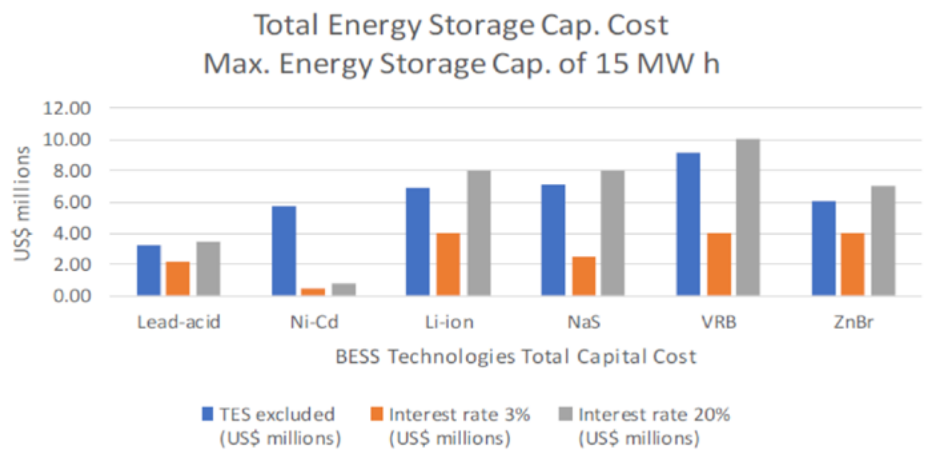
Source: Adapted from Kyriakopoulos, Arabatzis 2016 with data from Sundararagavan, Baker 2012.

As above stated, the key parameters associated with BESS technologies regarding policy making are power rating, energy rating, response time, energy density, power density operating temperature, self-discharge, round trip efficiency, lifetime, cycles, power and energy costs. On the European scenario, where BESS (and key EES technologies) are seen as a priority area in the future energy landscape, the determining parameters for BESS development are the unambiguous future need for energy storage capacity on EU, the penetration and availability of renewable energy, the capacity of electricity transmission (or communication fluxes), the penetration of demand side management, and the alternative back-up power availability (where BESS play a major role) (González *et al* 2015).

An interesting thermal energy storage (TES) model was proposed and applied to BESS technologies (as well as other EES technologies), with the aid of financial cost theory. The goal of the model was to compare different interest rates (0% vs 3% vs

20%) which would represent different perspective of the various decision makers involved. The model has a maximum need for energy storage capacity set at 15 MWh and need for power of 10 MW. Results are shown on **Figure 2** below (Sundararagavan, Baker 2012).

Figure 2
Thermal Energy Storage for total energy storage capital costs with or without interest rates



Source: Adapted from Sundararagavan, Baker 2012

Data from **Table 2** suggests that Power Cost is the highest priority factor while Lifetime is the lowest factor when considering the main impacts on total storage costs of BESS. However, as seen on **Figure 2**, VRB increases the most when interest rates are high, as well as NaS, Liion and ZnBr, implying that, although interest rates are not considered an overall major priority factor, they certainly play a significant role on the determination of BESS total capital cost.

According to IEC (2017), various IEC standards are already in place when assessing mature BESS technologies such as NiCd, NiMH and Li-ion. However, few exist and only applied for special topics coverage when concerning new BESS technologies such as flow batteries. Also, there is a standard planned for rechargeable batteries based of any chemistry, despite not being implemented yet. The IEC standardization topics include: terminology; basic characteristics of BESS components and systems (definitions, measuring methods and technical evaluation – capacity, power, discharge time, lifetime, standard BESS unit sizes); communication between components (protocols, security); interconnection requirements (power quality, voltage tolerances, frequency, synchronization, metering); safety (electrical, mechanical); testing; and guides for implementation (IEC 2017).

Moreover, IEC (2017) has provided a set of recommendations for policy-makers and regulators which broadly encompasses the BESS and overall EES. These recommendations are as follows:

1) Public support for development of conventional storage – policy makers should consider further development of conventional storage such as pumped hydroelectricity;

2) Long-term storage, on the order of months – long-term storage capacity is key to handle multi-TWh range of demand in the future.

3) Cooperation between energy sectors; coherent regulations – cooperation is key to achieving better regulations regarding electricity and gas, including infrastructure for long-term storage;

4) Incentives for development and operation of storage – Long-term storage of surplus energy from renewables can be more expensive, therefore requiring private actors to participate with heavy investments on this sector. Advantages of acquiring and operating renewable energy long-term storage must be backed by regulations which include financial incentives.

5) Public policy for and investment in storage research – governments and public authorities with roles on research to adjust their policies and investments in order to attend the desired targets for storage development.

6) Potential barriers to the introduction of microgrids – Regulatory regimes currently hinder the introduction or operation of microgrids or their storage components.

7) Regulations for the safety of new storage technologies – there is the need for international consensus standards for the safety of new storage technologies, thus requiring regulators to anticipate the requirement to guarantee this safety.

8) Environmental regulations for new storage technologies – regulators should help ensure that standards are in place to allow an internationally agreed technical basis for any new regulations on environmental impacts, avoiding unnecessary differences among countries and regions.

Furthermore, IEC (2017) also provides recommendations for research institutions and companies carrying out R&D, as well as recommendations for internal use (IEC specific) and its committees. This last set of recommendations include: cooperation needed for hydrogen and SNG standards; architecture and structure of EES systems; users' guide on planning and installing storage; interface, control and data element standards, standards for systems to relieve transmission congestion, standards for unit size and other factors affecting costs; safety of new storage technologies; and compatibility of EES with the environment (IEC 2017).

4. Conclusions

As seen on section 3, despite not being considered an overall major priority factor, interest rates certainly play a significant role on the determination of BESS total capital cost and of regulatory needs/implications for BESS. Moreover, the main regulations nowadays are still heterogenous in nature, which can be seen by the IEC (2017) recommendations. There is an increasing fear that regulations and policy-making decisions are not taking into account the development of new BESS and EES technologies. More than that, regulations are currently not taking into account the many studies both from economical and technical points-of-view, and lack standardization aimed at providing general safety either for companies to compete in equal terms or for environmental and social impacts of applying and deploying such technologies.

All-in-all, policy-makers and regulators should take into account the complex characteristics involving BESS and EES when considering approaches to new regulations and policy recommendations. Also, an effort to create a standardization for BESS as a hole is needed, which could be achieved by multi-level agent collaboration and the use of expert elicitation/research analysis. The literature on this topic is widespread and projects funded by government and private actors may boost the ever needed research and analysis of empirical implications for the new and matured technologies.

Future works for this research are to carry out better and more detailed specifications of BESS characteristics, especially focusing on communication fluxes and service types available, in order to better understand how policy-making and regulations can be achieved that better ensue the complex theme of BESS and EES in general. Moreover, a revisit and review of regulations and standards in place for each type of BESS, as well as an analysis of policy-making methodologies will come in hand in order to better comprise a research methodology that established policy-making methods aimed at BESS and EES.

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The Cycle of Recycling and Sustainable Development. Evidence from the OECD Countries

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Abstract

The aim of this study is to analyse the circular linkages between recycling and economic development, where renewable energy plays an additional role in this process. We use a two-equation model, which describes a cumulative causation process with feedback effects, where recycling (among other growth inducing factors) is assumed to be important for sustainable economic development (given by the Human Development Index) and vice-versa. The system of simultaneous equations is estimated by *3sls*, both in a static form and introducing dynamics into the model, for a panel of 28 OECD countries over the period 2004-2015. The empirical evidence suggests a strong relationship between the economic development level and the recycling rate with feedback effects, supporting the idea of a circular cumulative causation process driven mostly by higher human capital skills and, to a lesser extent, by innovation. Atmospheric pollution also stimulates the recycling process.

KEYWORDS
Recycling, economic development, simultaneous equation system, panel data

1. Introduction

Recycling plays an important role in modern societies from the point of view of sustainable economic development and environmental protection. Recycling the already used materials is one of the pillars of the modern economy to preserve the environment and increase the quality of standards of living worldwide (EU Commission, 2018; Grosse, 2010). However, to the best of our knowledge, there are almost no empirical studies that measure the impact of the recycling rates on economic development. The recycling determinants have also not been modelled in the empirical literature (Kalmykova, et al., 2018; Geissdoerfer, et al., 2017). The aim of this paper is to fill this gap in the literature, employing a model that describes the circular linkages between recycling and economic development (given by the Human Development Index, HDI henceforth).

Two main relations are used to describe such a process: the first, is an economic relationship representing the sustainable development levels which, along with the standard determinants like physical capital, human capital and innovation, includes the recycling rate and the renewable energy share as important factors for improving the countries' standards of living[1]; the second relation explains the main determinants of the recycling rate, which is mostly driven by human capital skills and innovation, depending also on the level of economic development and atmospheric pollution. The rationale behind these relations is that economically advanced countries realize that recycling is required for generating sustainable development. To this end, countries allocate resources to develop methods that reutilize the production means previously used in consumption goods, with the aim of reducing environmental degradation. Recycling is a new productive area with high technological content and labour skills, which will generate higher economic growth and development without harming the environment. A political wisdom is therefore needed to realize that recycling is among the key pillars for a sustainable economic development, strengthening the growth process, promoting innovation and higher labour skills through new production techniques.

In this paper, we employ a different approach to tackle the shortcomings in the literature: (i) we assume recycling as an important factor for higher economic development and environment protection; (ii) we implement a system of simultaneous equations which describes the important feedback linkages between economic development and recycling rate driven by innovation and higher labour skills; (iii) the important linkages between these variables are driven by the reciprocal correlation between the core variables of the system, which generates expanding and sustainable tendencies without environmental deterioration.

The outline of the paper is the following: besides the introduction, section 2 develops the structural model with the main behavioural relations that describe the

1 For more details on the impacts of renewable energies on the development level, see Soukiazis et al. (2017).

circular process between recycling and economic development. Section 3 describes the variables and data used in the empirical approach, as well as statistical tendencies. Section 4 discusses the results obtained from the *3sls* estimation of the model. The final section concludes with policy recommendations.

2. The structural model

The structural model employed in this paper consists of two main behavioural equations, which explain the important linkages between economic development and recycling rate. The first equation determines the factors that explain the development level, given by the Human Development Index (HDI), as follows:

$$HDI_{it} = \alpha_i + \alpha_1 GK_{it} + \alpha_2 HK_{it} + \alpha_3 R\&D_{it} + \alpha_4 RCR_{it} + \alpha_5 RNE_{it} + \alpha_6 POP_{it} + \varepsilon_{1,it}$$

Eq. (1)

As in the conventional growth approach, capital (GK) is included as a factor to explain the country's development path. This variable measures the growth of gross fixed capital formation which is expected to positively affect the development level (α_1>0). Additionally, and in line with the endogenous growth theory (e.g. Lucas, 1988; Barro, 2001), human capital (HK) and innovation (R&D) are important determinants, influencing positively economic growth and development, expecting therefore α_2, α_3>0. Furthermore, it is of particular interest to measure the impact of recycling rate (RCR) and renewable energy consumption (RNE) on the development level, expecting a positive and statistically significant effect in both cases (α_4, α_5>0). The growth of population (POP) is also used in the economic development function as a scale factor to check its significance. The constant term (α_i) captures country specific effects, which are invariant in time, such as the country size, natural resources, geographical location, and institutions, among others. All variables represent shares (percentages) except the capital and population which are in growth rates for the sake of normalization.

The second equation of the system explains the determinants of recycling rate, as follows:

$$RCR_{it} = \beta_i + \beta_1 HDI_{it} + \beta_2 R\&D_{it} + \beta_3 HK_{it} + \beta_4 POP_{it} + \beta_5 \ln CO2_{it} + \varepsilon_{2,it}$$

Eq. (2)

Equation (2) considers that the recycling rate is determined by the development level (HDI), stressing that advanced countries allocate more resources to the recycling process with the aim to reduce waste, reutilize production sources and prevent environmental degradation, expecting therefore β_1>0. Spending on research and development (R&D) is a required condition for developing new production processes linked to recycling resources and new production areas environment-friendly and, at the same time, reducing costs due to reutilization of previously used production sources. The relationship between recycling and R&D spending is thus expected to be positive (β_2>0). In addition to innovation, skilled labour is necessary to promote the recycling process, expecting that higher levels of human capital are required to be involved in these new productive areas. Furthermore, populations with higher levels of human capital better understand the importance of recycling to preserve the environment, expecting therefore β_3>0. Population growth (POP) is also used in this equation as a scale factor. Finally, CO2 emissions per capita are used to check its impact on the recycling rate. It is expected that the higher the atmospheric pollution, the higher the use of the recycling process to reduce environmental degradation and, therefore, β_5>0. The intercept β_i varies across countries capturing differences which are invariant in time.

Combining equations (1) and (2) a circular approach is established between economic development (HDI) and recycling rate (RCR) with feedback effects that will generate a production process with cumulative causation properties. Human capital skills and innovation are at the heart of this circular process. From equation (2), a moment will come that policy makers will realize that sustainable development will be reached through new growth policies environment friendly, and that recycling is one of the ways to achieve this goal. Innovation and skilled labour are necessary conditions to promote the recycling productive areas. These new sectors of production, in turn, promote higher economic growth and sustainable development (through Eq.1).

The above two equations will be estimated by *3sls*, the most efficient estimation approach that controls for the endogeneity of regressors and takes into consideration the cross-equation error correlation.

3. Variables and data description

Table 1 reports the variables used in the empirical analysis, and elementary descriptive statistics. The HDI index (from 0 to 1) is multiplied by 100 for the sake of data normalization. The mean value is 85.6, with 77.1 the minimum value (Romania) and 91.3 the maximum (Netherlands). RCR is the recycling rate of municipal waste with a mean value of 28.4%, varying between 7% and 63%, the lowest rate found in Malta and the highest in Germany. RNE represents the share of renewable energy in gross final energy consumption with a mean value of 15.5%, ranging from 0.1% (Malta) to 53.8% (Sweden). We use two proxies for human capital: the first HK1 is measured by the average years of schooling, representing the basic human capital skills; the second HK2 is the percentage of population with college degree, representing high human capital skills. GK indicates the growth of gross fixed capital formation, R&D is the spending on innovation activities as percentage of GDP, POP is the growth of population, and CO2 stands for the greenhouse gas emissions in the atmosphere measured in tons per capita. R&D is the variable where differences between countries are larger, with a mean value of 1.5%, the lower value found in Romania (0.3%) and the highest in Finland (3.8%). Regarding the remaining variables, differences across countries are not substantial.

Table 1
Descriptive statistics of variables, 2004 - 2015

Variable		Mean	Std. Dev.	Min	Max	Observations
HDI	overall	85.58065	4.108007	74.5	92.6	N = 336
Human Development Index	between		3.961486	77.13333	91.25833	n = 28
	within		1.302939	81.54732	88.68065	T = 12
RCR	overall	28.37848	17.25247	0.4	66.7	N = 330
Recycling Rate of municipal waste	between		16.57149	7.05	63.21818	n = 28
	within		5.918405	14.03682	54.17848	T = 12
RNE	overall	15.50774	11.19575	0.1	53.8	N = 336
Renewable energy share	between		10.9709	1.666667	47.09167	n = 28
	within		2.989375	7.116072	24.5994	T = 12
HK1	overall	11.19792	1.222657	7	13.3	N = 336
Human Capital (average years of schooling)	between		1.168417	7.841667	12.83333	n = 28
	within		0.417756	10.12292	12.82292	T = 12
HK2	overall	22.8	7.336895	8.7	39.6	N = 336
Human Capital (percentage of tertiary education)	between		6.775958	11.70833	31.96667	n = 28
	within		3.069859	14.44167	33.54166	T = 12
GK	overall	0.013863	0.110062	-0.49176	0.460342	N = 336
Growth of gross fixed capital formation	between		0.028594	-0.07072	0.060818	n = 28
	within		0.106408	-0.51682	0.421922	T = 12
R&D	overall	1.480506	0.876414	0.34	3.75	N = 336
Research and Development Spending as percentage of GDP	between		0.867114	0.428333	3.398333	n = 28
	within		0.202245	0.889673	2.349673	T = 12
POP	overall	0.0024554	0.008492	-0.024992	0.030071	N = 336
Population growth	between		0.007329	-0.013486	0.019194	n = 28
	within		0.004491	-0.022355	0.020055	T = 12
lnCO2	overall	2.283861	0.345687	1.609438	3.424263	N = 336
Greenhouse gas emissions (tons per capita)	between		0.337373	1.719731	3.257099	n = 28
	within		0.097039	1.976391	2.488182	T = 12

4. Empirical findings

The system of simultaneous equations is estimated by *3sls* approach, both in a static form and introducing dynamics into the model, for a panel of 28 OECD countries over the period 2004-2015, where consistent data is available[2]. Table 2 reports the estimation results, with the HDI equation in the first half and the recycling rate equation in the second half of the table. Model (1) is the static estimation and models (2) to (5) represent different versions of the dynamic specification assuming two-lag order for the dependent variables. Overall, the results are satisfactory in terms of the goodness of fit and the statistical significance of coefficients. Additionally, the Hausman test indicates that the *3sls* estimation approach is as much as consistent with the *2sls* approach, but we give preference to the *3sls* as being more efficient. The static model indicates error autocorrelation problems which are solved by estimating the dynamic versions with lagged dependent variables of order two.

2 Since data on renewable energy starts only at 2004, we are restricted to consider a shorter period. For RCR and HDI, we used the values of 2002 and 2003 in order not to lose observations.

Concerning the first equation, evidence shows that both the recycling rate and renewable energy have a positive and statistically significant impact on the countries' development level. This result suggests that allocating resources to new productive areas environment friendly is the right policy to improve the standards of living without environmental distortions. Specifically, if we consider Model (5), where all variables are statistically significant, the results show that a one percentage point increase in the recycling rate (everything else constant) is responsible for 0.00935 point increase in the development level in the short run, and 0.033 point increase in the long-run perspective. The renewable energy variable is statistically significant at the highest 1% level in all dynamic specifications, revealing that in the short run a one percentage point increase in this variable (everything else constant) generates a 0.0336 point increase in the development level, while the long run effect is even higher suggesting a 0.1195 point increase in HDI. The highest marginal impact on the development level is attributed to the growth of capital stock (GK), followed by the contribution of human capital through the basic levels of education (HK1) and the spending on innovation (R&D), as expected. Population growth and higher human capital skills through the tertiary education are not relevant factors in explaining the levels of sustainable development. Regarding the second equation of the system, which analyses the determinants of the recycling rate of waste, evidence is also encouraging. The development level given by the HDI is always statistically significant, both in the static and dynamic specifications. Considering the results of Model (5), where all variables are statistically relevant, we predict that a one-point increase in the development level will generate 0.603 percentage point increase in the recycling rate in the short run and 3.29 percentage points increase in the long run.

Combining the evidence of the two equations of the system, a strong reciprocal relation is established between the development levels and the recycling rate with feedback effects, generating a cumulative causation process with expanding tendencies that benefits sustainable economic development. Additionally, it is shown that higher atmospheric pollution through the CO2 emissions is a stimulus for developing recycling productive processes. Results reveal that the short run impact on the recycling rate is 0.06 percentage point increase given a 1% increase in the CO2 emissions per capita, while the long run impact is even higher and equivalent to 0.332 point increase. Although human capital at higher level is important to promote the recycling process, the spending on R&D reveals to be unimportant. Higher levels of skilled labour are needed to develop recycling productive processes. Furthermore, a more educated population better understands the need to recycling for the sake of the environment protection. Population growth again is not important for explaining the recycling rate for the OECD countries considered in this study.

Table 2
Regression results using 3sls estimation approach, 28 OECD countries, 2004-2015

Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Equation (1) HDI					
RCR	0.231**	0.00737	0.00809*	0.00808*	0.00935**
	(2.52)	(1.52)	(1.81)	(1.65)	(2.07)
GK	-0.0295	0.916***	0.930***	0.866***	0.878***
	(-0.32)	(6.07)	(6.13)	(5.64)	(5.72)
HK1	1.358***	0.456***	0.445***	0.440***	0.431***
	(6.72)	(7.52)	(7.54)	(7.17)	(7.29)
HK2	-0.107	0.00550		0.00798	
	(-1.19)	(0.57)		(0.81)	
R&D	0.330	0.259***	0.246**	0.260***	0.242**
	(0.74)	(2.61)	(2.52)	(2.59)	(2.50)
POP	11.13	3.457		2.866	
	(0.85)	(0.98)		(0.81)	
RNE	0.0230	0.0309***	0.0317***	0.0317***	0.0336***
	(0.46)	(3.20)	(3.38)	(3.25)	(3.59)
HDI-1		0.710***	0.720***	0.788***	0.799***
		(27.39)	(28.92)	(15.78)	(16.32)
HDI-2				-0.0799*	-0.0801*
				(-1.84)	(-1.88)
cons	66.44***	19.34***	18.78***	19.58***	18.96***
	(26.49)	(10.22)	(10.24)	(10.32)	(10.38)
R2 overall	0.9324	0.9951	0.9950	0.9950	0.9951
RMSE	1.05278	0.2832	0.2840	0.2832	0.2831
Chi2	4825.16 [0.000]	65989.01 [0.000]	65557.28 [0.000]	64775.02 [0.000]	65989.70 [0.000]
Hausman test	0.0147 [1.000]	0.5337 [1.000]	1.0454 [1.000]	0.5520 [1.000]	1.1185 [1.000]
AR test	43.815 [0.000]				
Equation (2) RCR					
HDI	3.722***	0.944***	0.608***	0.948***	0.603***
	(3.76)	(2.95)	(2.80)	(2.96)	(2.79)
HK1	-5.055***	-0.992		-1.019	
	(-2.99)	(-1.39)		(-1.43)	
HK2	0.537**	0.184*	0.211**	0.177*	0.218**
	(2.57)	(1.85)	(2.18)	(1.75)	(2.26)
R&D	-0.900	-0.324		-0.275	
	(-0.45)	(-0.33)		(-0.27)	

Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
POP	-45.70 (-0.80)	-26.94 (-0.76)		-25.32 (-0.71)	
lnCO2	1.577 (0.41)	5.385** (2.28)	5.952*** (2.70)	5.678** (2.37)	6.075*** (2.76)
RCR-1		0.812*** (20.65)	0.818*** (21.19)	0.778*** (13.34)	0.817*** (21.17)
RCR-2				0.0426 (0.70)	
cons	-251.0*** (-3.95)	-80.86*** (-3.62)	-66.63*** (-3.40)	-81.72*** (-3.66)	-66.64*** (-3.41)
R2 overall	0.9330	0.9734	0.9734	0.9730	0.9734
RMSE	4.4579	2.7948	2.793	2.7989	2.7936
Chi2	4627.55 [0.000]	11992.68 [0.000]	12000.87 [0.000]	11699.53 [0.000]	12001.29 [0.000]
Hausman test	0.000 [0.000]	3.2183 [1.000]	3.0895 [1.000]	3.5625 [1.000]	3.6153 [1.000]
AR test	75.914 [0.000]				
N	330	327	327	324	327

Endogenous variables: HDI and RCR.

Exogenous variables: GK, HK1, HK2, R&D, POP, RNE, lnCO2, the lagged variables and all dummies used in the regressions.

Notes: numbers in parentheses are z-ratios and numbers in square brackets are p-values P>|z|. Chi2 is the statistic for overall significance of coefficients. The coefficients of the specific-country dummy variables are not reported due to space limitations.

The null hypothesis in the Hausman test assumes that *2sls* and *3sls* are both consistent but *3sls* is more efficient. The AR test uses the Wooldridge statistic for idiosyncratic error autocorrelation in panel data (see Wooldridge, 2002; Drukker, 2003).

***,**,* indicate that coefficients are statistically significant at the 1%, 5% and 10% significance level, respectively.

5. Conclusions

This paper deals with the important relationship between recycling rates and economic development using a set of 28 OECD countries for the period 2004-2015. The study aims to fill the gap of the literature in this field that has not analyzed yet this relationship empirically. A simultaneous system of two equations is estimated by using the *3sls* approach to detect the strong linkages between the development levels and recycling, explained by a circular cumulative causation process. The regression results confirm robustly this relationship driven by human capital skills and, to a less extend, by innovation. Atmospheric pollution also contributes to better understand the need for adopting recycling policies.

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Management of Solid Urban Waste in Brazil: A Brief Overview

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Abstract

Every day seems to consolidate the view that the current economic model strongly stimulates the consumption of products and disposable goods despite the real reflection of the consumer's need. The reflection of this consumerist logic has a direct impact on the increase of generation rates and waste discards, forcing countries to rethink their models of solid urban waste management. It is the result of the development of the doctoral thesis project and iff work aims to contribute to the discussion on the still predominant urban solid waste management model in Brazil from the submission of general data on the current situation regarding the generation, collection and final disposal. The research is characterized by being qualitative, exploratory and descriptive and the systematization of the information discussed here was made possible by the use of secondary sources of research. The results presented here indicate little adherence by Brazil to the global prerogatives based on circular waste management, especially because it still presents an unpriced scenario, in more secular stages of the waste management process, such as the collection and the final disposal.

KEYWORDS
Urban Solid Waste, Urban Solid Waste Management, Final Disposal.

1. Introduction

Each day, it seems to consolidate the view that the current economic model strongly stimulates the consumption of disposable products and goods, a fact perceived by the speed with which world-wide new products are inserted in the market accompanied by the efficiency of the marketing mechanisms responsible for awakening in the consumer the desire for new acquisitions and consequently future discards of waste. Consumption stimulated continuously, in spite of the real reflection of the consumer's need, directly impacts on the increase of the rates of solid urban waste generation, being configured in a scenario that is precisely against the global objectives drawn by forums of environmental protection discussions.

Historically the individual is considered a waste generator and this condition will always be inherent to it either to a greater or lesser degree. Therefore, the problem of increasing generation of waste can not be exclusively attributed to the current economic model, since it is not yet possible to conceive the survival of the individual without consuming at least the goods and products to meet his basic needs: feeding, dressing, sheltering. Waste generation in as signals (Alfaia, Costa and Fields, 2017) will always exist, however good decisions about what constitutes waste (avoiding waste), minimizing the generated amount and the implementation of appropriate management practices by of the authorities, are essential to avoid irreversible ecological problems. There is in fact a paradox where the losses of the increase of the generation of residues are, in one form or another known, however restrictive forces such as the cultural ties and the habits of the individual prevent the change of behavior demanded by the environmental conscience, added the low efficiency in the construction and / or implementation of public policies capable of neutralizing the effects of generation.

A city can contribute to sustainable development by conducting individual and collective activities in the various environmental sectors, especially in the waste sector. It is suggested in this sector to take into account the development of activities throughout its cycle: generation, storage, collection, sorting, transportation, treatment and final disposal. Making waste management even more relevant is a challenge for municipalities in the face of population growth. (CONKE, 2018).

Since the 1970s, the discussion related to environmental protection issues has gained a global profile especially when it comes to the generation of urban waste. In 1970, when waste generation came to be seen as a public health problem, waste became an environmental issue at the international level. Having been the subject addressed in major world meetings, such as Stockholm conferences - 1972, ECO 92, in Rio de Janeiro and at the Tibilisi-1997 Conference. (God, Battistelle and Silva, 2015 apud Velloso, 2008 and Wilson, 2007).

Global discussions on this issue are important in setting targets both for the adequacy of the waste management model applied in the countries and for those related to reducing the environmental impacts imposed by the generation of these wastes.

(Fuss, Barros and Poganietz, 2018), stresses that although the problems between municipalities in countries are similar, the models to be adopted must take into account different economic and political conditions.

In a waste management based on linear vision, the solution for the growing generation of waste would be precisely in the historical practice tied to the final disposal. In this context the generation would apparently be solved, but new problems would arise, for example, the infinite need for physical spaces for new dispositions and the environmental adequacy of these spaces to neutralize the impacts of their byproducts. This management model applied by municipalities traditionally especially in developing countries, like Brazil, is now questioned globally, as well as a simplified view of municipal managers on this issue.

In this sense, this work intends to contribute to the discussion about the model of solid urban waste management still predominant in Brazil through the demonstration of general data that reflect the current scenario of the country in terms of waste management.

2. Brazil and the evolution of normative instruments in waste management

With the GDP of $1,772,589 (IMF, 2015) Brazil is the ninth largest economy in the world, it is the fifth largest in the world in territorial extension 8,516,000 km^2 and the sixth largest in population with 207,660,929 million inhabitants (IBGE, 2017). With 26 federal units and one Federal District, the country has 5570 municipalities in 5 major regions, North (17,936,201 hab), Northeast (57,254,159 inhabitants), Central West (15,875,907 inhabitants) Southeast (86,949,714 inhabitants) and South (29,644.94 inhabitants). The magnitude of the country, both economically and from the population point of view, makes it an important target for the emergence of research in several areas, especially those related to the environmental context.

In a ranking of 163 countries, Brazil ranks 62nd in environmental performance, according to a study by the Universities of Yale and Columbia (Marchi, 2011). For this country, the enactment of the Federal Constitution in 1988 (CF / 1988) represented a milestone in environmental protection, and is covered by Chapter VI, Title VIII. Despite this gain, the country lacked more precise instruments to treat the various sectors related to the environment, especially the solid waste sector. It was necessary to establish clearer guidelines that would better guide public managers in the establishment of public policies aimed at this area. It is only after almost 20 years since the enactment of CF / 1988 that guidelines for some environmental sectors have been consolidated into a more specific legal instrument, namely Law 11.445 / 2007, which presented the basis of the National Policy on Basic Sanitation (PNSB), contemplating the waste sector as well as other related sectors.

The management activity of municipal solid waste gains greater visibility from the PNSB, however the presence of other sectors that instrument, such as water supply, management will rainwater, collection and treatment of sewage, pest control, among others, added to the complexity of the waste sector pointed to the need for a regulation that deal exclusively with issues related to the management of solid urban waste in the country. Three years after the approval of the PNSB is that more dense and specific guidelines on waste management were systematized in Law 12,305 / 2010, then the National Solid Waste Policy of Brazil emerges.

The establishment of regulatory instruments for waste management is considered to be late compared to other countries or blocks, such as the European Union (Juras, 2012), which, with its Directive adopted in 1975, influenced the origin of more specific policies or instruments aimed at the sustainable management of solid waste from its member countries in the following years: (France / 1957, Germany / 1986, Spain / 1998, Portugal / 1997). In this context, the USA has also approved its law in 1965 and Japan in 1970. This Brazilian temporal deficit in terms of the vigor of the legislation offers numerous challenges for the municipalities with regard to the adequacy of their management models. waste.

The deficit faced by Brazil in the global context regarding the creation of normative instruments and their implementation is a matter of concern and should be the object of study, especially since there is a gap between the vigor of legislation and its implementation in municipalities. (Maiello, Brito and Valle, 2018) draws attention that in the field of Brazilian public policy, there is a distance, both physically and structurally, between the government's policy, formulated by national standards and guidelines, and what is implemented in practice. Almost a decade ago the approval of the PNRS, the municipalities have very little or almost nothing to present of public policies that contemplate effective actions aligned to the PNRS, this is possible in the data presented by ABRELPE (2016) that identifies weaknesses in the management stages from the collection of waste generated to the final disposal stage, indicating that the country still faces difficulties in the most basic stages of the management process.

Commonly three stages are easily understood in the process of waste management or waste treatment, being: A) generation; B) collection and C) final disposal. What has sometimes occurred in most Brazilian municipalities is a management concept linked to a "linear model", which invests too many resources in stages B and C, still prevailing myopia in the emergency need to establish actions and strategies directed to the stage A. It is necessary to think of a logic of management inverse to that currently practiced by the municipalities and that is able to seek the continuous articulation of all the actors of the society (public managers, private initiative, schools, universities, research centers, associations, etc.), in order to discuss and define strategies for the proper management of waste, in addition to understanding the threats and opportunities that RSU'S offer to the environment and society . (Costa, 2015). Another point about the linear model that merits further reflection is the explicit absence in its stages of the possibilities of returning the waste to the productive chain, opening perspectives for the insertion of new management stages that anticipate the recovery of the waste, its return to the productive chain from the actions of reuse and recycling and consequently the reduction of the volume of waste to be directed to the final disposal systems.

The provision of solid waste collection, treatment and final disposal services is more complex than it appears to be and its dimensions in face of social, territorial, technical and environmental repercussions should influence the creation of public policies based on strategic planning aimed at solving related issues with the inefficiency of waste management. (Mota and Silva, 2016).

The pressures for adequacy in management models and yet reduction of environmental impacts react to both developed and developing countries; for the latter the challenges may be greater because of the intellectual, technological and financial gaps compared to the developed countries.

3. Methodology

The research is characterized by being qualitative, exploratory and descriptive and the systematization of the information discussed here was made possible by the use of secondary sources of research. The results presented here indicate little adherence by Brazil to the global prerogatives based on circular waste management, especially since it still presents a poorly disposed final disposal scenario in the most secular stage of the waste management process.

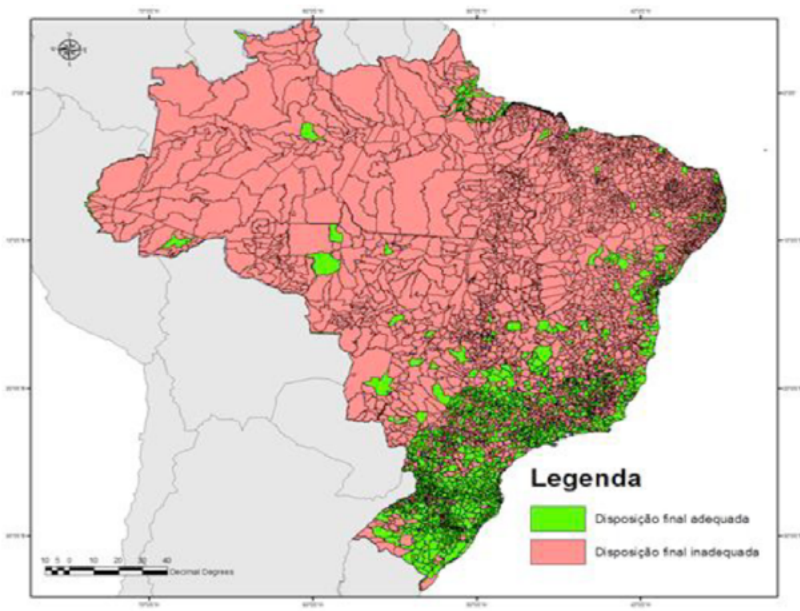
4. Results and discussions

In the year 2016, Brazil generated 78.3 million tons of waste, of which 71.3 million tons were collected. The collection, a basic step in the waste management process, still points to deficiencies in the country. 9% of the amount generated in the year 2016, or the equivalent to 7 million tons were not properly collected. This percentage may be relatively low when compared to 91% coverage, however the collection in its entirety is one of the most basic requirements of the PNRS, so the fragility in this basic stage points to an inefficient management reality since the initial process representing signs of fragility in more complex steps, such as that concerning the final destination of the waste or its reuse. Another worrying statistic in Brazil is worsening in performance related to final disposal stage, compared with the year 2015, whose percentage of waste properly designed was 58.4%, in 2016 this percent u al extended to 58, 7% (ABRELPE, 2016). Of the 5570 municipalities in the country, 3331 municipalities still allocate waste generated to inadequate sites, or the percentage referring to 41% (29.7 t million), contrary to the final deadline established by the

PNRS, namely August / 2014, for the adequacy of final disposition of all municipalities in the country.

According to the ABRELPE survey (2016), solid waste generation in Brazil grew by more than 26% in the last decade (2005-2015), 76.5 million Brazilians (more than 1/3 of the population) still suffer from the destination inadequate waste disposal in a country where 30 million tons have been deposited in dumps or controlled landfills, which from the technical point of view present the same problems as dumps, since solid waste is deposited indiscriminately in the soil, without any kind of care or treatment, see fig 01.

Fig. 1
Final Disposal of Waste in Brazil



Source: Waste Group of the UFPE (2014)

The fig. 01 demonstrates the widespread predominance of inadequate waste disposal in Brazil. The final destination systems used by the 5570 Brazilian municipalities are distributed as follows: 40.19% (landfills - adequate disposal system), 31.81% and 27.98% (controlled landfills and dumps respectively, both inadequate disposal sites.

If we analyze the questions related to Selective Collection, another objective indicated by the PNRS, the data are also of concern, firstly because there were about 1692 (30.37%) of municipalities without any type of differentiated delivery initiative, according to that, of the 3878 (69.63%) municipalities that do, do not cover the total of the municipal area, representing, in many cases, isolated and disarticulated actions of the waste management process. (ABRELPE, 2016). The data reveal the long path that Brazil still has to face in the face of the global situation and this represents for the municipal managers several challenges in the search for the alignment to the PNRS precepts that goes from the diagnosis of the current situation with regard to the management system of residues until the identification of the gaps and actions necessary for alignment to the PNRS, especially in regions where this delay is more latent. The vast territorial extension of the country, together with its multiculturalism, suggests more specific studies in the area of waste and especially in the localities with expressive population indices whose data still show a performance below the basic precepts of the PNRS.

The Northeast is the second most populous region in the country, after the Southeast Region is the second largest generator of waste in the country. It is the largest region in number of States, being the total of 09, namely Bahia, Sergipe, Alagoas, Pernambuco, Paraíba, Rio Grande do Norte, Piauí, Ceará and Maranhão. (IBGE, 2017). The northeast represents the region with the largest number of dumps in the country, 836 of the total of 1559, clearly demonstrating the non-compliance with the legislation that has prohibited since August 2014 the use of these spaces for the final disposal of waste. The generation, collection and final disposal in the year 2016 present alarming data such as: of the 55.056 million tons generated per day the percentage of 21% did not receive coverage of the collection. Of the amount collected 64.4% or the equivalent of 27,906t / day were allocated to inadequate final disposal sites, namely landfills and controlled landfills. Regarding the selective collection, more than 50% of the municipalities do not have any initiative of differentiated delivery, either in an articulated way or in an isolated way. (ABRELPE, 2016). The data from the Northeast region show a significant misalignment with the guidelines of the PNRS, and its municipalities are therefore relevant targets for future studies in the field of waste management both to contribute and deepen the present discussion and to provide more subsidies for the thesis project. doctorate of the author.

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On the Impacts of Removing Coal from the Portuguese Power System

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Abstract

As in many countries, the decarbonization of the Portuguese power system is undergoing, under the commitment of achieving a 60% renewable electricity share by 2020. The phase-out of the two remaining coalfired power plants has been widely discussed, as they still contribute to about one fifth of the total generation. This work assesses the impact of removing this coal-fired power generation from the Portuguese power system, analyzing the results of its replacement by other supply sources. We show that the deployment of about 8 GW of solar-photovoltaics coupled with a modest increase on the hydro pump capacity to store energy is a credible option: besides the socio-economic benefits that intrinsically brings, such as improving the balance of payments with the exterior, it results in an electricity renewable share of 76% and a decrease in CO2 emissions of 56%.

KEYWORDS
Coal phase-out; photovoltaics; energy storage.

1. Introduction

The awareness about climate change has been the leading force for the adoption of decarbonizing policies worldwide. The shifting of power system towards renewables, which still contribute 25% to CO_2 emissions (United States Environmental Protection Agency (EPA), 2014), has largely been the focus of such policies. Coalfired generation is among the most carbon-intensive and pollutant supply sources (Moazzem, Rasul, & Khan, 2012), but its cost competitiveness and major role on a reliable baseload generation has been hampering its substitution by non-dispatchable renewables (Dolter & Rivers, 2018).

Having presently already an high share of renewable electricity – varying between 40 and 56% (National Energy Networks (REN), 2017), depending if the year is less or more wet, as the system largely relies on hydro –, the Portuguese power system is an interesting case to study coalphase out, since it could leverage the fulfilment of the national goal of achieving 60% of renewable electricity generation by 2020 (Presidência do Conselho de ministros, 2013), even if after this date. Having two coal-fired power plants on operation (Sines and Pego, both accounting for 1.7 GW), responsible for 26% of the energy generation in 2017 (National Energy Networks (REN), 2017), there is potential to act here to keep decarbonizing the power system. As Portugal continues to be engaged in decarbonizing the economy (see Roadmap for Carbon Neutrality 2050 (GET2C, FCT, AGROGES, Lasting Values, & J. Walter Thompson, 2018)), the coal phase-out could be one of the first steps to become closer to such goal. Moreover, the decommissioning of those power plants has gained more interest from the Portuguese media, academia, environmental groups and industry, due to the recent revisions of their exploration licenses (National Board of Quercus, 2017) and the announcement by the Portuguese Government, yet non official, of the coal phase-out to "before 2030" (Gomes, 2017).

This work studies the impacts on the power system operation and CO_2 emissions of replacing the Portuguese coal-fired power plants by photovoltaics coupled with hydro pump to store energy in excess. It is structured this way: Section 2 presents a summary of the Portuguese power system; Section 3 presents the methods; Section 4 describes a possible vision for the coalfree Portuguese power system and assesses its impacts; finally, Section 5 concludes the study.

2. Context: the Portuguese power system

The high penetration of renewables on the Portuguese power system makes it strongly dependent on the meteorological conditions, mainly precipitation, i.e., in dry years the system is more dependent on fossil fuels than in wet years, such as 2015, 32% dryer than the average (Portuguese Institute of Sea and Atmosphere (IPMA), 2015)).

In that year, renewables accounted for 64.8% of the total installed capacity (Fig. 1), representing 51% of the total electricity generation (being 23% wind, 18% hydro, 6% biomass, 2% photovoltaics and 2% resulting from hydro pump) (National Energy Networks (REN), 2015b). Hydro pump capacity[1] was of 1.6 GW (National Energy Networks (REN), 2015b).

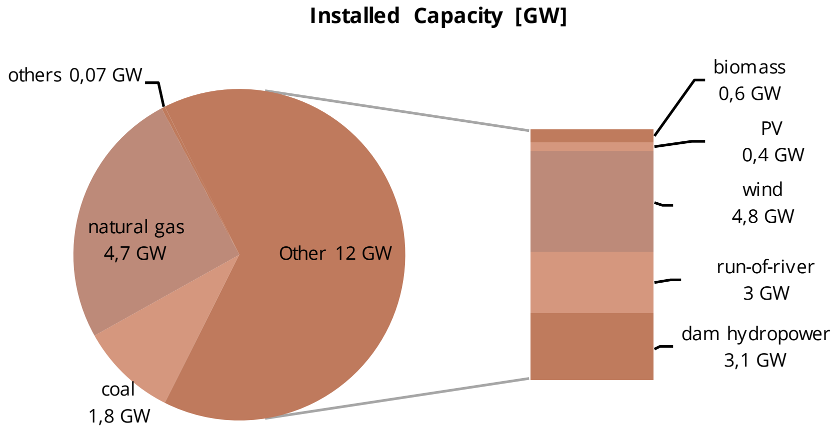

Fig. 1 Installed capacities in the 2015 power generation fleet (National Energy Networks (REN), 2015b).

The energy exchanges of the Portuguese power system are solely with the neighbour country, Spain, which happen under the MIBEL, the Iberian market for electricity trade. The interconnection peak observed in 2015 was of 3 GW (National Energy Networks (REN), 2015a), the imports were 4.5 TWh (9% of the electricity demand) and the exports were 2.2 TWh (5% of the electricity generation).

3. Methods

The Portuguese power system was simulated using the EnergyPLAN computer model (Aalborg University, 2017), using as reference the year 2015 – Reference Case. At the time of performing this analysis, the most recent year with the required available data was 2016, a wet year, but 2015 was chosen due to being a dry year, making the analysis more conservative.

EnergyPLAN is an energy planning tool that allows the simulation of power systems from a technical perspective. It performs hourly electricity balances between supply and demand, prioritizing the renewable generation and grid stability (constraining the minimum power output for condensing power plants and the minimum share of dispatchable generation). EnergyPLAN is an energy planning software that has been widely used to simulate energy systems. In (Fernandes & Ferreira, 2014) and (Krajačić, Duić, & Carvalho, 2011), a wide range of power supply scenarios serve to test the feasibility of a 100% renewable based power system in Portugal. Both

1 Currently, the hydro pump capacity installed is almost of 2.7 GW (National Energy Networks (REN), 2017).

studies found that energy storage is critical to achieve such level of renewable penetration, even more when considering variable renewables.

A model validation was performed matching simulation results with historical data (e.g. generation per source, fuel consumption per type of fuel, CO_2 emissions) by adjusting parameters such as the power plants' efficiency and the water supply.

The main indicators used to study the impacts of the scenarios tested were: (1) the share of renewable electricity sources (RES); and (2) the CO_2 emissions – it accounts for emissions within the Portuguese power system and the ones related to imports. In the Reference Case, the imports' emissions factor was considered to be the same one as the national electricity mix, while any further imports in the remaining scenarios are assumed to be from coal-fired power plants with an efficiency of 30% (lower than the 36% efficiency of the current Portuguese coal-fired power plants)[2].

4. Coal-free power system

The scenario without coal – NoCOAL scenario – aims to study the impacts of a sudden shut down of coal-fired power plants, based on the Reference Case. It would result in significant cost savings by avoiding expensive coal purchases: in 2015 it accounted for 285 M€, about 3.5% of the energyrelated imports (Direção-Geral de energia e Geologia (DGEG), 2018)[3]. The substitution of coal generation with already existing power capacity is explored.

The NoCOAL scenario results in increased natural gas power plants operation, and, even so, in 5-fold increase of imports (Fig. 2). The power import needs exceed the interconnection capacity during 4.8% of the year (mainly during daytime and evening hours). Therefore, solar energy coupled with storage could be a solution for those excessive imports.

The optimal photovoltaic (PV) capacity to deploy was considered to be the one with which the annual exports offset the imports. The result is 8 GW of photovoltaics, which is achievable to install considering the cost competitiveness of the technology and the solar potential of the country. Moreover, as the deployment of over 13 GW of PV is required to reach the long-term CO_2 emissions goals for Portugal (Nunes, Farias, & Brito, 2014), the 8 GW of PV suggested only contributes to such targets.

2 Such assumption turns the analysis conservative and in accordance to the statement made by the CEO of EDP (the dominant Portuguese electricity operator, owner of Sines, and also an important player in Spain): "the generation from these power plants would be replaced by imports from less-efficient coal-fired power plants in Spain" (Milheiro, 2018).

3 In 2017, the expenses were 5.5% of the national energy-related costs (Direção-Geral de energia e Geologia (DGEG), 2018).

Although the implementation of 8 GW of photovoltaics leads to a significant decrease of the imports compared to the NoCOAL scenario, it also leads to a significant amount of energy to export or curtail. As shown before in other studies, energy storage is crucial in power systems highly dependent on variable renewables (Krajačić et al., 2011)(Fernandes & Ferreira, 2014), thus a solution could be the coupling of PV generation with storage, which attenuates the PV generation profile and variability.

Adding reverse pumping to existing hydro power plants would enable the excess energy generated during off peak periods to be latter used at high demand peaks. About 2.75 GW was found to be the needed hydro pump capacity that decreased the imports to the Reference Case level.

The coupling of 8 GW of PV with 2.75 GW of hydro pump is the basis for the SOLAR-STORAGE scenario. Even though the exports increase compared to the Reference Case, the imports decrease, being the duration of the periods with interconnection requirements above capacity negligible (Fig. 2).

Table 1 summarizes the distinguishing features of each scenario.

Table 1 – Distinguishing features of each scenario. All other features remain the same.

Distinguishing features of each scenario	
Reference Case	1.7 GW of coal-fired power plants
NoCOAL	0 GW of coal-fired power plants
SOLAR-STORAGE	0 GW of coal-fired power plants + 8 GW of photovoltaics + 2.75 GW of hydro pump

Fig. 2 presents the annual import and exports needs. Fig. 3 shows the load duration curves for the imports and exports during the year for each scenario.

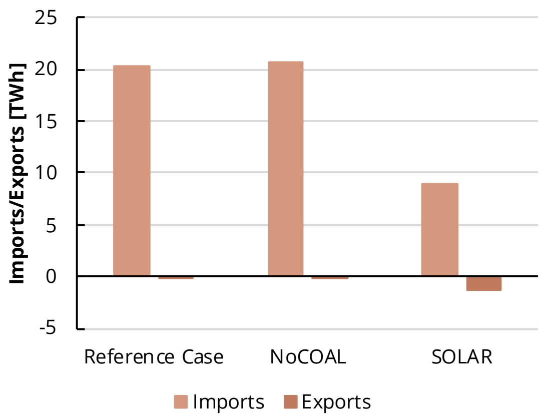

Fig. 2
Annual import and export needs for each scenario.

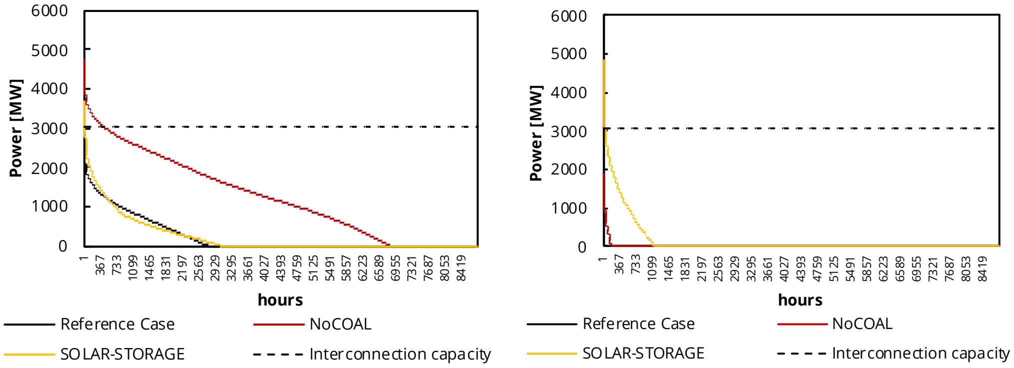

Fig. 3
Load duration curves for imports (left) and exports (right) needs.

Table 2 shows the RES share and CO_2 emissions of each scenario.

Table 2
RES share and CO2 emissions for all the scenarios.

	RES share [%]	**CO2 emissions amount or relative difference to the Reference Case**
Reference Case	49.9	20.4 Mton
NoCOAL	61.0	+1%
SOLAR-STORAGE	75.5	-56%

A slight increase in CO_2 emissions is projected for the NoCoal scenario due to the added imports attributed to less efficient power plants in the neighbor country, resulting in a displacement of about 9.86 Mton of CO_2 emissions to Spain. As expected, a considerable increase of the renewable electricity share is achieved but at the expense of fossil generation from the outside.

The 8 GW proposed PV deployment coupled with hydro pump – SOLAR-STORAGE scenario – allows to reach 76% of renewable electricity share and to decrease 56% the CO_2 emissions comparing to the Reference Case.

5. Conclusion

In this study, the coal phase-out of the Portuguese power system is explored by suggesting alternative supply sources and by quantifying the impacts of such modification on the system. It was found that 8 GW of photovoltaics accompanied by 2.75 GW of hydro pump capacity, about 2% more than the presently installed, enable the replacement of the current coal generation, keeping the system dependency from the neighbour country comparable to that of the present system and complying with the technical requirements.

The proposed configuration, in a dry year, unfavourable for generation from renewables, would enable an increase on the renewable electricity share from about 50 to

76% and a 56% decrease of CO_2 emissions, a significant contribution to meet environmental targets. Furthermore, it would provide socioeconomic benefits for Portugal, such as an improving in the balance of payments (avoiding coal imports).

Given the cost competitiveness of PV and the high solar potential that Portugal has, the proposed photovoltaics penetration in Portugal is expected to be easily accomplished in the short term, especially if combined with a policy framework that facilitates its deployment and integration in the grid. The replacement of coal by renewables is an important and attainable step to achieve a clean future energy system, increasingly nearly 100% renewables based.

Acknowledgments

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Energy Consumption, Macroeconomic and Financial Effects over CO2 Emissions: A European Approach

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Abstract

We study the environmental Kuznets curve, adding the explanatory variables: energy consumption, renewable energy consumption, financial development, dependence on oil, and population growth. This empirical work is applied using data from 20 member states of the European Union for the period between 1997 and 2015. After application of the panel vector autoregressive model (PVAR) and Granger causality, we confirmed the existence of an inverted U-shaped EKC. Results seem to indicate that economic growth, previous CO_2 emissions and energy consumption increase environmental pollution. Consumption of renewable energies and the population growth seem to improve the environmental conditions. According to Granger's causality tests, only economic growth and energy consumption cause carbon dioxide emissions. All the explanatory variables introduced in the model were shown to be relevant, since the EKC hypothesis was always validated as more variables were introduced in the model.

KEYWORDS
Environmental Kuznets Curve (EKC), CO_2 emissions, Economic growth, Energy consumption, Financial Development, Oil dependence, Population growth

Introduction and Hypothesis

It is well documented in the literature that there is a relationship between economic growth and pollution, translating into CO_2 emissions caused by economic growth (Kuznets, 1955). The EKC hypothesis suggests that economic development initially leads to a deterioration of the environment, but after a certain level of economic growth, a society begins to improve its relationship with the environment and levels of environmental degradation decrease, mainly due to development and technological progress. In this inverted U-shaped relationship between economic growth and environmental degradation, we can infer that economic growth turns out to be good for the environment. However, there are authors who criticize this view of Kuznets arguing that there is no guarantee that economic growth will lead to a better environment, because in reality the opposite is often the case. At the very least, this relationship requires much focused policy and attitudes to ensure that economic growth is compatible with an improved environment. In the literature we find several studies that relate economic growth to environmental pollution, but more recent studies have included other variables and to study different contexts in comparative terms to try to explain this relationship. One of the variables most used to help explain CO_2 emissions is energy consumption (e.g., Moutinho et al., 2017). However, we find in the literature many other indicators, such as renewable energy consumption, financial development, trade liberalization, fuels, globalization, urbanization and even population growth (e.g., Burakov and Freidin, 2017; Antonakakis et al., 2017; Balsalobre-Lorente et al., 2018).

Moutinho et al. (2017) confirm the EKC hypothesis for Portugal and Spain in their study for the period 1975-2012 for 13 different sectors, including as explanatory variable of this relation energy consumption. They also found evidence of an inverted N-shaped relationship between economic growth and carbon dioxide emissions. In the study by Balsalobre-Lorente et al. (2018) where carbon dioxide emissions, per capita GDP, renewable electricity consumption, trade liberalization, abundance of natural resources and energy innovation are being analyzed, results are found for an N-shaped curve that explains CO_2 emissions. Antonakakis et al. (2017) bring together a group of 106 countries, separated into subgroups of countries with low, medium low, medium high and high incomes. Here the results point to the conclusion that renewable energy consumption is conducive to economic growth and that economic growth increases carbon dioxide emissions so that it cannot be concluded that developed countries can actually escape environmental pollution.

Although there are these and other studies on the EKC hypothesis, we find in the empirical literature on the subject different conclusions about this relationship to date. It is possible to verify that this inclusion of variables capable of explaining this relation (EKC) has been done gradually and we have verified that the different conclusions allow for a possibility of further study. As far as it can be ascertained, there is as yet no more comprehensive study combining carbon dioxide emissions as a dependent variable with economic growth, energy consumption, energy consumption of renewable energy, financial development, dependence on oil and population growth as explanatory variables and simultaneously. Moreover, our study hopes to be an additional contribution to an already existing literature, in the sense that in addition to the inclusion of these variables simultaneously, this study serves to combat this gap in the literature and to explain in a more complete way the increase of emissions. Additionally, we try to explore this hypothesis by including additional explanatory variables in the context of the European Union (EU).

The results allowed to confirm the existence of EKC (an inverted U-relationship between CO_2 emissions and economic growth) in the simplest form. These seem to indicate that renewable energy consumption and population growth are factors that positively influence CO_2 emissions, i.e., reduce environmental degradation, as well as dependence on oil and financial development (impact on CO_2 emissions is negative in terms of coefficient sign, although not significant), while energy consumption plays the opposite role in relation to environmental pollution, i.e., its contribution to carbon dioxide emissions is negative, considering that it increases the emissions (increasing environmental degradation, although not always significant). Table 1 presents our main hypothesis, summarizes the conclusions reached for each of the hypothesis formulated and compares our results with those of other authors.

Table 1
Hypothesis, validation and literature review

Hypothesis	Validation	Authors	Authors validation
H1a: There is evidence of the EKC hypothesis in EU countries.	yes	Kuznets (1955), Agras and Chapman (1999), Roca et al. (2001), Andreoni and Levinson (2001), Dinda (2004), Özokcu and Özdemir (2017)	yes
		Mazur et al. (2015), Esmaeilpour Moghadam and Dehbashi (2017)	no
H1b: There is evidence of an N-shaped relationship between economic growth and environmental degradation in EU countries.	no	Grossman and Krueger (1991), Moutinho et al. (2017) – inverted, Boamah et al. (2018), Balsalobre-Lorente et al. (2018)	yes
H2a: There is a direct relationship between energy consumption and environmental degradation.	yes (+1), (Only in Granger)	Arouri et al. (2012), Kasman and Duman (2015), Wang et al. (2011)	+, Uni and bidirectional yes
H2b: There exists a direct relationship between energy consumption and economic growth	no2	Narayan and Popp (2012), Chotanawat et al. (2008)	+, TCE => - CE, and -
H3a: There is an inverse relationship between financial development and environmental degradation.	yes (-3)	Sadorsky (2010), Cole and Elliot (2005), Salahuddin et al. (2018), Dogan and Turkelul (2016), Boysen et al. (2017), Esmaeilpour Moghadam and Dehbashi (2017)	no, + , DF => + CE => + ECO2
		Tamazian et al. (2009), Tamazian and Bhaskara Rao (2010), Shahbaz et al. (2013), Jalil and Feridun (2011)	yes, - , DF => - ECO2
H3b: There exists a direct relationship between financial development and economic growth.	no4; yes (Only in Granger)	Dogan and Turkelul (2016), Boysen et al. (2017), Esmaeilpour Moghadam and Dehbashi (2017), Salahuddin et al. (2018)	DF => + CE => + ECO2 Yes, TCE + CE => +ECO2
H4: The high oil dependence has a direct relationship with environmental degradation.	no (-5)	Lotfalipour et al. (2010), Gregg et al. (2008)	yes, +
H5: There is an inverse relationship between consumption of renewable energy and CO2 emissions.	yes (-6)	Hu et al. (2018), Inglesi-Lotz and Dogan (2018), Sinha and Shahbaz (2018), Balsalobre-Lorente et al. (2018)	yes, -
		Mathiesen et al. (2011), Apergis and Payne (2010), Shahbaz et al. (2012), Sbia et al. (2014)	yes, +, CER => + TCE

Hypothesis	Validation	Authors	Authors validation
H6: There is a direct relationship between population growth and environmental degradation.	no (-7)	Dogan and Turkekul (2016), Sharif Hossain (2011), Xu and Lin (2015), Katircioğlu and Katircioğlu (2018), Zhang and Lin (2012)	yes, +, AP => + CE => +ECO2
		Hart (2013), Sharif Hossain (2011)	no, -

Source: Own elaboration. Notes: 1 Not always significant; 2 The results show that it is the economic growth that causes the consumption of energy. 3 The impact of financial development on CO_2 emissions is negative but not significant. 4 Financial development has to be considered together with CO_2 emissions to have an impact on economic growth (Granger causality). 5 The impact of oil dependence on CO_2 emissions is negative but not significant. 6 Where significant, renewable energy consumption has a negative impact on CO_2 emissions. Indeed, Granger's causality tests show that CO_2 emissions and renewable energy consumption cause economic growth. 7 An inverse (negative) and significant relationship was detected between population growth and CO_2 emissions.

This work is divided in the following sections. In section 2 we present the data used in this study, and the applied methodology. The empirical results, policy implications and main conclusions are presented in section 3.

Data and methodology

In order to carry out this work, we selected European Union countries for which it was possible to obtain time series with the greatest longevity, so that we would have not only a greater number of data but also a greater consistency in results. To this end, we collect data from Belgium, Czech Republic, Denmark, Germany, Estonia, Greece, Spain, France, Italy, Latvia, Lithuania, Hungary, Malta, Netherlands, Poland, Portugal, Slovakia, Finland, Sweden and the United Kingdom for the period 1997-2015. All data were obtained from Eurostat as the database is in greater detail and more complete, regarding the need for data for the present study, on the countries belonging to the European Union, in the context of annual series that had to be collected.

As a dependent variable, representative of environmental degradation, data on CO_2 emissions were collected. CO_2 emissions are measured in thousands of tones, such as Moutinho et al. (2017). The CO_2 emissions will be used in per capita terms, where for this purpose the annual volume of these emissions was divided by the total population of each country and each year. Regarding the independent variables, we collected the necessary variables to be able to answer the hypotheses 1 to 6 stated in the previous section. For this study it was then necessary to collect data on energy consumption. The data were collected in thousands of tons of oil equivalent, as the authors Ang (2007) and Apergis and Payne (2010) used, being that in this work we divided the energy consumption by GDP per capita, per year and per country. As a variable representing economic growth, we used data on the annual Gross Domestic Product (GDP), and the data were transformed to obtain the GDP growth rate. This method was used by several authors, namely Mazur et al. (2015) and Balsalobre-Lorente et al. (2018). Regarding the financial development explanatory variable, we processed the data so that we could achieve the desired results. We obtained the flow of credit to the private sector as a fraction of GDP, which we use as a proxy. Following the example of Shahbaz et al. (2013), we multiply the flow of credit to the private sector as a fraction of GDP by GDP and then divide the result by the Consumer Price Index of each year and each country to obtain real values. Finally, we subtract the value of year n from year n-1 and divide it by the value of year n-1 to obtain the growth rate since the final objective is to obtain the financial development data (measured by its rate growth). In order to obtain representative data on oil dependence, we initially collected data on the quantities of oil imported by each country under analysis, and later these amounts were divided by the total energy consumed. With the division of imported oil by the total energy consumed it is possible to determine the level of dependence on oil in each country and in each year, as in the Eurostat study (Poland and France, 2006). For renewable energy consumption we collect the annual consumption data in all 20 countries under analysis, and the values collected were measured in thousands of tons of oil equivalent. The variable renewable energy consumption was calculated by dividing this value by the total energy consumed, per year and per country. Finally, for the population growth, the records of the annual population for the period concerned were collected. After this collection, we proceeded to determine its growth rate by the same method applied in the calculation of economic growth, following the example of Lantz and Feng (2006).

Descriptive statistics for the variables, in the entire sample and by country, were computed, as well as Pearson correlations. In total we work with 380 observations. The CO_2 emissions represented by ECO2 have a negative mean of 4.8193, with a standard deviation of 0.5157, which may indicate a reduction in emissions for this group of countries on average. Of all the variables under analysis, oil dependence is the one with the greatest risk or volatility if we choose to measure it by the standard deviation of the variable. The lowest economic growth (TCE) in this period is -0.2143 in the year 2009 in Latvia and the maximum is 0.3888, registered in Lithuania in 1997. The average energy consumption (CE) is positive at 0.7808, and the average consumption of renewable energy (CER) is negative at -2.6235. The lowest entry was in Malta in 2002 (-8.3249). Oil dependency (DP) is the second highest standard deviation variable (2.9824), being exceeded only by the financial development (DF), which reaches 4.8050. The minimum value verified in the DP variable was -10.2653 in Greece in 2010. This indicates that there is a gradual reduction of dependence on oil in the countries under review. The highest DF rate verified reached a rate of 82.8007, its greatest decrease being 14.7066.

We can verify that energy consumption has a low negative correlation with economic growth (-0.0548), however this relation is not statistically significant at any level. CE, DP and population growth (AP) have a positive correlation of 0.2042, 0.1748 and 0.1995 with CO_2 emissions, respectively, being these statistically significant at 1%. CER also has a correlation with ECO2 statistically significant at 1%, however this correlation is negative at 0.4299. Also the economic growth rate (TCE) has a negative correlation with ECO2 in the value of 0.0932, with significance of 10%. Renewable energy consumption has a negative correlation of 0.2481 with the population growth, a statistically significant value at 1%. Also, the correlation between oil dependence and population growth is statistically significant at 1%, and this correlation is 0.143 (positive value).

Our contribution to the existing literature is firstly to build a robust database of 20 European countries for the period 1997-2015. Second, we include other variables capable of explaining the relation of the EKC hypothesis because they are directly or indirectly linked to economic growth and CO_2 emissions. Third, we analyze the dynamic relations between endogenous variables using a dynamic panel model (PVAR) originally created by Douglas et al. (1988), and later developed by Canova and Ciccarelli (2013), whose code for STATA is available from Love and Zicchino (2006). The advantage of using a PVAR methodology relative to other methods (such as Antonakakis et al. (2017) use and refer in their study of the relationship between energy consumption, CO_2 emissions and economic growth) is evident. In particular, the PVAR models are useful when there is little or no ambiguous theoretical information about the relationship between the variables that guide us in terms of model specification. Another important advantage is that PVAR models are explicitly constructed to deal with problems of endogeneity, which can become a relevant challenge in empirical research, especially in the study of the relationship between energy consumption, economic growth and emissions (Antonakakis et al., 2017). For example, Moutinho et al. (2017) used techniques such as those of the variables centered to reduce the high degree of correlation that may exist between the variables GDP, GDP squared and GDP per cube. Moreover, the PVAR models help to reduce endogeneity problems by treating all variables as potentially endogenous and allowing explicit modeling of feedback effects between variables (Antonakakis et al., 2017; Canova and Ciccarelli, 2013).

To verify the existence of the EKC we will use the following function described by equation (1), this being the general model. For the sake of robustness of analysis some of the explanatory variables were included and removed from the analysis in order to verify if the introduction of variables to the model maintains the form of the EKC hypothesis that is intended to be obtained.

$$lnECO_2 = \propto_0 + \propto_1 TCE + \propto_2 (\mathrm{TCE})^2 + \propto_3 (\mathrm{TCE})^3 + \propto_4 * X_t + \varepsilon_t \quad (1)$$

In that X_t is a vector of other variables capable of affecting the environmental quality measured by CO_2 emissions per capita represented by lnECO2 (CER/CE; lnCE/GDPpc; AP; Imp/CE; DF), where CER designates the consumption of renewable energy, CE total energy consumption, GDP Gross Domestic Product, AP population growth rate, Imp oil imports and DF designates the rate of financial growth. TCE refers to the per capita GDP growth rate being TCE^2 and TCE^3 the GDP growth rate per capita squared and its cube, respectively, to be able to capture the effect of the inverted or U-shaped or N-shaped EKC. The values of the coefficients α are associated with the coefficients of the variables that succeed them and whose signals help to understand the shape of the EKC curve. Finally, ε represents the error term. This equation allows us to test various forms of the relation environment / economic development / economic growth, namely, following the authors Esmaeilpour Moghadam and Dehbashi (2017), if: α1=α2=α3=0 there is no relationship between economic growth and CO_2 emissions; α1 > 0 and α2=α3=0 there is a growing monotonic relationship or a linear relationship between both variables; α1 < 0 and α2=α3=0 there is a decreasing monotonic relationship between both; α1 > 0, α2 < 0 and α3=0 there is an inverted U-shaped relationship (validating the EKC hypothesis); α1 < 0, α2 > 0 and α3=0 there is a U-shape relationship; α1 > 0, α2 < 0 and α3 > 0 then we are in the presence of a polynomial cubic function or a N-shaped curve; α1<0, α2>0 and α3<0 thus we have the opposite of the N shaped curve.

In order to estimate the equation (1) through the PVAR model, all variables were computed in the logarithmic form except for growth rates. To verify if the variables meet the necessary requirements for a PVAR model to be applied, we need them to be stationary. For this purpose, we performed unit root tests to the form that the variables will take in the final model (logarithms and rates) (Antonakakis et al., 2017). The appropriate lag structure was computed and cointegration tests were also performed. Subsequently, we performed the Granger causality tests, following Antonakakis et al. (2017). The final model took the form represented in equation (2).

$$\Delta lnECO2_{it} = \alpha_{it} + \beta_{i.t}\Delta lnTCE_{it-1} + \gamma_{i.t}\Delta ln\theta_{it-1} + \delta_{i.t}\Delta lnECO2_{it-1} + \varepsilon_{it} \quad (3)$$

Where index i refers to country and t to time period (t = 1,…,T). In the same way as the authors, ΔlnTCE denotes real per capita GDP growth, Δlnθ represents the growth of each of the variables CE (energy consumption), CER (renewable energy consumption), DP (oil dependence), AP (population growth) and DF (financial development). ΔlnECO2 denotes the growth of CO_2 emissions and ε_{it} refers to the term of the white-noise error.

Results, policy implications, discussion and conclusions

In this section we seek to summarize all the possible conclusions to make. To facilitate this discussion, we present in table 1 we already presented a summary of the hypotheses and the verification or not of the same through the results of this study, as well as the validation of these same hypotheses or not by other authors. Table 2 presents some of the results of the estimations (in total 42 equations).

Table 2
Estimation results: from equations 29 until 42

	Eq29	Eq30	Eq31	Eq32	Eq33	Eq34	Eq35	Eq36	Eq37	Eq38	Eq39	Eq40	Eq41	Eq42
Variable	Coef	Coef	Coef	Coef	Coef	Coef	Coef	Coef	Coef	Coef	Coef	Coef	Coef	Coef
ECO2	0,9311***	0,9314***	0,9615***	0,9483***	0,9418***	0,9242***	0.9256***	0.9236***	0,9322***	0,9338***	0,9314***	0,9341***	0,9318***	0,9620***
TCE	0,2286*	0,2509*	0,3182**	0,5955***	0,5257***	0,5083***	-0.0291	0.4644***	0,2509*	0,2459*	0,2278*	0,2705**	0,2494*	0,2985**
TCE2	-1,9618**	-1,9821**	-2,0201**	0,3179	0,0783	-0,0209	-0.0291	-0.0953	0,0275***	-2,0131**	-1,9643**	-2,0390***	-1,9851**	-1,9160**
TCE3				-14,2289***	-12,7534**	-12,5618**	-12.1562**	-11.4500**						
CE	0,0260				0,0359	0,0183	0.0197	0.0174	0,0275	0,0291	0,0259			
CER	-0,0300*	-0,0360**				-0,0248	-0.0255*	-0.0276*	-0,0268*	-0,0278*	-0,0300*	-0,0346**	-0,0359**	
DP	-0,0040	-0,0038					-0.0024	-0.003		-0,0034	-0,0040	-0,0032	-0,0039	-0,0028
AP	-0,0641***	-0,0648**						-0.0617***			-0,0642***		-0,0649***	-0,0634***
DF			-0,0002	-0,0006	-0,0006	-0,0006	-0.0006	-0.0002	-0,0003	-0,0003	0,0001	-0,0002	0,0001	0,0002
Cons	-0,4572**	-0,4516**	-0,2052	-0,2858	-0,3405*	-0,4749**	-0.4837**	-0.4901**	-0,4326***	-0,4476**	-0,4560**	-0,4414**	-0,4500**	-0,2081
Wald chi2	757,16	751,87	710,91	727,24	738,85	747	745.6	764.04	735,44	735,39	754,8	729,25	749,51	728,64
Pvalue	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000

Source: Own elaboration. Note: ECO2 refers to the natural logarithm of CO2 emissions proxy for environmental degradation; TCE refers to the economic growth rate, TCE2 squared TCE and TCE3 the TCE cube; CE represents the logarithmic energy consumption; CER refers to the logarithm of renewable energy consumption; DP refers to the logarithm of oil dependence; AP refers to population growth and DF refers to financial development. *,**,*** - Statistically significant at 10, 5 and 1%, respectively.

By applying the PVAR model, it was possible to validate the EKC hypothesis, even when other explanatory variables were introduced in the model such as energy consumption, renewable energy consumption, oil dependence, growth population and financial development. Therefore, H1a is verified even with the inclusion of other explanatory variables in the model. This result was expected because it has already been reported in the literature that the EKC is verified if the countries are already at sufficiently high levels of development (as in our sample of the 20 EU countries), that is, it is verified if we are able to observe people's increased concern for the environment, increased income and technological development (Balsalobre et al., 2018). However, we have not been able to validate the EKC hypothesis in N-shaped form, perhaps because of the level of development and economic growth already achieved by the countries under review. It was also possible to verify a bidirectional relationship between CO_2 emissions and economic growth by the Granger causality tests[1] carried out.

Contrary to Antonakakis et al. (2017), we do not question the effectiveness of government policies to promote renewable energy consumption as a form of sustainable growth (the authors do not confirm that renewable energy consumption leads to economic growth), as our results seem to indicate that promoting the consumption of renewable energy are producing the desirable effects in terms of CO_2 emissions (where significant, renewable energy consumption has shown a sign of a negative impact coefficient on emissions). However, energy consumption still leads to increased CO_2 emissions, as our results demonstrate, as well as economic growth, leading us to question, provided there is still excessive consumption of fossil energy sources given the still high levels of dependence of the 20 countries under review, if this is not constraining sustainable growth (one of Europe 2020 targets). Thus, policy makers should put more pressure on the substitution of energy consumption / production for renewable energy consumption / production, so as to reduce dependence on fossil energy sources (reduction of dependence on oil) and thus promote the desirable sustainable growth at EU level. Also Wang et al. (2011) argue that reducing energy consumption, especially fossil energy, would reduce CO_2 emissions, only increasing the consumption of clean energy.

It was possible to observe that the emissions of the previous period have a positive and significant impact on the emissions of the current period, leading to the conclusion that the level of previous emissions negatively influence the environmental degradation allowing this increasing extension over time. Also economic growth has a positive impact on CO_2 emissions at an early stage, and we were able to validate the EKC hypothesis regardless of the inclusion of new variables in the relation. There is also a positive and significant effect (although not in all the different specifications of the model) of energy consumption, the result of which was further corroborated by the unidirectional Granger causality test. Conversely, Wang et al. (2011) conclude in favor of a bidirectional relationship between energy consumption and CO_2 emissions. Thus, the results seem to indicate that both emissions from the previous

1 These were omitted for space reasons, but will be provided upon request.

period, economic growth and energy consumption are relevant factors to explain the environmental degradation favoring the results of Arouri et al. (2012) and Kasman and Duman (2015).

Another conclusion that we can draw from this analysis is that financial development shows a sign of a negative coefficient on CO_2 emissions. However, we cannot plausibly affirm that financial development improves environmental degradation because the results were not statistically significant. From the results of Granger's causality it has also been possible to gauge that financial development causes economic growth and that simultaneously emissions and financial development also lead to economic growth. Also in the literature, there is evidence that financial development leads to environmental improvement (reducing emissions), perhaps because more and more money is available to companies that are more efficient in protecting the environment (Shahbaz et al., 2013).

Both oil dependence and financial development are variables that revealed a negative sign in the estimates but the same was not significant. The countries under analysis still have excessive dependence on fossil energy sources and the coefficient signal can be explained by price swings. An increase in the price of oil leads to a reduction in energy consumption and encourages the preference for the alternative of energy consumption through renewable energy sources. This inverse relationship between oil prices and energy consumption for importing countries was verified by Jiménez-Rodriguez and Sánchez (2005).´

Using renewable energies in fact decreases energy dependence (Yazdi and Shakouri, 2018). Our results show that when the impact of renewable energy consumption on CO_2 emissions is significant, as evidenced by Hu et al. (2018), English-Lotz and Dogan (2018) and Sinha and Shahbaz (2018) for developing countries, but there is evidence of this negative relation also in developed countries (Balsalobre-Lorente et al., 2018). Therefore, in this group of 20 EU countries, we can say that a great effort has been made to increase the consumption of renewable energies and reduce energy dependence. Something explained by the transposition of EU rules internally in each member state but also as a way to be able to continue to grow economically, since the consumption of renewable energies increases economic growth (Sbia et al., 2014) and decreases energy dependence, making countries less sensitive to oil price fluctuations (Jiménez-Rodriguez and Sánchez, 2005; Yazdi and Shakouri, 2018). It was also possible to verify that it is only when we consider together CO_2 emissions with the consumption of renewable energies that we can obtain a unidirectional relation between these and economic growth.

Finally, it was possible to conclude on the negative and significant impact of the population growth on CO_2 emissions. Therefore, the results seem to indicate that the population increase ends up reducing the environmental degradation. Also Sharif Hossain (2011) conclude in this sense and a plausible explanation may be that greater population growth is largely related to more children. New generations are more environmentally aware and better prepared for environmental awareness, whether by inducing a more environmentally conscious mind in their parents (via recycling or by changing behavior and habits) or by the fact that parents are more aware and want to leave a legacy to their children of growth and sustainable development (Hart, 2013). It seems that at least in this group of EU countries consumption and production habits have changed and there are also more and more environmentally conscious people.

In policy terms, policy makers should strengthen the substitution of fossil energy consumption for alternative and more environmentally sound energy sources, as this contributes to a large extent to reducing energy dependence in these countries and can contribute to a healthier and more environmentally conscious lifestyle. This also requires that older people become aware of the need to change consumer habits, starting to prefer products from more efficient companies to protect the environment or to achieve a more sustainable energy consumption (the requirement ends up imposing changes in terms of production) and to change habits (Hart, 2013) such as those relating to recycling and re-use, as well as the treatment of waste and the use of the natural resources which are not always efficient.

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Investing in Smart Grids: Assessing the Influence of Regulatory and Market Factors on Investment Level

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Abstract

This paper explores how market and regulatory factors affect stakeholder's investments in smart grid projects in Europe. Distribution System Operators (DSOs), universities, and technology manufacturers represent the leading investors in smart grid projects, with a cumulative 2286 M€ invested since 2002. This question is approached through an application of statistical tests to compare with a dataset of direct investments from 2008-2015. From a market perspective, the level of distribution sector concentration did not significantly affect smart grid investments for DSOs, while it did for technology manufacturers and universities. From a regulatory perspective, countries that employed hybrid, incentive or innovation-stimulus regulatory mechanisms motivated investments by market-minded stakeholders, such as DSOs and technology manufacturers; meanwhile, these factors did not affect investment level by knowledge-seeking collaborative institutions, such as universities. Consideration of these findings help policy makers design adequate incentives for stakeholders.

KEYWORDS
Smart grids, Smart grid regulation, Smart grid investment

1. Introduction

Countries around the world are committing to combat the effects of climate change in order to reach a low-carbon future. This effort is demonstrated by the worldwide support of the 2015 Paris Agreement, of which 176 of the 197 Parties invited to the convention have ratified the agreement in their countries (United Nations, 2018). Europe in particular has been incredibly focused on these goals, which is highlighted by their aim to become a global market leader in the clean energy transition.

In November of 2016, the European Commission (EC) presented the *Clean Energy for all Europeans* package, a piece of legislation whose three-fold goals include: increasing energy efficiency, leading in the deployment and integration of renewable energy, and maintaining a fair deal for consumers. Through this package, the EU plans to mobilize both private and public investments to 177 billion euros per year by 2021 (European Commission, 2016).

Reforming the electricity sector has become a key part of the EU's transition to a clean energy future. Central to this goal is the need to invest in, and upgrade, the electricity grid in order to increase the share of Renewable Energy Sources (RES) from 21% today to 45% by 2030 (European Commission, 2015). Smart grid technology allows for an increased flexibility of distribution grids so that they are able to handle the influx of RES, along with their variable loads, and are a central technology in achieving EU energy goals (European Commission, 2006). While this new technology could very well be the answer to many of the challenges that come with the clean power transition, cost is a major barrier to the implementation of smart grid technologies. Thus, heavy investment in these technologies is necessary, and tailored regulations can create the framework to incentivize these investments (Cambini, Meletiou, Bompard, & Masera, 2016; Marques et al., 2014).

The objective of this study to assess the extent that regulatory and market factors play a role in different stakeholders' investments in smart grid technology in Europe. The present study focuses on investments by Distribution System Operators (DSOs), universities, and technology manufacturers because they represent the top three stakeholders with the highest investment in smart grid technology in Europe (Gangale, Vasiljevska, Covrig, Mengolini, & Fulli, 2017). Furthermore, they provide a good basis of comparison as they represent a mix of organizations with different structures, goals, and relationships with the electricity sector. In order to answer this question, we applied statistical tests to compare a dataset of direct investments by these three groups in the EU-28 and Norway and Switzerland from 2008-2015.

2. Methodology

We used investment data from the Joint Research Centre (JRC) Smart Grid Outlook Database corresponding to the value of direct investments by DSOs, technology manufacturers and universities from 2008-2015 for the 28 EU member states, Norway, and Switzerland (Joint Research Centre, 2018). The investment data was normalized to investments per capita (€/capita) and investments per million Euro GDP (€/M€ GDP) of each country analyzed. The population and GDP data were obtained from the Eurostat database (Eurostat, 2018b, 2018a). Average population and GDP from 2008-2015 were used when performing the normalizations.

The present work applies and expands upon the methodology proposed by Cambini et al. (2016). We considered data on direct investments by DSOs, technology manufacturers, and universities, advancing on the existing literature that only considered investments in smart grid projects in which DSOs were involved in. We grouped the 30 European countries studied into three regulatory characteristics: distribution-sector concentration (level of market concentration in the electric power distribution sector), regulatory mechanisms (capacity of regulatory scheme to provide incentives), and innovation-stimulus mechanisms (schemes designed by regulators to encourage project implementation). These three regulatory characteristics are considered to be an accurate portrayal of the regulatory panorama in Europe at this time.

In order to determine the appropriate statistical test to be used to compare these samples, three assumptions must be addressed: normality, independent observations, and homogeneity of variances (Cambini et al., 2016). Additionally, to determine if a parametric or non-parametric test is to be used, it is first important to understand if the data has a normal distribution (Razali & Wah, 2011).

The results of the normality tests showed that only a few data points were considered normal. The independence assumption is satisfied, since none of the observations in one group overlap with another, and the Levene's test verified homoscedasticity except in two cases, thus, for all cases except these two mentioned, equal variances can be assumed.

Following the assumptions presented above, both parametric and non-parametric tests were used to check for differences in means among the country groups in terms of investments. For the normally distributed data, a Student T-test was used considering equal variances (except for the cases that did not fit the assumption of homoscedasticity), while for non-normally distributed data a Mann-Whitney U-Test was used.

For the statistical analyses, one-tailed tests were done for the following null and alternative hypotheses:

$$\textit{Null Hypothesis}:\ H_0 = \mu_1 - \mu_2 = 0 \leftrightarrow \mu_1 = \mu_2 \quad (1)$$

$$\textit{Alternative Hypothesis}: H_1 = \mu_1 - \mu_2 > 0 \leftrightarrow \mu_1 > \mu_2 \quad (2)$$

This implies that under the null hypothesis, the mean values that reflect the level of smart grid investment by the groups of countries, are unchanged by the difference in values of the regulatory factor, in other words, (Cambini et al., 2016).

3. Results and Discussion

The results of the tests to check for differences in means among the country groups in terms of investments, are summarized in Table 1, Table 2, and Table 3. In this section we will go over the results for each factor.

Table 1
Average investment in smart grids by distribution-sector concentration

Organization		High		Medium		Low		P-Value T-Test			P-Value U-Test		
		$\overline{X_H}$	n_H	$\overline{X_M}$	n_M	$\overline{X_L}$	n_L	$\mu_L > \mu_M$	$\mu_M > \mu_H$	$\mu_L > \mu_H$	$\mu_L > \mu_M$	$\mu_M > \mu_H$	$\mu_L > \mu_H$
Distribution System Operator	€/Capita	0.51	7	1.99	15	1.12	8	0.3	0.2	0.1*	0.8	0.1*	0.1*
	€/M€GDP/Capita	23.37	7	42.90	15	16.80	8	0.1*	0.2	0.3	0.3	0.1*	0.3
Technology Manufacturer	€/Capita	0.49	7	0.71	15	2.54	8	0.0002***	0.3	0.003***	0.001***	0.1*	0.006***
	€/M€GDP/Capita	24.07	7	31.18	15	36.006	8	0.3	0.3	0.3	0.5	0.1*	0.1*
University	€/Capita	0.816	7	2.66	15	4.5	8	0.3	0.3	0.09*	0.002***	0.6	0.01***
	€/M€GDP/Capita	40.284	7	62.35	15	44.15	8	0.3	0.3	0.3	0.776	0.5	0.5

Note: * p 0.1, **p 0.05, *** p 0.01, - p 0.1

For DSOs, there is not a big change in investment level based on distribution sector concentration and if any, there is a slightly higher investment between medium to high and between low and high, but significance values are too low to really make any concrete statements. For both technology manufacturers and universities, there seems to be higher investment in countries with low distribution sector concentration compared to medium and high, with no difference when comparing the level of investments between medium and high concentrations. This only seems to be the case when considering the normalization of €/Capita and does not hold true under the normalization of €/M€ of GDP. When considering all three stakeholders, we cannot support the claim that there is a positive correlation between countries with low concentrated distribution sectors and level of smart grid investment. This could be attributed to the point drawn in Agrell, Bogetoft, and Mikkers (2013), that while the unbundling of the electricity sector provides many benefits in terms of competition, it also presents more actors, which leads to more negotiations that at the end of the day, result in compromises that could lead to under investment.

Table 2
Average investment in smart grids by regulatory mechanism

Organization		Cost		Hybrid		Incent.		P-Value T-Test			P-Value U-Test		
		$\overline{X_C}$	n_C	$\overline{X_H}$	n_H	$\overline{X_I}$	n_I	$\mu_H > \mu_C$	$\mu_H > \mu_I$	$\mu_I > \mu_C$	$\mu_H > \mu_C$	$\mu_H > \mu_I$	$\mu_I > \mu_C$
Distribution System Operator	€/Capita	0.19	6	1.05	9	2.11	15	0.06*	0.2	0.1*	0.06*	0.5	0.008***
	€/M€$_{GDP}$/Capita	6.53	6	27.35	9	43.74	15	0.1*	0.2	0.1*	0.1*	0.5	0.03**
Technology Manufacturer	€/Capita	0.45	6	1.49	9	1.21	15	0.1*	0.3	0.1*	0.05**	0.6	0.1*
	€/M€$_{GDP}$/Capita	11.98	6	43.5	9	30.68	15	0.09*	0.2	0.2	0.05**	0.3	0.2
University	€/Capita	1.8	6	2.6	9	3.12	15	0.3	0.3	0.3	0.4	0.3	0.4
	€/M€$_{GDP}$/Capita	33.8	6	47.8	9	62.4	15	0.3	0.3	0.2	0.5	0.9	0.4

Note: * p 0.1, **p 0.05, *** p 0.01, - p 0.1

For DSOs, there is a high significance level between investment in countries employing incentive-based compared to cost-based mechanisms, and a small significance between those implementing hybrid compared to cost-based regulations, with no difference between hybrid and incentive-based schemes. Considering technology manufacturers, countries with hybrid regulatory mechanisms tend to invest more than in cost-based, and there is little difference between other mechanisms. The higher investment level in hybrid schemes when compared to cost-based schemes for both DSOs and technology manufacturers may be attributed to the fact that smart grid technologies do not require an incredibly high capital investment and can save on operational costs (Marques et al., 2014)such as smart meters or instruments of communication, sensing and auto-correction of networks. Nevertheless, the cost is still an important obstacle for the transformation of the current electricity system into a smarter one. Regulation can have an important role in setting up a favorable framework that fosters investments. However, the novelty with SG is the disembodied character of the technology, which may change the incentives of the regulated network companies to invest, affecting the effectiveness of the regulatory instruments (\" cost plus\" or \". price cap\". With universities, there does not seem to be any significant difference in the investment level between any of the regulatory mechanisms. As knowledge seeking institutions, one hypothesis is that universities´ investments are following more the interest of the scientific community rather than regulatory policies or the market. In contrast, DSOs and technology manufacturers are more susceptible to regulatory changes because they are more market-motivated by nature.

Table 3
Average investment in smart grids by innovation-stimulus mechanism

Organization		**Yes**		**No**		**P-Value T-Test**	**P-Value U-Test**
		X_Y	n_Y	X_N	n_N	$\mu_Y > \mu_N$	$\mu_Y > \mu_N$
Distribution System Operator	€/Capita	1.62	8	1.34	22	0.3	0.06*
	€/M€GDP/Capita	61.56	8	20.4	22	0.03**	0.01***
Technology Manufacturer	€/Capita	2.13	8	0.78	22	0.007***	0.01***
	€/M€GDP/Capita	61.93	8	19.4	22	0.04**	0.008***
University	€/Capita	3.42	8	2.4	22	0.3	0.1*
	€/M€GDP/Capita	54.8	8	51.4	22	0.3	0.2

Note: * p 0.1, **p 0.05, *** p 0.01, - p 0.1

For both DSOs and technology manufacturers, high significance can be found when comparing the countries that have high innovation stimulus mechanisms and those that do not. With universities, there does not seem to be any significant difference in the investment level between the countries employing and not employing these mechanisms. One reason for this could be the role of the university as a collaborator. According to Gangale et al. (2017), the universities act as the stakeholder that collaborates the most on projects with other stakeholders. Because of this, the level of investments by universities may be more motivated by the different projects they collaborate on, independent of market mechanisms.

4. Conclusion

This study compared and commented on the findings from Cambini et al. (2016) that the three key enablers of smart grid investments for additional stakeholders: "(1) lower market concentration in the distribution sector, (2) incentive-based regulatory schemes and (3) the adoption of innovation-stimulus mechanisms" (Cambini et. al., 2016, p 1).

The results of this analysis were different depending on the stakeholder assessed. For the DSOs, these results were consistent on points 2 and 3 and diverged on point 1. For technology manufacturers, these results conformed on all points. For universities, only point 1 was consistent, and points 2 and 3 diverged.

DSOs´ and technology manufacturers´ investments showed that countries that adopted innovation-stimulus mechanisms invest more in smart grid technology than those that did not have these schemes, a finding that conforms with existing literature. Furthermore, when compared to cost-based models, incentive-based regulatory schemes were seen to encourage more investments. Technology manufacturers and universities both tended to follow the trend that the more unbundled the electricity sector, the higher level of investments.

This study diverged from the existing literature on three key points. First, this analysis did not find any significant difference between distribution sector concentration and the level of investment for DSOs, and therefore, cannot corroborate that lower market concentration in the distribution sector enables smart grid investment. Second, hybrid-based regulatory models, when compared to cost-based models, encouraged more investments for DSOs and technology manufacturers, while Cambini et al. (2016) did not find any significant difference between these two factors for DSOs. And third, university investments were not affected by any sort of regulatory or innovation stimulus mechanism.

Policy makers should consider these results when designing adequate incentives to each stakeholder involved in smart-grid R&D and/or deployment. Whilst the development of any new technology is based on R&D at universities, technology providers somehow support this R&D and deploy pilot/demonstration projects to be of interest to market operators, such as DSOs. Therefore, policies should address specifically each stakeholder group in accordance with the development/implementation phase of smart-grids in each country.

As we attempt to transition to a cleaner energy economy, major updates will need to be done on our electricity sector. The smart grid is one key technology that will be incredibly important in this energy transition, and we should continue to develop further mechanisms that encourage investments in these projects to further develop this technology.

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Eco-Efficiency Actions and Firm Growth in Portugal

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Abstract

This study investigates the effect of eco-efficiency actions on firm performance, considering the turnover growth, on a sample of 7083 enterprises located in Portugal. Empirical results suggest that in general, for all the sectors involved, the undertaking of an eco-strategy aimed at being more resource efficient is related with increased growth in turnover. They also seem to show that there exists an inverted U-shaped relationship between the number of eco-innovation strategies implemented and turnover growth, allowing us to conclude that while in an initial stage an increase on the number of eco-innovations implemented by a firm increases turnover growth, in a second stage it will lead to decreased turnover growth. This may induce the existence of an optimal value for eco-innovation-strategies implemented within the firm. The substitution of fossil fuels by renewable sources also seems to be an important strategy that benefits turnover growth, as well as the environmental benefit of recycled waste, water or materials for own use or sale.

KEYWORDS
Eco-innovation, Eco-strategy, Turnover Growth, Portugal.

1 Introduction: eco-innovation strategies - firm performance

The understanding of how eco-innovation strategies, to reduce environmental impact, affect firm performance is still widely debated (Jové-Llopis and Segarra-Blasco, 2018). If, for a long time, economists, policy-makers and business managers believed that eco-strategies necessarily increased firms' internal costs but not their profits, recent evidence (Jové-Llopis and Segarra-Blasco, 2018; Barbieri et al., 2016; Dixon-Fowler et al., 2013; Albertini, 2013) reveal diversity in the empirical results, ranging from negative, to non-significant and to positive links between eco-innovation and firm performance. Thus, mixed evidence turns clear that this relationship is still poorly understood and indicates the need to investigate this linkage. Conclusions undertaken might help managers to bring a win-win strategy for firms and society, as well as to help designing more effective eco-innovation policies in the future.

Eco-innovation strategies are expected to have a positive effect over the environment but its effect over firm performance is less straightforward. There are arguments in literature pointing out that investing in environmental activities reduces negative externalities but involves a cost to the enterprise with no direct benefit, eroding the enterprise competitiveness (Palmer et al., 1995). There exists also the opposite overview that eco-innovation activities would offset operational costs and increase firm performance in the long term (Porter and Linde, 1995). Porter and Linde (1995) argue that well designed eco-regulation (pollution taxes and tradable permits) may stimulate innovation that improves productivity and in turn increases enterprise benefits (the Porter hypothesis). Thus, eco-regulation is a means whereby a firm may benefit from environmental and economic performance (turning valid also the environmental Kuznets curve hypothesis) at the same time.

A recent literature survey regarding the relationship between eco-innovation and performance is provided by Barbieri et al. (2016). However, different concepts are used in the literature to measure firm performance such as: productivity (value added, gross output, turnover per employee), growth (in terms of sales or turnover growth) and financial measures (operating margins, return on sales, Tobin's Q).

Regarding the relationship between eco-strategies and productivity, Riilo (2017) used turnover per employee for a sample of 890 Italian firms finding that green practices are U-shaped related to performance. Turnover per employee is also used by Doran and Ryan (2012) and Doran and Ryan (2016) for a sample of 2181 Irish firms in the Community Innovation Survey (CIS) 2006-2008. They found a positive and significant effect of eco-innovation on firm performance and that only two out of nine types of eco-innovation positively impacted firm performance (reduced CO_2 "footprint" and recycled waste, water or materials). Using value added for a sample of 12 OECD countries and considering sector level (patents) Soltmann et al. (2015) also found that green practices are U-shaped with respect to performance. Marin and Lotti (2017), for a sample of 11938 Italian manufacturing firms, used real value added per employee, to find that eco-innovations exhibit a lower return relative to other innovations. Using a sample of 5989 Dutch firms, Van Leeuwen and Mohnen (2017) used gross output per employee to conclude that resource-saving eco-innovations increase total factor productivity (TFP) effect and the end-of-pipe eco-innovations tend to reduce TFP. Finally, for a sample of 555 Italian firms, Antonieli et al. (2016) conclude that some firms' productivity performances are positively related to eco-innovation (in a positive way revenue over total labour cost and non-significant value added per employee).

With respect to eco-strategies and growth, and using turnover growth, Cainelli et al. (2011) found a negative effect of eco-innovation on turnover growth, and a negative but not significant effect of labour productivity growth, considering a sample of 773 Italian service firms (using CIS II). By contrast, Colombelli et al. (2015), considering 456240 firms from 6 European countries, found that firms producing eco-innovations are characterized by higher growth rates than those generating generic innovations. Also Hojnik and Ruzzier (2016) and Jové-Llopis and Segarra-Blasco (2018) used turnover growth. The formers, for a sample of 223 Slovenian firms, found a positive and significant effect between eco-innovation and firm growth. The latters, using a sample of 11336 small and medium enterprises located in 28 European countries, based on the European Commission's Eurobarometer Survey 426, found that not all eco-strategies are positively related to better performance. They found that European enterprises using renewable energy and recycling or designing products that are easier to maintain, repair or reuse, perform better, where those that aim at reducing water or energy pollution seemed to show a negative correlation to firm growth. Jové-Llopis and Segarra-Blasco (2018), using an ordered logistic model, also found a U-shaped relationship between eco-strategies and firm growth, indicating that a greater breadth of eco-strategies is associated with better firm performance.

Finally, considering the relationship between eco-strategies and finance performance, Wagner et al. (2002) used return on capital employed, return on sales and return on equity, using data from 37 firms located in Germany, Italy, The Netherlands and UK finding a negative and non-significant relationship. Earnhart and Lizal (2007) used operating profits for a sample of 436 Czech Republic firms to find that better pollution control neither improves nor undermines financial success. Ghisetti and Rennings (2014), considering a sample of 1063 German firms, and Rexhäuser and Rammer (2014), considering a sample of 3618 German firms, both used operating margins, reaching the same conclusion (reduction in the use of energy or materials per unit of output positively affects firms' competitiveness, but externality reducing innovations hamper firms' competitiveness). For a sample of 439 Polish and Hungarian publicly traded firms, Przychodzen and Przychodzen (2015) used return on equity and return on assets to find that green research and development is positively related to financial performance. More recently, Trumpp and Guenther (2017) used return on assets and total share return for a sample of 696 manufacturing and services firms publicly traded in the CDP Global 500, S&P 500 and FTSE 350, finding a U-shaped relationship between corporate environmental performance and profitability. Finally, Miroshnychenko et al. (2017) used Tobin's Q and also return on equity to conclude that internal green practices (pollution prevention and green supply chain management) are the major eco-drivers of financial performance, for a sample of 3490 publicly-traded companies from 58 countries.

Based on the work of Jové-Llopis and Segarra-Blasco (2018), this study focus on the role of the Portuguese enterprises' eco-strategies in improving their eco-performance, by analysing whether they create economic opportunities, with respect to firm growth as measured by turnover growth. For the effect, data from the 2014 CIS of the European Commission, with two years' frequency, is used. In 2014, a separate section on environmental innovations was introduced (section 13). This section asks directly if the enterprise has introduced any innovation with environmental benefits, during the three years 2012-2014, providing a valuable opportunity to examine the role of eco-innovation strategies in firm growth.

Applying a cross-sectional data regression analysis for 7083 Portuguese firms, our empirical developments offer interesting results. First, we validate the Porter hypothesis by identifying an inverted U-shaped relationship between turnover growth and eco-innovations. Second, product innovations with environmental benefits drive higher turnover growth than do process, organizational and marketing innovations. Third, undertaking eco-innovation strategies lead to higher turnover growth. Fourth, results are sensitive to the type of section (or sector). Despite this, these conclusions are important contributions for both consumers, policy makers and enterprises, in recognizing that eco-innovation has important and distinctive roles. For consumers, it contributes to a more environmental consciousness consumption, for producers it helps realizing that eco-innovation investments are also important for turnover growth, and for policy makers by giving clues about how to delineate strategies to increase and facilitate the introduction of eco-innovations within firms, namely the access to finance.

This study contributes to the previous literature in several ways. First, the Portuguese sample of firms is mostly composed by small and medium enterprises (considering the entire sample contained within the CIS 2014 survey, 4738 of the enterprises have less than 50 employees, 1900 state to have between 50-249 employees, and only 445 revealed to have 250 employees or more). It must be stressed the relevant role of small and medium enterprises in the Portuguese economy, which have received lower attention regarding that most of the studies focus on large firms (Jo et al., 2015; Jové-Llopis and Segarra-Blasco, 2018). Moreover, short run costs incurred by these firms regarding eco-innovations are higher and they face higher financial constraints, with lower access to external financing sources (Ghisetti et al., 2016). Second, sector analysis of eco-innovations at firm level are still scarce (Wagner et al., 2002; Aragón-Correa et al., 2008; Jové-Llopis and Segarra-Blasco, 2018), and those that exist are usually applied to one or a few sectors. Different sectors have different environmental costs and adopt different eco-innovation strategies, thus turning important an analysis at the sector level. Third, there are few studies that focus on the Portuguese eco-innovation strategies and when they exist they are presented in a disguised way, considering also other countries and or not at the sector level (see Mavi et al, 2018, and references therein; Jové-Llopis and Segarra-Blasco, 2018). The existent literature on Portugal does not consider the more recent CIS 2014 survey, as far as we are aware. Finally, despite the fact that the connection between eco-strategies and firm performance has been examined extensively for countries that have been members of the EU for many years, little is known for the individual case of Portugal, and at the sector level.

The remaining of this article is structured as follows. Section 2 presents the database, some descriptive statistics, the variables and the econometric methodology. Section 3 shows our main findings and results and section 4 presents our conclusions and the consequent policy implications.

2 Data and methodology

Several firms from several different sectors answered the CIS2014, where eco-innovations are measured on ten different areas of environmental impacts.[1] The question to be answered was: "During the three years 2012 to 2014, did your enterprise introduce a product (good or service), process, organisational or marketing innovation with any of the following environmental benefits?" Respondents had to answer 10 dichotomous questions, yes or no. Six referred to impacts stemming from environmental benefits within the enterprise (EBWE), while the remaining four referred to areas of environmental impacts related to after sales use of a product by its end user (EBEU). All environmental innovations had to be introduced during the three years' period, 2012 to 2014. Despite a total of 7083 Portuguese firms have answered the survey, only 4167 enterprises provided valid answers with respect to eco-innovation strategies adopted.

We implement a cross-section data analysis considering that our dependent variable is a growth rate. The independent variables are represented by a binary-choice variable x=1 if the event occurs and 0 otherwise. A Cross-section regression was run for one dependent variable, the turnover growth, where firms were asked about the enterprise's total turnover between 2012 and 2014. Turnover is defined as the market sales of goods and services, including all taxes except VAT. Independent variables include EBWE (dichotomous variables: 1 if the firm adopted any of these 6 innovations and 0 otherwise) and EBEU (dichotomous variables: 1 if the firm reported any of these 4 benefits and 0 if not). EBWE is related to the first set of eco-innovators, where each firm might have adopted 0 to 6 innovations with environmental benefits from the production of goods or services, process, organizational or marketing within the enterprise. EBEU respects to the second set of eco-innovators, where each firm might have implemented 0 to 4 innovations with environmental benefits obtained

1 During the three years 2012 to 2014, did your enterprise introduce a product (good or service), process, organisational or marketing innovation with any of the following environmental benefits? 1) Environmental benefits obtained within your enterprise: 1.1) Reduced material or water use per unit of output (ECOMAT); 1.2) Reduced energy use or CO_2 'footprint' (reduce total CO2 production) (ECOENO); 1.3) Reduced air, water, noise or soil pollution (ECOPOL); 1.4) Replaced a share of materials by less polluting or hazardous substitutes (ECOSUB); 1.5) Replaced a share of fossil energy by renewable energy sources (ECOREP); 1.6) Recycled waste, water, or materials for own use or sale (ECOREC). 2) Environmental benefits obtained during the consumption or use of a good or service by the end user: 2.1) Reduced energy use or CO_2 'footprint' (ECOENU); 2.2) Reduced air, water, noise or soil pollution (ECOPOS); 2.3) Facilitated recycling of product after use (ECOREA); 2.4) Extended product life through longer-lasting, more durable products (ECOEXT).

during the consumption or use of a good or service by the end user. We also include the eco-Innovation breath (EcoBreath) as independent variable, measured by the number of eco-innovations introduced by firms. Altogether, each firm might have reported from 0 to 10 innovations with environmental benefits. EcoBreath is defined as a count variable by referring to the ten different types of eco-innovations that the CIS 2014 encompasses as in Jové-Llopis and Segarra-Blasco (2018). Also, similar to these authors, we will use the variable EcoBreath2 (the square of the number of eco-strategies implemented by each firm).

As independent variables we also include a dummy variable indicating whether or not a firm is undertaking any eco-strategy to be more efficient and environmental friendly (Eco: 1 if the firm has adopted any of the 10 strategies and 0 otherwise). To avoid multicollinearity issues, separate estimations were performed. As control variables we include size (a dichotomous variable) measured by the number of employees (Size1: 1 if under 50, 0 otherwise; Size2: 1 if from 50 until 249 employees, 0 otherwise) and the percentage of the enterprise's employees with a tertiary degree in 2014 (Empud1: 1 if less than 25%; Empud2: 1 if more than 25%; 0 otherwise). Instead of using dummies as control variables for sectors we perform different regression estimates considering different economic activity sectors.[2]

Previous environmental empirical databases using CIS data or similar ones offer only aggregate information at the country level. However, we will have one dimension in the same database allowing sector views and different perspectives on the data. The main drawback with our cross-sectional dataset, inducing simultaneity, is unavoidable, but so far, it has also been a problem common to all studies using CIS or similar databases with only one year of observations across different firms (Doran and Ryan, 2012, 2016; Van Leeuwen and Mohnen, 2017; Jové-Llopis and Segarra-Blasco, 2018).

Table 1 displays the characteristics of the sample for Portugal and by sector group. Correlation values were also computed but not presented due to space restrictions. Turnover growth has a negative correlation with most of the variables, as well as Empud2 and Size1.

From table 1 we are able to observe the characteristics of the sample group. About 58.8% of the firms state they had introduced, at least, one eco-innovation during the analysis period (2012-2014). Only turnover growth presents higher volatility, followed by EcoBreath, being both variables those which present higher mean values. The sector with higher number of valid answers is the manufacturing and the size

2 From the available survey sample we had available the following sectors (NACE1 codes). Section C – Manufacturing (divisions 10-33): 13, 16-18,21-33,14-15, 19-20; Sections D + E – Electricity, Gas Steam and air conditioning supply (35) + Water supply, sewerage, waste management and remediation activities (divisions 35 + 36-39): 35, 36, 37-39. Section F – Construction (divisions 41-43): 42-43. Section G – Wholesale and retail trade, repair of motor vehicles and motorcycles (divisions 45-47): 46-47. Section H – Transportation and Storage (divisions 49-53): 49-53. Section J – Information and Communication (divisions 58-63): 58, 61, 59-60, 62-63. Section K – Financial and Insurance activities (divisions 64-66): 64-66. Section M + Q – Professional, scientific and technical activities (divisions 69-75): 71, 73, 74, 69-70, 72, 75 and Section Q – Human health and social work activities (divisions 86-88): 86. Available number of companies by section: C – 3382, D+E – 278, F – 568, G – 1191, H – 495, J – 347, K – 300, M+Q – 522.

of the firms with a higher percentage of valid answers is the one with less than 50 employees. Most of the firms confirm to have introduced a product (good or service), process, organisational or marketing innovation with the environmental benefit, obtained within the enterprise, of recycled waste, water, or materials for own use or sale (50.23%), followed by reduced energy use or CO_2 'footprint' (reduce total CO_2 production) (33.09%) and reduced air, water, noise or soil pollution (29.45%). Regarding turnover growth, 2209 firms stated to have a negative turnover growth within the period and 1315 affirmed to have a null turnover growth, while 2887 revealed to have a positive turnover growth between 0 and 0.5 and 672 firms declared to have turnover growth higher than 0.6. Provided that there is statistical evidence that the sample has 4 outliers with respect to turnover growth (higher than 213.3) we have removed these 4 firms from the sample and proceeded with the model estimations.[3]

Table 1
Descriptive Statistics and Sample Distribution

Variable	Mean	Std.Dev.	Valid Obs.
ECOMAT	0.2863	0.4521	4167
ECOENO	0.3309	0.4706	4167
ECOPOL	0.2945	0.4559	4167
ECOSUB	0.2695	0.4438	4167
ECOREP	0.0998	0.2998	4167
ECOREC	0.5023	0.5001	4167
ECOENU	0.2412	0.4279	4167
ECOPOS	0.2112	0.4082	4167
ECOREA	0.2784	0.4483	4167
ECOEXT	0.2366	0.4251	4167
EcoBreath	1.6182	2.6197	7083
Eco	0.3860	0.4869	7083
EBWE	0.3662	0.4818	7083
EBEU	0.2571	0.4371	7083
ECOPRD	0.2992	0.4580	2734
ECOPRC	0.4104	0.4920	2734
ECORG	0.2568	0.4369	2734
ECOMKT	0.1017	0.3023	2734
Empud1	0.7500	0.4331	7083
Empud2	0.2500	0.4331	7083
Size1	0.6689	0.4706	7083
Size2	0.2682	0.4431	7083
Turn. Growth	169.5783	14242.14	7083

EcoBreath (% firms with respect to valid answers when X=1)										
X	ECOMAT	ECOENO	ECOPOL	ECOSUB	ECOREP	ECOREC	ECOENU	ECOPOS	ECOREA	ECOEXT
1	0.65%	1.63%	0.41%	0.55%	0.24%	6.07%	0.36%	0.24%	0.55%	0.62%
2	1.61%	2.74%	1.44%	1.39%	0.60%	7.06%	1.66%	0.70%	2.90%	1.94%
3	3.22%	3.70%	2.50%	2.62%	0.60%	6.89%	2.28%	1.01%	3.36%	2.42%
4	3.29%	3.55%	3.67%	3.02%	0.74%	5.86%	1.97%	1.80%	2.98%	2.50%
5	4.06%	4.30%	4.34%	4.20%	1.01%	5.83%	2.45%	2.21%	2.95%	2.62%
6	3.77%	4.08%	4.10%	3.22%	1.30%	5.14%	2.74%	2.69%	3.17%	2.93%
7	3.43%	4.03%	4.01%	3.31%	1.03%	4.30%	3.65%	3.60%	3.29%	2.62%
8	2.74%	3.17%	3.05%	2.81%	0.96%	3.26%	3.07%	2.93%	2.81%	2.28%
9	3.10%	3.12%	3.14%	3.05%	0.72%	3.05%	3.17%	3.17%	3.05%	2.95%
10	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%
TOTAL	28.63%	33.09%	29.45%	26.95%	9.98%	50.23%	24.12%	21.12%	27.84%	23.66%

	% firms with respect to valid answers when X=1 and Y=1											% firms with respect to valid answers when Y=1							
Y X	ECO	EBWE	EBEU	ECOPRD	ECOPRC	ECORG	ECOMKT	EMPUD1	EMPUD2	Size1	Size2	C	D+E	F	G	H	J	K	M+Q
ECOMAT	28.63%	28.63%	20.71%	16.46%	24.54%	14.96%	6.47%	21.65%	6.98%	14.01%	10.03%	16.37%	1.46%	3.17%	2.93%	1.51%	0.74%	0.91%	1.54%
ECOENO	33.09%	33.09%	23.81%	18.51%	26.88%	16.39%	6.18%	25.05%	8.04%	15.41%	12.12%	18.43%	1.73%	2.95%	3.91%	2.38%	1.13%	0.77%	1.80%
ECOPOL	29.45%	29.45%	22.17%	16.39%	24.51%	15.25%	6.22%	23.88%	5.57%	15.21%	10.22%	18.24%	1.54%	2.98%	2.76%	1.82%	0.55%	0.43%	1.13%
ECOSUB	26.95%	26.95%	21.09%	16.86%	22.31%	14.37%	6.33%	21.48%	5.47%	14.47%	9.00%	16.80%	0.94%	2.66%	3.02%	1.32%	0.50%	0.41%	1.30%
ECOREP	9.98%	9.98%	7.68%	6.62%	8.74%	5.63%	2.89%	7.56%	2.42%	4.78%	3.46%	5.38%	0.62%	1.25%	1.46%	0.41%	0.31%	0.07%	0.48%
ECOREC	50.23%	50.23%	34.25%	22.49%	33.03%	22.13%	8.71%	39.21%	11.02%	28.77%	15.93%	28.56%	2.35%	4.66%	6.34%	2.98%	1.34%	1.42%	2.59%
ECOENU	24.12%	22.63%	24.12%	16.17%	19.79%	12.36%	6.00%	17.85%	6.26%	12.65%	8.02%	13.20%	1.13%	1.78%	3.19%	1.92%	1.10%	0.41%	1.39%
ECOPOS	21.12%	19.97%	21.12%	13.64%	17.37%	11.30%	5.60%	16.56%	4.56%	11.71%	6.74%	12.46%	1.15%	1.73%	2.57%	1.51%	0.46%	0.29%	0.96%
ECOREA	27.84%	26.33%	27.84%	15.58%	21.10%	14.05%	7.21%	22.22%	5.62%	16.97%	8.14%	15.57%	0.96%	2.86%	4.54%	1.49%	0.77%	0.48%	1.42%
ECOEXT	23.66%	22.08%	23.66%	17.89%	19.20%	12.33%	6.36%	18.60%	5.06%	13.97%	7.32%	15.02%	0.53%	1.54%	3.65%	0.89%	0.62%	0.24%	1.18%

3 Empirical Results

The results of the estimation values are presented in table 2. From this table it is visible an inverted U-shaped relationship between the number of eco-innovation strategies and turnover growth, except for the G sector (although not significant), but only significant for the entire sample and the Transportation and Storage sector (H). It is reasonable to state that our R^2 values are low, which is also common in other previous related literature (Jové-Llopis and Segarra-Blasco, 2018), inducing the need to include more variables into estimations to explain turnover growth besides those related to eco-innovations.

3 After removing the 4 outliers, the average of turnover growth became 0.2271 and its standard deviation 1.7993. Thus, after the treatment, EcoBreath turned out to be the variable with higher mean and volatility within the sample.

There are clear differences with respect to eco-innovations able to influence TG in Portuguese sectors. For now, and considering all firms in the survey, it can be observed that only facilitated recycling of product after use seems to exert a negative influence over TG. All the other environmental benefits obtained within the enterprise or by the end user (EcoBreath) have a positive influence over TG. When significant, the environmental benefits associated to marketing innovations (ecomkt) seem to negatively impact TG (for the entire sample, as well as in sections D+E, G and H). Size has also showed to have a clear positive impact over TG, despite not always being significant. For all firms and in sections C, H and K there is evidence to state that the higher the firm size, the higher the impact in TG. Employees education (percentage of employees with a tertiary degree: Empud1 and Empud2) only seems to have positive influence over TG in sections F and G, while negative in J and K, leading us to conclude that experience from employees maybe more important than education to TG.

With respect to environmental benefits obtained within the enterprise (EBWE) and considering the economic activity sectors, it is observable that the reduced air, water, noise or soil pollution (ECOPOL) has a negative and statistically significant impact over TG in the manufacturing sector (C) and in the wholesale and retail trade (G), but a positive one in Transportation and storage. Replacement shares of fossil energy by renewable energy sources have a positive and significant impact in G and in financial and insurance activities (K). Recycled waste, water, or materials for own use or sale (ECOREC) only reveals to be negative and statistically significant in transportation and storage (H), which may be related to the type of sector we are analysing. The same coefficient sign is present in the professional, scientific and technical activities and in the human health and social work activities sectors (M+Q). In all the other economic activity sectors and for the entire sample the coefficient is positive, although not significant, meaning that this type of eco-innovation improves TG.

Table 2
Regression results: Dependent variable Turnover Growth (TG - period 2012-2014)

Independents	All sample: Coeff.		Section C: Coeff.		Section D+E: Coeff.		Section F: Coeff.		Section G: Coeff.		Section H: Coeff.		Section J: Coeff.		Section K: Coeff.		Section M+Q: Coeff.	
EcoBreath		0.0705*		0.0223		0.5123		0.0567		-0.0021		0.2756***		0.1419		0.0238		0.0714
EcoBreath2		-0.0069*		-0.0040		-0.0462		-0.0061		0.0017		-0.0281***		-0.0121		-0.0039		-0.0048
ecomat	-0.0648		-0.0859		0.0054		-0.0548		-0.0400		-0.1098		0.1161		0.0287		-0.1730	
ecoeno	0.0312		-0.0176		0.3965		-0.0223		0.0447		0.1250		-0.3196		-0.1191		0.2704	
ecopol	-0.0062		-0.1174*		0.0967		0.0896		-0.0819***		0.5233**		0.6156		0.0607		0.2104	
ecosub	-0.0151		-0.0377		0.2844*		0.1046		-0.0143		-0.4451**		-0.2455		0.0768		-0.2511	
ecorep	0.1834		0.4096		-0.4561		-0.0144		0.1145**		0.0502		-0.2444		0.2269*		-0.2541	
ecorec	0.0466		0.0664		0.4772		0.1316		0.0936		-0.3496*		0.0579		0.0537		-0.0392	
ecoenu	0.0637		0.3031		-0.0128		-0.4052		-0.2467***		0.0414		-0.8151		-0.1319		-0.3299	
ecopos	-0.0309		-0.2609		-0.0374		0.3234		0.2878**		-0.0434		0.6143**		-0.1559**		0.5228**	
ecorea	-0.2044**		-0.2100		-0.1185		-0.4154		-0.2018**		-0.0688		-0.1185		-0.2386		-0.3444	
ecoext	-0.0228		-0.0363		-0.0455		-0.0895		0.1996***		-0.3005*		-0.4723		-0.0486		0.3236*	
EBWE	0.0623	0.0341	0.3127*	0.2776	-0.1129	0.2276**	-0.0228	0.0391	-0.3961**	-0.4107**	0.5735	0.2655	-0.2428	0.0497	0.1149**	0.1128	0.0182	-0.1361
EBEU	0.2015	0.0587	0.2260	0.1199	0.0647	-0.2711	0.4376	0.1272	0.0396	-0.0467	0.4341	0.1634	0.3448	-0.2063	0.3373	0.1147**	0.1328	0.0928
ecoprd	0.1030	0.1223	0.0556	0.0829	0.1410	0.1684	-0.0125	-0.0399	0.1741**	0.2230**	0.7065	0.6520	0.0986	-0.2236	-0.1150**	-0.0845*	-0.0611	-0.0012
ecoprc	-0.0017	-0.0147	-0.0065	-0.0208	-0.2291	-0.3244	-0.0774	-0.1064	0.2734*	0.2240**	-0.1691**	-0.1192**	0.2326	0.1451	-0.0418	-0.0593	0.0176	0.0011
ecorg	-0.0535	-0.0559	-0.0309	-0.0323	-0.1888	-0.1520	-0.0001	-0.0240	-0.2115**	-0.1842**	-0.1358	-0.2094	-0.1735	0.0868	-0.0642	-0.0316	0.1368	0.1255
ecomkt	-0.1206***	-0.1243***	-0.0711	-0.0611	-0.1311***	-0.2704**	0.0154	-0.0420	-0.1859*	-0.2287*	-0.3947**	-0.2867	-0.1479	-0.2048	0.0130	-0.0156	-0.2424	-0.2756
Empud1	-0.1645	-0.1860	-0.5002	-0.5352	0.2139	0.0683	-0.0465	0.0010**	0.1608**	0.1543**	omitted	omitted	omitted	-0.3160**	-0.0697	-0.1137*	0.0027	-0.0004
Empud2	-0.0540	-0.0592	omitted	omitted	omitted	omitted	omitted	omitted	omitted	omitted	-0.0497	-0.1028	0.1668	omitted	omitted	omitted	0.0000	0.0000
Size1	0.3049***	0.2742***	0.3772***	0.3269***	0.2810	0.1247	0.0729	0.0942	0.2260	0.2099*	0.6406***	0.5770*	0.4875	0.4278	0.0885	0.1174	0.0335	-0.0551
Size2	0.1377***	0.1174***	0.1774***	0.1559***	0.0657	-0.0405	-0.0156	0.0050	0.0900	0.0636	0.1488	0.1703	0.2573	0.1325	0.2336***	0.2776**	0.0535	0.0148
R^2	0.0319	0.0282	0.0259	0.0129	0.0593	0.0527	0.0773	0.0138	0.0715	0.0476	0.1016	0.0671	0.1619	0.0432	0.2658	0.1927	0.1313	0.0328

Both G and H sectors have more coefficients revealing statistical significance. With respect to the wholesale and retail trade sector (G) and considering environmental benefits obtained during the consumption or use of a good or service by the end user (EBEU), it is noticed that reduced air, water, noise or soil pollution (ECOPOS[4]) positively and significantly affects TG, as does extended product life through longer-lasting, more durable products (ECOEXT). ECOEXT also has a positive impact in TG in M+Q, but a negative one in transportation and storage (H). Considering the environmental benefits obtained within the enterprise (EBWE), section G is negatively influenced, which is not the case in K, C and D+E (Electricity, gas, steam and air conditioning supply + water supply, sewerage, waste management and remediation activities).

Finally, environmental benefits derived from product innovations have a positive influence in TG in G, but negative in K. Those derived from process innovations positively influence TG only in G section, while exerting negative pressure in TG in section H. Although not being statistically significant, except in the G section, the coefficient associated to environmental benefits due to organisational innovations seems to have a negative influence in turnover growth. From the four kinds of innovations (product, process, organisational and marketing) only product innovations seem to positively influence TG (even if not statistically significant overall, coefficient signs are positive for most sectors and the overall sample), except in the construction sector (section F), in sections J, K and M+Q. Our results are similar and contrast some of other authors' previous results for the entire sample, but provide useful thought about the need to consider sectors in an independent way while analysing the relationship between turnover growth and eco-innovations, leaving room for other future research avenues.

4 Conclusions

This work analyses the relationship between turnover growth (TG) and eco-innovation strategies for a sample of 7083 Portuguese firms, whose data is available in the CIS 2014 survey. As far as we are aware we are the first to use this more recent data and survey to analyse this relationship. Although a lot more remains to be done within the field, we have considered different economic activity sectors in order to analyse if the relationship changes among them. The study has, however, some limitations, namely with respect to the data availability in the sample that does not allow us to take a deeper look on other factors the influence turnover growth and because we had to restrict the analysis to a cross section regression. Nevertheless, results suggest that different eco-innovation strategies have different influence over different sectors. Replacement shares of fossil energy by renewable energy sources have a positive and significant impact in two sectors. This may induce that replacement of fossil fuels increases TG, an important result for firms, which have to accomplish with the European rules – increase of renewables share in total energy consumption. This result thus evidences that firms may gain from this replacement in terms of turnover growth, while contributing to overall European policies. Recycled waste, water, or materials for own use or sale (ECOREC) only reveals to be negative and statistically significant in transportation and storage (H), but it may be related

4 Also, it has a positive impact in TG in section J (Information and Communication sector), in section M+Q, but a negative and significant effect in section K.

to the specific activity in this sector. We find the same coefficient sign in the professional, scientific and technical activities and in the human health and social work activities sectors (M+Q). In all the other economic activity sectors and for the entire sample the coefficient is positive, although not significant, meaning that this type of eco-innovation improves TG, leaving room for a higher bet in recycling that seems to increase firms turnover growth. Finally, and contrarily to Jové-Llopis and Segarra-Blasco (2018), we may conclude that, in general, for all the sectors involved, the undertaking of an eco-strategy, in order to be more resource efficient, is associated with increased growth in turnover. Furthermore, there seems to exist an inverted U-shaped relationship between the number of eco-innovation strategies implemented and the turnover growth.

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Does Government Support for Private (Eco-) Innovation Matter? A European Comparison

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Abstract

Eco-innovation is defined as an innovation that achieves a life-cycle of products with less use of natural resources and with less environmental impact. For that, innovation efforts are required from firms, and government support, contributes to eco-efficiency, despite allowing for firms general innovation performance. In recent years, European countries sought to improve the innovation performance of companies by increasingly offering grants for innovation activities. Looking at a large sample of data of several European countries from the most recent community innovation survey (CIS 2014), this article empirically examines whether government aid has improved innovation performance as well as eco-innovation performance, measured by the introduction of environmental friendly practices. With this research, we intend to contribute to the literature of the determinants of eco-innovation. We find that government aid for R&D activities has contributed to better eco-innovation performance by firms in European countries. However, firms attribute only a medium importance rule to this kind of policies. Taxes seem to be more effective than subsidies or grants, being market instruments more relevant for production process eco-innovations. However, the concerns on reducing for instance energy costs lead to more sensitiveness of firms to regulations. Recommendations regarding government support are suggested.

KEYWORDS
Innovation; Eco-innovation; Manufacturing firms; Government support; Determinants; Policy directions.

1 Introduction

In the transition of the developed economies from a linear paradigm to a circular paradigm, eco-innovation has been playing a key role. EIO (2012) refers to Eco-innovation as any innovation that reduces the use of natural resources and decreases the release of harmful substances across the whole life-cycle. EEA (2016) shows that there is a strong investment gap in eco-innovation related, for example to the circular design of products, recycling and recovery of waste. Business models based on new product features and new consumption patterns need to be supported and to have the right framework to grow.

The range of policy measures mentioned to be applied are regulatory instruments, economic instruments, such as fiscal and financial incentives (taxes, fees), direct funding, demand pull instruments (e.g. procurement), R&D support measures, such as grants, infrastructure provision, supporting R&D personnel, information, education and networking support measures, and voluntary measures including performance labels and guarantees for products, voluntary agreements and commitments. According to EEA (2016), most of these policies in European countries, on one hand, are connected to waste targets and to the use of secondary raw materials, but it does not yet have a truly circular character. On the other hand, these policies are perceived and interpreted differently by different countries or stakeholders, and are not connected to particular context (such as climate, competitiveness or employment). The type of policies that have become more popular are linked to consulting services and to the provision of information on circular economy and eco-innovation for both companies and consumers. There is also a growing trend towards networking and collaboration platforms as policies. A less common type of policy are the measures to support professional training or skills enhancement.

The most common categorization of environmental policies, tailored to eco-innovation, is divided between command and control policies (regulation) and market-based instruments (such as taxes and subsidies). In the literature, it is often argued that market instruments are more cost- and flexibility-efficient than the first type (Demirel and Kesidou 2011, Requate 2005, Cleff and Rennings 2000). Despite this, another strand of literature argues that, for promoting eco-innovation, the tools of command and control may be more effective (Porter 1991, Porter and Van Der Linde 1995, Hart 2004, Popp, 2005).

In the literature, we may also find an intermediate perspective, which states that the two types of instruments are more or less effective, depending on the type of eco-innovation considered (Rammel and van den Bergh 2003, van den Bergh et al. 2007, Nill and Kemp 2009). Johnstone (2007) shows that market instruments are not considered as the most important drivers for eco-innovation, being more relevant to changes in the production process. In fact, both in the context in which eco-innovation is developed and the type of clean technology that aims to be stimulated, there is not one instrument superior to another (Kemp 1997). Frondel et al. (2007) and Demirel and Kesidou (2011) show that command and control instruments are an important driver in end-of-pipeline solutions, but have a minimal role for integrated cleaner production technologies.

There are authors who argue for a joint use of both types of instruments (command and control and market instruments), since environmental innovation is complex and involves technical, economic, social components and others (Geels and Schot 2007). In fact, Triguero el al. (2013) state that the lack of effectiveness of subsidies or fiscal incentives in promoting eco-innovation makes it necessary to regulate more rigorously. The authors recommend EU certification of environmental management systems, as EMAS or ISO 14001, instead of subsidies or tax incentives. The success of the instruments depend in part on how companies understand policies, that is, companies that innovate, have to transform the present policy sustainability objectives into value creation for customers, adding to it temporal constraints, information constraints on customer needs, financial constraints and other elements (Keskin et al. 2013).

Many companies look to public policies and support as fundamental to the development, diffusion and success of eco-innovation (Boons et al. 2013, Kanda et al. 2014). There is a great deal of uncertainty for firms on the success of eco-innovation, both financially and on their commitment to sustainability. This issue often leads them to naturally decide not to adopt eco-innovation (Kemp 2000). In this sense, public policies are a key piece (Paraskevopoulou 2012, Beise and Rennings 2005, Kemp 2011). The literature suggests that environmental regulations affect eco-innovation as firms respond to environmental regulations with higher levels of eco-innovations.

The goal of this article is to statistically examine whether government aid has improved innovation performance as well as eco-innovation performance, measured by the introduction of process innovations, product innovations new to the firm and new to the market, as well as environmental friendly practices. This research is innovative in the literature due to the data analysis on the most recent CIS and eco-innovation support success (eco-innovation is only included in the most recent CIS 2014, and previously it had only been included in CIS 2008) to assess this question in European firms, through a model of endogenous support. The results should be relevant to propose new government support policy or reinforcing existing policies and to compare different strategies among European countries.

The next section describes the methodology and data, section 3 the main results, and conclusions and recommendations are included in section 4.

2 Methodology and Data

Our study rests on data collected in the context of the Community Innovation Survey of the European Commission, carried out with two years' frequency. In 2008, a separate section on environmental innovations was introduced (section 10) and more recently repeated in 2014 (section 13). These sections question directly if, during the three years 2006-2008 and 2012-2014, the enterprise introduced any innovation with environmental benefits.

Several firms from several different sectors answered the CIS. Eco-innovations are measured on ten different areas of environmental impacts (see table 1). The question included was "During the three years 2012 to 2014, did your enterprise introduce a product (good or service), process, organisational or marketing innovation with any of the following environmental benefits?" Six refer to impacts stemming from processes in the firm, while four are areas of environmental impacts from the after sales use of a product by its user. All environmental innovations must have been introduced during the three years' period, 2012 to 2014.

Table 2 describes the questions and the answers to questions related to kinds of innovation associated to eco-innovation, driving factors and procedures in place. The analysis to be performed is statistical and split by country, considering the survey answers available. Data will be presented in percentage terms from the total. The next section discusses the main results and evidences resulting from the data treatment performed with special emphasis over the importance of the provided factors in driving the enterprise's decision to introduce innovations with environmental benefits.

Table 1
Innovations' environmental benefits

Environmental benefits obtained within the enterprise	
Reduced material or water use per unit of output – ECOMAT	Yes=1; Otherwise=0
Reduced energy use or CO2 'footprint' (reduce total CO2 production) – ECOENO	Yes=1; Otherwise=0
Reduced air, water, noise or soil pollution – ECOPOL	Yes=1; Otherwise=0
Replaced a share of materials with less polluting or hazardous substi	Yes=1; Otherwise=0
Replaced a share of fossil energy with renewable energy sources – ECOREP	Yes=1; Otherwise=0
Recycled waste, water, or materials for own use or sale – ECOREC	Yes=1; Otherwise=0
Environmental benefits obtained during the consumption or use of a good or service by the end user	
Reduced energy use or CO_2 'footprint' – ECOENU	Yes=1; Otherwise=0
Reduced air, water, noise or soil pollution – ECOPOS	Yes=1; Otherwise=0
Facilitated recycling of product after use – ECOREA	Yes=1; Otherwise=0
Extended product life through longer-lasting, more durable products – ECOEXT	Yes=1; Otherwise=0

Table 2
Kinds of innovation associated to eco-innovation, driving factors and procedures in place

From where environmental benefits come from?	
Product (goods or services) innovations – ECOPRD	Yes=1; Otherwise=0
Process innovations – ECOPRC	Yes=1; Otherwise=0
Organizational innovations – ECORG	Yes=1; Otherwise=0
Marketing innovations – ECOMKT	Yes=1; Otherwise=0
Importance of factors for environmental benefits innovations?	
Existing environmental regulations – ENEREG	High=3; Medium=2; Low=1; No relevance=0
Existing environmental taxes, charges or fees – ENETX	High=3; Medium=2; Low=1; No relevance=0
Environmental regulations or taxes expected in the future – ENREGF	High=3; Medium=2; Low=1; No relevance=0
Government grants, subsidies or other financial incentives for environmental innovations – ENGRA	High=3; Medium=2; Low=1; No relevance=0
Current or expected market demand for environmental innovations – ENDEM	High=3; Medium=2; Low=1; No relevance=0
Improving your enterprise's reputation – ENREP	High=3; Medium=2; Low=1; No relevance=0
Voluntary actions or initiatives for environmental good practice within your sector – ENAGR	High=3; Medium=2; Low=1; No relevance=0
High cost of energy, water or materials – ENCOST	High=3; Medium=2; Low=1; No relevance=0
Need to meet requirements for public procurement contracts – ENREQU	High=3; Medium=2; Low=1; No relevance=0
Procedures in place to identify and reduce environmental impact?	
No = 0 / Yes = 1 – ENVID	
Some procedures were implemented before 2012 (tick = 1) – ENVBF	
Some procedures were implemented or significantly changed between 2012 and 2014 (tick = 1) – ENVBT	

3 Results and discussion

Table 3 presents the results considering the percentage of firms that stated in the survey to have introduced environmental benefits, obtained within the enterprise, and environmental benefits obtained during the consumption or use of a good or service, by the end user, by country. Concerning data on countries, we may conclude that Czech Republic, Germany, Greece, Croatia and Portugal are among those countries where firms seem to have introduced more eco- innovations, whereas most firms in European countries state to have introduced environmental benefits within the firm related to reduced energy use or CO2 'footprint' (reduce total CO2 production - ECOENO), followed by recycled waste, water, or materials for own use or sale (ECOREC). The number of firms answering the survey is not identical for all countries, turning into a difficult task the comparisons among the available sample.

However, table 4 evidences the percentage of firms, which declared that, the environmental benefits introduced and identified, were due to the following types of innovations: product, process, organizational or marketing. From these firms and not considering Czech Republic and Germany, where we had no answers, in most of the country firms the eco-innovations adopted were related to process innovations, whereas only in Hungary most firms answered that eco-innovations were mostly due to product innovations.

With respect to the factors which drive the enterprise's decisions to introduce innovations with environmental benefits, during 2012 to 2014, the percentage of respondents for each factor identified in the survey are presented in table 5, considering the importance degree stated by each firm in each country. In all countries, we might infer a very interesting result considering the factors presented. Firms in Bulgaria, Cyprus, Hungary, Lithuania, Latvia and Slovakia attribute high importance to environmental innovations which improve the enterprise's reputation (ENREP), followed by the introduction of environmental benefits due to high cost of energy, water or materials (ENCOST) more than they do to government grants, subsidies or other financial incentives for environmental innovations (ENGRA). Nevertheless, this result may not be extended to all countries in our sample.

Results point that in countries as Germany, Estonia Greece, Croatia, Portugal and Romania, environmental regulation is of high importance among the other factors considered. Moreover, in Germany, Estonia, Croatia and Portugal, firms attribute high importance to high cost of energy, water or materials for the introduction of environmental innovations. Even so, in almost all countries the factor most pointed with high importance is high costs incurred. Thus if firms introduce more eco-innovations, considering high costs will be an advantage in environmental terms. Existing environmental taxes, charges or fees (ENETX), environmental regulations or taxes expected in the future (ENREGF) and government grants, subsidies or other financial incentives for environmental innovations (ENGRA) are not factors pointed firstly according to the importance to justify the introduction of environmental friendly innovations. However, they are considered, by all countries and firms, as having medium importance among all reasons. Unfortunately, there are less firms stating to have introduced eco-innovations than those with product, process, organizational and marketing innovations. Nevertheless, we may argue from this fact that more and better environmental policies should be implemented in order to improve eco-friendly practices among firms in all European countries.

Table 3
Percentage of firms having introduced environmental benefits (table 1 for variables description)

	BG	CY	CZ	DE	EE	EL	HR	HU	LT	LV	PT	RO	SK
ecomat	2.58%	6.02%	12.43%	23.11%	8.64%	13.32%	10.63%	5.56%	9.75%	6.66%	16.84%	1.79%	6.31%
ecoeno	2.34%	8.47%	**15.76%**	**36.61%**	**10.68%**	**17.19%**	**11.30%**	**5.87%**	**18.59%**	**9.19%**	19.47%	1.78%	**6.77%**
ecopol	**2.59%**	6.32%	11.31%	23.16%	7.10%	12.49%	10.57%	5.03%	13.05%	6.93%	17.32%	**2.63%**	6.02%
ecosub	2.21%	5.05%	8.25%	13.26%	6.53%	11.57%	8.36%	5.52%	8.14%	5.46%	15.85%	1.40%	3.55%
ecorep	0.73%	4.01%	3.46%	11.49%	3.24%	3.79%	3.15%	2.05%	3.35%	1.73%	5.87%	0.46%	1.43%
ecorec	2.33%	**9.51%**	14.02%	20.42%	8.01%	15.36%	10.66%	4.88%	7.15%	5.53%	**29.55%**	2.35%	5.77%
ecoenu	1.60%	4.61%	11.70%	23.70%	8.18%	15.80%	9.13%	4.40%	11.36%	5.86%	14.19%	1.36%	4.66%
ecopos	2.01%	3.86%	8.62%	15.66%	6.14%	11.17%	9.59%	3.71%	9.71%	5.46%	12.42%	1.94%	3.94%
ecorea	1.77%	4.38%	7.39%	13.10%	3.86%	14.76%	8.48%	2.99%	5.91%	4.73%	16.38%	1.39%	3.41%
ecoext	2.03%	2.90%	9.73%	12.45%	5.57%	12.41%	7.53%	3.80%	6.28%	4.73%	13.92%	1.52%	3.48%

Table 4
Percentage of firms whose eco-innovations where product, process, organizational or marketing innovations (table 1 for variables description)

	BG	CY	CZ	DE	EE	EL	HR	HU	LT	LV	PT	RO	SK
ecoprd	2.48%	7.80%	0.00%	0.00%	7.16%	14.24%	5.70%	**5.18%**	9.09%	8.39%	11.55%	1.63%	5.30%
ecoprc	**2.67%**	**14.26%**	0.00%	0.00%	**9.66%**	**16.00%**	**7.57%**	3.51%	**21.77%**	**9.86%**	**15.84%**	**1.83%**	**5.70%**
ecorg	2.26%	6.24%	0.00%	0.00%	3.41%	11.45%	6.37%	1.66%	5.87%	6.13%	9.91%	1.61%	3.01%
ecomkt	0.98%	2.82%	0.00%	0.00%	2.39%	7.62%	2.08%	1.03%	2.81%	2.47%	3.92%	0.74%	1.29%

Figure 1 represents the medium and high importance attributed to the factors directly related to environmental policies and regulations. To construct both figures the percentage of firms answering for the relevance of factors related to these policies where reconstructed on the basis 100 for medium and high importance degrees.

From 2012 to 2014, firms had to answer to the question: how important were the factors, in driving the enterprise's decision to introduce innovations with environmental benefits. Those factors to be considered were existing environmental regulations (ENEREG), assumed as a variable of command control, environmental regulations or taxes expected in the future (ENRREGF), as an expectation variable, and the market policies government grants, subsidies or other financial incentives for environmental innovations (ENGRA) and existing environmental taxes, charges or fees (ENETX). All not pointed out above other factors were summed up and considered as others. As evidenced in figure 1, in some countries, both the command control factor and the expectations factor have a higher importance attributed. However, in Croatia, Lithuania, Latvia and Slovakia, the factor most considered with medium importance was the market factor and existing environmental taxes, charges or fees. Thus, in these countries the existent fiscal charges justify on the firm´s point of view, the introduction of environmental innovations. The ENGRA factor was mentioned as the less relevant in all countries. Therefore, financial incentives are not so effective as taxes, or command and control policies.

However, considering the high importance attributed to some of the factors, we observe in figure 1 that the highest relevant one mentioned to justify the introduction of environmental innovations in terms of product, process, organizational or marketing innovations is the existence of environmental regulations. Germany is the country where enterprises seem to be more influenced by this policy as a driver for eco-innovation. Thus, firms introduce eco-friendly innovations, both nationally and in European context, since they are demanded by law to do it, evidencing that governments need to continue enforcing the implementation of eco-innovations in order to oblige firms to do it. Moreover, we may infer from here that firms in Europe seem to still not take advantage from government grants, subsidies or other financial incentives for environmental innovations. Indeed, the percentage of firms that mention both medium and high importance to this factor is still very small, as compared to other market policies like taxes, command and control and expectation factors, related to public policies to enforce environmental innovations.

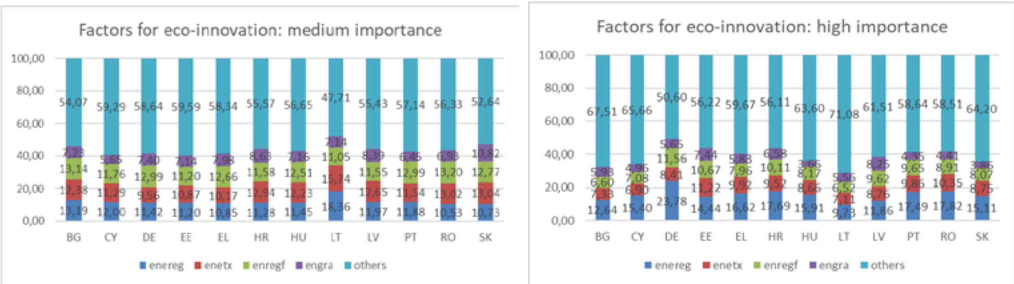

Figure 1
Medium and high importance relevance: factors considered by firm and country: command control, expectations, market and others

To end up, we present in table 5 the percentage of firms which have answered positively to if they have procedures in place to regularly identify and reduce the enterprise's environmental impacts and if they had them implemented before 2012 or if these procedures were implemented or significantly changed between 2012 and 2014. Results are clear and, in almost countries, around 25% of the sample of firms' remark they have regular procedures in place. Among the countries, Greek firms are those evidencing the highest percentage, most of them previously to 2012. We may conclude that environmental policies are being considered by firms that are using these rules and impositions to highlight themselves in the environmental degradation context.

	BG	CY	CZ	DE	EE	EL	HR	HU	LT	LV	PT	RO	SK
envid	7.03%	27.56%	0.00%	0.00%	22.16%	34.46%	24.66%	27.23%	26.81%	24.72%	28.15%	15.93%	19.75%
envbf	3.80%	23.70%	0.00%	0.00%	16.93%	25.37%	17.49%	22.30%	0.00%	15.12%	19.03%	0.00%	15.95%
Envbt	3.91%	5.72%	0.00%	0.00%	13.35%	18.79%	11.33%	9.70%	0.00%	16.59%	20.47%	7.37%	11.40%

Table 5
Percentage of firms with procedures in place to reduce environmental damage (table 3 for variables description)

4 Conclusions

We might conclude from this research that firms are very different regarding the importance attributed to different factors able to explain eco-innovation practices among European countries. Yet, most of these firms mention the high importance on the high-energy costs as main reason to justify the implementation of eco-friendly practices, when it turns to innovations. Considering governmental policies and EU policies, firms refer only a medium role of importance to these as being one of the factors in driving the enterprise's decisions to introduce innovations with environmental benefits, regardless of the country. .

It is not clear if enterprises are driven by market instruments or by command and control instruments. Nevertheless, through market instruments, taxes seem to be more effective than subsidies or grants. As Triguero el al. (2013) revealed, the lack of effectiveness of subsidies or fiscal incentives in promoting eco-innovation justifies the need for more rigorous regulation, recommending EU certification or environmental management systems, instead of subsidies or tax incentives.

The effect of public policies seem to be connected with the kind of eco-innovation adopted, as seen in former literature. Our results are in accordance to Johnstone (2007) that conclude that market instruments are not the most important driver for eco-innovation, being these instruments more relevant for changes in the production process. In fact, most firms in European countries have introduced eco- innovations related to reduced energy use or CO2 'footprint', followed by recycled waste, water, or materials for own use or sale, and related to process innovations.

Moreover, our results seem to show that eco-innovating companies are more concerned about reducing costs, mainly aiming to become more competitive and efficient. As stated by authors before (Porter 1991, Porter and Van Der Linde 1995) these concerns lead to more sensitiveness of firms to regulations. Summing up, if regulations exist, companies produce more "green" goods and services and have more profits. This, in turn, encourages innovation and economic growth, and firms will be more competitive.

Acknowledgements

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Covenant of Mayors for Climate and Energy Study Area: Northern Region of Portugal

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Abstract

Climate change is currently one of humanity's greatest challenges, for which the participation of the Regional and Local Power is crucial, in the definition of policies and synergies "aligned" with European directives, with regard to the assumed energy and climate commitments.

The Covenant of Mayors for Climate and Energy and the targets defined by the European Union, is an example of voluntary adherence by a group of Signatories adhering to the Covenant. They commit to defining and implementing measures and actions to reduce CO2 emissions by at least 40% by 2030 and to adopt an integrated approach to dealing with mitigation and adaptation to climate change.

To that end, the energy matrix adopted by the Signatories is one of the main pillars for achieving such objectives and serving as a conduit for better energy efficiency and eco-efficiency in the goals defined by the municipalities in the various vectors and sectors identified, as well as in participation of citizens in favour of a better quality of life.

KEYWORDS
Covenant of Mayors for Climate and Energy, Climate Change, Energy and Sustainable Action Plan, Northern Portugal

1 INTRODUCTION

In order to reduce CO_2 emissions, in 1997 the Kyoto Protocol was adopted. This obliges the signatory countries to limit or reduce their emissions, compared to 1990 levels. The particularly harmful nature of air pollution, in relation to other risk factors in the urban environment, justifies the importance given to it (Andrade, 2005).

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) points out that scientific evidence regarding the influence of anthropogenic activities on the climate system is stronger than ever and that global warming of the climate system is unequivocal, highlighting an enormous probability that GHG emissions are the dominant cause of warming in the 20th century (QEPIC, 2015).

The objective of this article is based on understanding and discussing the importance of the Agreement of Accession to the Covenant of Mayors for Climate and Energy, within the framework of the commitments made by Signatories to the Covenant.

It is intended to demonstrate the importance of municipal government participation and the need to define policies and synergies that are aligned with European guidelines on energy and climate commitments for the sustainable development of cities and the planet.

Still, the implementation of sustainable energy policies and measures, in view of the territorial dynamics of reducing CO_2 emissions by at least 40% by 2030, integrated to deal with mitigation and adaptation to climate change, contributing to sustainability till 2030 (URL 1, 2017), having as a case study the Northern Region of Portugal.

2 COVENANT OF MAYORS FOR CLIMATE AND ENERGY

In 2008, following the adoption of the EU Energy-Climate Package (Package 20-20-20) and in light of the IPCC reports, the European Union affirmed its contribution to climate change mitigation and reduction of CO_2 emissions through dependence on fossil fuels. Then emerged a European movement - The Covenant of Mayors launched in 2008 by the European Commission. Considered by the European institutions as an exceptional model of governance of urban initiative, it brings together a panoply of local and regional authorities whose membership is voluntary for designated Signatories and who are committed to the implementation of initiatives on climate and energy European Union in their regions / municipalities.

Following the adoption of the EU Energy-Climate Package for 2020, the European Commission launched the Covenant as a way of subscribing and supporting the efforts of local authorities in the implementation of sustainable energy policies. In 2014, the “Mayors Adapt” initiative was launched, which invited municipalities to commit themselves to anticipatory actions regarding possible impacts of climate change. By the end of 2015, the two initiatives merged into the new integrated Covenant for Climate and Energy, adopting the EU’s 2030 objectives and an integrated approach to climate change mitigation and adaptation, implementing the GHG reduction target by 40% by 2030, advocated by the European Union. Furthermore, the adoption of an integrated approach to mitigation and adaptation to climate change, ensuring access to safe, clean and affordable energy that is sustainable and accessible to all (URL 1, 2017).

During the Climate Summit in Paris, the geographical extension of the Covenant of Climate and Energy was announced with new regional secretariats to be established in Sub-Saharan Africa, North and South America, Japan, India, in China and Southeast Asia (URL 1, 2017). The "Covenant of Mayors for Climate and Energy" was launched in January 2017 and is aligned with the United Nations Sustainable Development Goals and the principles of climate justice.

The Action Plans of the Covenant of Mayors, designated by the PAES (Sustainable Energy Action Plans) and PAESC (Sustainable Energy Action Plans) sent by the Signatories, include the Reference Energy Matrix for a given territory, which is based on a Reference Inventory of emissions (IRE) and an Impact Assessment and Vulnerability on Climate Change. In the preparation and drafting of an IRE, a survey of the energy situation of the city by the Signatories of the Pact is conducted to determine which sectors are most carbon-intensive, and around which public, private or municipal funding measures should be adopted through public or private partnerships.

The 7589 Signatories, covering 52 countries adhering to the Covenant, cover a population of 235,853,133 inhabitants. Their spatial distribution, mainly European, represent cities, which varies according to their population size. According to the 2014 report of the Covenant, the largest population, including 56%, with Signatories adhering to the Covenant belong to large urban centres and large metropolis with a population of over 250,000, 17% to medium, 16% in medium-sized and 9% in small urban centres. With the objective of providing strategic guidance, technical support and financial support to the Signatories, in the elaboration of the CO_2 IRE and the PAES/PAESC, the Covenant also includes "supporting figures", namely 205 Coordinators, 106 promoters and 66 Local and Regional Energy Agencies, crucial in ensuring good implementation and implementation of the SEAPs. Furthermore, in addition to the EU, the Covenant also has the support of the Committee of the Regions, the European Parliament and the European Investment Bank (EIB), which provide support to local authorities as regards the release of their potential investments (URL 2, 2017). In a Global scale, Italy, Spain, Belgium, Greece and Portugal are the countries with the highest PAES submitted by region.

3 STUDY AREA: NORTH REGION OF PORTUGAL

The Northern Region of Portugal has a resident population of 3 689 682, according to the census of 2011, a population distributed in 86 municipalities and 1426 parishes, in the eight sub-regions. It is limited to the north and east of Spain, to the south with the Central Region and to the west with the Atlantic Ocean, covering all the Districts of Braga, Bragança, Porto, Viana do Castelo and Vila Real and some municipalities of the districts of Viseu, Guarda and Aveiro.

Methods

The accomplishment of this article presupposes a directed reading for the Plans of Action for the Sustainable Energy, based on collecting qualitative information of the Energy Matrix that served as base for each municipality. The study area was directed to the municipalities of the North of Portugal adhering to the Covenant of Mayors for Climate and Energy. As regards its methodological process, the Energy Matrix of these Municipalities varies between 2003 and 2009 in its base year, and the Emission factor corresponds to the "IPCC - Standard emission factors in line with the IPCC principles".

3.1 Results

Of the commitments made in the PAES, 5854 PAES are already registered in the Covenant Portal. 5690 refer to a commitment to 2020 on climate change mitigation, 105 with a commitment to adapt to climate change and to reduce CO_2 emissions by 20% by 2020 and 59 with a commitment by 2030 to the level of mitigation, in 40% reduction of CO_2 emissions.

Of the 113 municipalities adhering to the Covenant in Portugal at the date of this article (table 1), 50 (44%) belong to the Northern Region of Portugal (Fig. 1), 99 have already been accepted by the Covenant Council and are available on the Covenant Portal, 96 aim to reduce CO_2 emissions by 20% by 2020 at a mitigation level and 10 aim to reduce 20 % emissions by 2020 at the level of adaptation.

Table 1
Signatory municipalities adhering to the Covenant of Mayors in the Northern Region of Portugal. Source: (URL 2, 2017)

Área Metropolitana do Porto	Alto Minho	Alto tamega Tâmega	Ave	Cávado	Douro	Tâmega e Sousa	Terras de Trás-os-Montes
Arouca	Arcos de Valdevez	Boticas	Cabeceiras de Basto	Amares	Alijó	Amarante	Alfândega da Fé
Espinho	Caminha	Chaves	Fafe	Barcelos	Armamar	Baião	Bragança
Gondomar	Melgaço	Montalegre	Guimarães	Braga	Carrazeda de Ansiães	Castelo de Paiva	Macedo de Cavaleiros
Maia	Monção	Ribeira de Pena	Mondim de Basto	Esposende	Freixo de Espada à Cinta	Celorico de Basto	Miranda do Douro
Matosinhos	Paredes de Coura	Valpaços	Póvoa de Lanhoso	Terras de Bouro	Lamego	Cinfães	Mirandela
Oliveira de Azeméis	Ponte da Barca	Vila Pouca de Aguiar	Vieira do Minho	Vila Verde	Mesão Frio	Felgueiras	Mogadouro
Paredes	Ponte de Lima		Vila Nova de Famalicão		Moimenta da Beira	Lousada	Vila Flor
Porto	Valença		Vizela		Murça	Marco de Canaveses	Vimioso
Póvoa de Varzim	Viana do Castelo				Penedono	Paços de Ferreira	Vinhais
Santa Maria da Feira	Vila Nova de Cerveira				Peso da Régua	Penafiel	
Santo Tirso					Sabrosa		
São João da Madeira					Santa Marta de Penaguião		
Trofa					São João da Pesqueira		
Vale de Cambra					Sernancelhe		
Valongo					Tabuaço		
Vila do Conde					Tarouca		
Vila Nova de Gaia					Torre de Moncorvo		
					Vila Nova de Foz Côa		
					Vila Real		
					Resende		

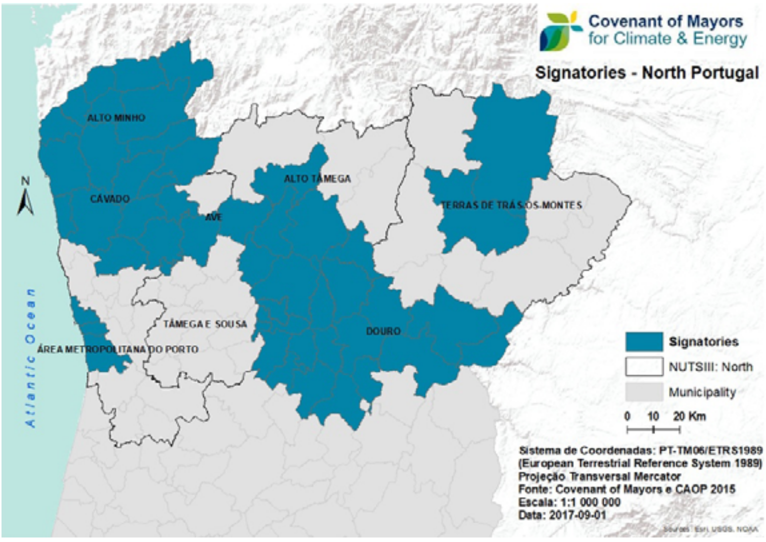

Fig .1
Northern Region of Portugal

There was a greater adhesion of Signatories of the Northern Region between 2012 and 2015. Based on the indicator "Greenhouse gas emissions (GHG) and final energy consumption per capita (MWh/ capita), there was a higher consumption in the municipalities of Esposende (67 MWh/capita), and in Matosinhos whith 18,8 MWh / capita (Fig.2).

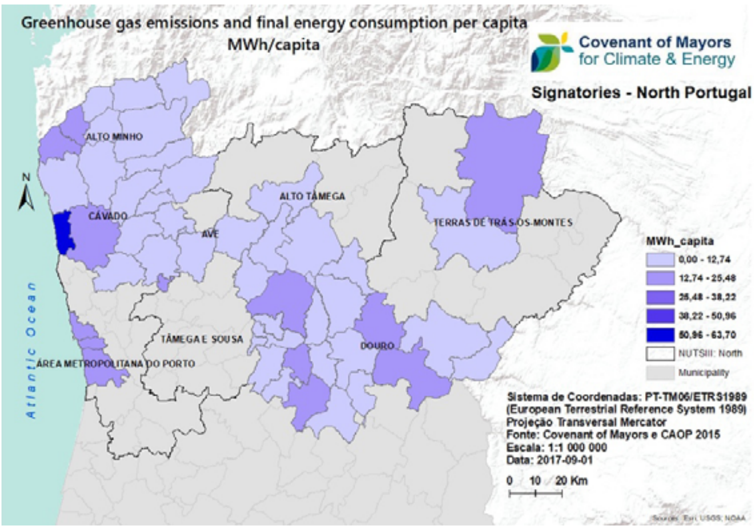

Fig .2
Signatories of the Northern Region of Portugal - Greenhouse gas emissions (GHG) and final energy consumption per capita (MWh/capita)

Having present the target defined in the Covenant, namely 20% in the reduction of CO_2 emissions, it was verified that the municipality of Porto as the most ambitious target, in the reduction relative to 45%, which makes according to the calculations of this municipality a reduction of CO_2 emissions corresponding to 586 747,8 t/ CO_2.

3.1.1 Energy Vectors

The emissions inventory is the first phase of the PAES, which allows a sectorial energy analysis of the most representative sectors in a given territory. Based on the consistency of the results presented in comparative terms between the data provided in the PAES consulted, the information presented in the following data refers only to 30 Signatories of the 50 Signatories adhering to the Pact in the northern region of Portugal (Fig. 3).

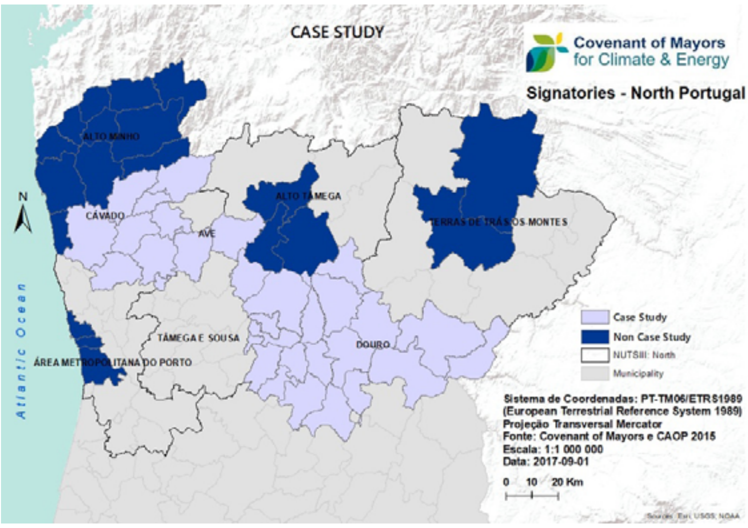

Fig .3
Signatories of the Northern Region of Portugal - Area Study (Municipality)

In a comparative context, between the scenario 2010 and 2020 the following analyse was verified:

- In the evolution of the proportion of the consumption of each energy vector in the total consumption of energy consumed, it was verified that the electricity presents less positive results in a long-term scenario in a regional context;

- In energy consumption by activity sector, it was found that the industry sector and the services sector are those that in a long-term scenario show a slight increase;

- In the consumption of petroleum fuels by sector of activity, there was a slight increase of consumption in the domestic sector and in the transportation sector;

- Total consumption of energy by activity sector, the results show a slight increase in the domestic sector;

- The domestic sector, presents an increase, with respect to the CO_2 emissions by sector of activity consuming electric energy;

- In the distribution of results by sector CO_2 emissions (tCO2e) per energy vector consumed, there was a slight increase in the electricity sector and in the Natural Gas sector;

- With regard to local renewable energy production, it was verified that in 2010 water production is clearly the one with the highest energy performance, followed by wind energy, Biogas and photovoltaic energy production;

- With regard to this information and estimates of the value of investment in energy sustainability required for the implementation of PAES measures, it has been verified that, overall, the largest investment is of a private nature, namely in municipal buildings infrastructures, investments in the transport sector and Renewable Energy Production.

With regard to local renewable energy production, water production and wind energy are the most evidence of a higher energy performance, so it is essential to build common goals for the territory, taking advantage of the natural resources that boost its renewable energy increment, as well as to adapt policy instruments that promote substantive measures face of common municipal challenges and practices in sustainable energy.

In summary, it should be noted that this whole process not only contributes to urban sustainability, but also to the very growth and economic and environmental development of cities across the globe.

4 Conclusions

Between the preparation of diagnoses of Action Plans for Climate and Energy, private or public support or support from private, public or municipal sources, it is important to rethink and continue the work carried out by the authorities at local or regional level in in terms of initiatives and measures to mitigate and adapt to climate change, through various instruments and territorial agents, so that they can be increasingly effective in overcoming the challenges and problems diagnosed at the municipal level.

From the point of view of the objectives of this article and the cross-cutting of the final results, undoubtedly the transport sector and the domestic sector, are the sectors of electricity consumption activity that most need in the medium and long term of a definition of environmental policies with regard to CO_2 emissions.

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Commercial Possibilities, and Energy Gain Potentials of Exploiting Waste, Tree Bark and Hemp Residues to Construct Insulation Boards

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Abstract

Two dissimilar waste materials have been mixed to constructing an insulation board. Tree bark from Greek pine "Pinus Nigra" together with Cannabis Sativa (Hemp) residues was combined in altered proportions with a methyl-cellulose glue. The objective was to identify the possibilities of a combined insulation board for structural use. Diverse methods of processing the final boards have demonstrated altered thermal properties based also on the different humidity. The results have validated the possibility of exploiting local waste materials to produce an eco-friendly, low priced insulation product with an acceptable thermal properties compared to the market products. The energy requirements of these boards were kept low and the carbon footprint is more advantageous compared to traditional chemical insulation materials due to the small distance (≤100Km) between the source (waste materials) and the production site (laboratory).

KEYWORDS
Waste to energy, insulation boards, wood by-products, agricultural residues

1. INTRODUCTION

Domestic buildings are the foremost contributors to carbon emissions (IGT, 2010). In this sector, the highest portion of energy is spent on retaining indoor thermal ease via space heating. Until recently, this was accommodated by massive fossil fuel consumption. This heat energy demand may be reduced by adequately insulating buildings (Mackenzie et al, 2010). However, the trend which comes from political as well as from environmental policies, desires to find alternatives to fossil fuels. The need to exploit waste materials at the highest possible percentage, is a one-way path towards a sustainable and eco-friendly energy approach.

The most commercial insulation products today are based on oil. Switching to more environmental friendly materials to insulate the dwelling's shell has to be everybody's primary target. The tree bark comprises approximately ten per cent of any given tree. The bark protects the layer of cambium of the tree mitigating also the harmful effect of fire (Bauer et al, 2010, Wang – Wangen 2011). A number of products come from tree bark like absorbers and raw material for fertilizers, however, the need for higher valued products is always the ultimate goal for each material (Naundorf et al, 2004). It has been already used within a wood-based sandwich panel, proven the thermal insulation properties (Kawasaki T, Kawai S, 2006). Single layer bark insulation boards have been also constructed in laboratory, demonstrating that bark is a promising new insulation material (Kain et al, 2016). On the other hand, hemp, has been used as insulation material together with wood, where the hydrothermal performance was studied. The thermal performance of this board was also competitive compared to existing commercial oil based insulation panels, with an average thermal resistance (U-value) of 0.30 W/m^2K (Latif et al, 2015).

It hasn't been yet fabricated a mixed insulation board, consisting of the two previously mentioned materials. The goal of constructing trial composites was to identify the possibility of making insulation boards from waste natural materials originating from a short distance with regards to the manufacturing site. Both are carbon-negative materials as well as the glue which is a non-chemical one based on cellulose.

In Greece, the tree bark is considered as a waste by-product with no actual use. Hemp (Cannabis) fibres are also treated as agricultural residues with an additional cost for the producer to dispose of them.

There is a gap in knowledge in terms of understanding the consistency of the two materials especially with this glue and how mingling them together results a relative stiff yet light final composite insulation board.

In the present report, the construction method of the two insulation boards is stated comprehensively.

2. MATERIALS AND METHOD

2.1. THE TEST MATERIALS

The two by-products (bark – Fig. 1 and cannabis –Fig. 2) were collected in October 2017 from forest and cropland in Central Greece at a distance < 100 km from the laboratory in Karditsa, where two low-density insulation boards were constructed.

Figure 1
Pine tree bark at the drying chamber.

Figure 2
Hemp (cannabis) fibres

After harvesting, the moisture content measurement was undertaken according to DIN:52183/1977 and BS EN 322 – 1993 (Ntalos et al, 2002). The bark was chipped by a mechanical hammer-mill chipper with a 20 mm round hole screen and the particles were dried with a hot air dryer from a moisture value 60% down to 5%. The same procedure was carried out for the cannabis fibres as well, excluding the use of the chipper. The fibres were manually cut with a pair of scissors into approximately 0.10 m length stripes to allow them to connect with the bark.

A non-toxic methylcellulose glue was used for both boards. It is a hydrophilic white powder which dissolved in room temperature water. The two boards differed in the percentage of the two basic ingredients, "Board A" consisted of 70% bark and 30% hemp and "Board B" consisted of 60% bark and 40% hemp. The first attempt was undertaken as follows: According to the glue's manufacturer, the solution was of 1,25% glue (dry powder) and water (Table 1). The thickness of the boards was set to

0,047m to fill a 0,095m void of a wooden test masonry with an overall wall thickness of 0,160m.

Table 1
Boards with glue solution of 1,25%.

Insulation Board	Overall Weight OW (Kg)	Tree Bark TB (Kg)	Hemp Fibres HF (Kg)	Board Dimensions L*W*T (m)	Board's Dry Glue DG (%)	Board's Dry Glue DG (Kg)	Solution's Glue SG: (%)	Solution's Water SW (Kg)
Board A *70%***TB***-30%***HF**	1,717	1,202	0,505	0,4*0,4*0,047	2,5	0,042	1,25	3,293
Board B *60%***TB***-40%***HF**	1,717	1,030	0,687	0,4*0,4*0,047	2,5	0,042	1,25	3,293

This solution was stirred for 15 minutes and poured into the two materials while they were mixed together before placed in two 0,40 X 0,40 m casts. The casts were covered with flat fibreboards with a light pressure in order to form the final board thickness of 0.047 m. They stayed under pressure for 48h at an average room temperature of 23 degrees Celsius before opened. When the boards were taken out of the casts, non-consistent products were witnessed. The boards had no consistency, were not being solidified (Fig. 3).

Figure 3
The first attempt resulted a non-solid insulation board.

It is believed that this was due to the small percentage of the glue. This was the reason to further experiment with higher quantities of glue to identify if and when a consistent and robust insulation board may be the result. A few attempts to make the two boards were undertaken, with higher glue percentages. After the first of 1.25% glue, it was tried the 2%, 3% and 4% glue. The 4% glue, was the one having followed the exact same procedure, which resulted in satisfactory boards with regards to the stiffness and consistency of those trial boards (Table 2).

Table 2
Boards with glue solution of 4,0%.

Insulation Board	Overall Weight OW (Kg)	Tree Bark TB (Kg)	Hemp Fibres HF (Kg)	Board Dimensions L*W*T (m)	Board's Dry Glue DG (%)	Board's Dry Glue DG (Kg)	Solution's Glue SG: (%)	Solution's Water SW (Kg)
*Board A 70%**TB**-30%**HF***	1.709	1.196	0.513	0.4*0.4*0.047	3.0	0.050	4.0	1.194
*Board B 60%**TB**-40%**HF***	1.709	1.030	0.687	0.4*0.4*0.047	3.0	0.050	4.0	1.194

The two insulation boards "Board A" (70%-30%) and "Board B" (60%-40%) remained for five days indoors (at the laboratory) at an average room temperature of 23 degrees Celsius. After that period, they were cut in the final dimensions of 0.27m X 0.27m (Fig. 4) to fit in the thermal conductivity apparatus to determine their thermal conductivity values (board's thermal performance).

Figure 4
The two final insulation boards, "Board B" (left) & "Board A" (right)

3. Results and discussion

The relative humidity and the density of the two boards were measured accordingly. The boards were weighted at their final dimensions (0,27m X 0,27m) and directly upon remaining at a furnace at a temperature of 103°C until their weight was stable according to the BS EN 322.

Two different readings were undertaken for each board with regard to the thermal conductivity value. This was followed to identify any value differences subject to the humidity (moisture content) of each board. The first reading was before drying and the second reading for both boards was right after ~~the~~ drying (Table 3).

Table 3
Thermal conductivity (λ) values of the two insulation boards.

Insulation Board	Thermal conductivity value (λ) (W/m*K) Before Drying	Thermal conductivity value (λ) (W/m*K) After Drying
Board A (70%**TB**-30%**HF)**	0.094	0.078
Board B (60%**TB**-40%**HF)**	0.111	0.079

One of the objectives of this study was to identify the thermal conductivity of the constructed insulation boards and to assess any potential differences depending on their moisture content. The results verified how significant role the relative humidity plays to the thermal conductivity. It has to be stated that the lower the thermal conductivity value is; the better insulation capacity has the item (for a given thickness). The thermal conductivity value (λ) is a measure of the rate at which heat passes through a material. The units are watts per unit thickness per degree temperature difference across that unit thickness. The λ for the two boards was greater compared to existing commercial insulation products (Greenspec), (Table 4) however, reaching such values taking into account the circular economy aspect as well as the reuse of waste materials, demonstrates a promising performance, which is estimated to be further improved by trying different material's proportions and glues during the next steps of this research.

Table 4
Thermal conductivity (λ) values of different insulation boards -comparison.

Insulation Board	**Thermal conductivity value (λ) (W/m*K)**
Board A (70%**TB**-30%**HF)**	0.078
Board B (60%**TB**-40%**HF)**	0.079
Wood fibre	0.038
Hempcrete	0.060
Straw	0.080
Rock mineral wool	0.044
Expanded Polystyrene (EPS)	0.038
Extruded Polystyrene (XPS)	0.035

A major issue addressed in this study was the connectivity of two different materials with unlike proportions and the consistency of the final mixed products (insulation boards). The challenge to attempt to combine the tree bark together with the cannabis fibres with a glue as this had not been done previously, led to interesting results with regards to the percentage of the glue solution. The 4% (glue solution), was the limit where the boards could stand alone with such stiffness to allow them to be positioned within a wooden masonry without breaking into small parts. Thus, the light weight of both boards (approximately 0,24 g/cm^3) has a satisfactory value for a future new insulation product. The use of such waste materials is expected to prove the energy-efficiency for masonry use and also to become economically beneficial to the producers of these products.

The impact of using such resources apart from reducing the carbon footprint of the final composite product, plays also a significant role to the LCA (Life Cycle Assessment) due to the nature of the materials (Zampori et al, 2013) and the relative small distance from the source to the final manufacturing place. The energy requirements for constructing both boards were kept low due to the little energy input during the whole procedure. The energy input during the production of these boards was for the mechanical hammer-mill and the drying chamber (furnace) which was used to reduce the humidity of the two materials. Usually, the manufacturing procedure for a typical insulation board, with regards to the energy input during the production line, is immense due to the nature of the basic ingredients (petrol based materials). This results a more advantageous carbon footprint compared to typical chemical insulation board.

A feasibility study to exploit commercially the final product is the next step of this study expecting to identify the board's behavior to fire. An insulation product will usually need to pass British Standard tests regarding fire protection. The two main standards under which such products are assessed are *BS-EN 476-1: Fire tests on building materials and structures* and *BS-EN 13501-1: Fire classification of construction products and building elements*. The process for classification under these standards involves a combination of tests designed to assess the product on a range of characteristics, including combustibility, heat levels, flame spread and smoke release.

4. Conclusions

This paper has focused on the construction as well as on the energy assessment of two mixed insulation boards constructed – in a small scale- from waste Pine tree bark and cropland residues (Hemp fibres). The heat flux through those boards was simulated with the use of a thermal conductivity measurement unit (EI-700) and the values for both boards were undertaken with different moisture contents (before and after drying them). A non-chemical (methylcellulose) glue was used. One of the objectives of this study was to produce a 100% eco-friendly and chemical-free product from a close distance (≤ 100 Km) from the production site (laboratory). This is expected to improve the carbon footprint of the insulation board and also to address a financially viable solution for producers who currently direct the residues in landfills with an additional cost.

The two materials were not layered to form the insulation boards. However, they were mixed together unevenly. This method in addition to the proposed fibres length (0,10 m) proved to be effective to bonding the final board and comprise of a robust yet not indestructible composite.

Both boards resulted in acceptable thermal conductivity values of 0.078 W/m*K & 0.079 W/m*K. This is based on the value λ<1.15 W/m*K which is considered to be the base for an appropriate insulation material (JIS, 1994).

The next step of this study is to identify the exact energy footprint of such an insulation board undertaking an LCA to prove what has been observed during this research, which is the low energy input needed to construct this board taking also into account the benefit of using only waste materials from nearby areas.

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The Impact of Oil Crisis on Innovation for Alternative Sources of Energy: Is There an Asymmetric Response When Oil Prices Go up or Down?

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Abstract

The shift from depletable to sustainable resources seems inevitable and crucial to develop a low carbon and oil independent future, as climate and energy security concerns became a burgeoning debate. However, to what extent is innovation in alternative (clean) energy technologies affected by oil prices? Do lower oil prices translate into less innovation more than higher oil prices translate into more innovation? We employ negative binomial regression models to assess the impact of crude oil price variations on innovation for alternative energy technologies, using counts of patent applications as a proxy for innovation. The analysis is focused on the four countries that show the highest innovation level regarding alternative energies, China, Germany, Japan, and the United States of America (USA). Our

KEYWORDS
Falling oil prices; patents for alternative energies; asymmetric response.

data includes the declining prices period after the 2014 oil crisis. Controlling for other relevant variables, our results show a positive relationship between oil prices and number of patent applications for alternative energies. However, the impact is asymmetric depending on whether prices rise or fall. In Japan and the USA the impact is larger when prices go down than when prices go up, whereas in China and Germany it is larger when prices go up than when prices go down. This chief result should be taken into account when conducting energy policy, as these variations in the prices of oil can be used as a tool to reinforce climate policies and help to reach environmental objectives.

1. Introduction

There is nowadays a strong pressure to achieve a higher degree of security for energy supply, given the concentrated nature of oil reserves and the political unsteadiness in the countries with the largest deposits. Concerns over energy security and global climate change enhance the expansion and search for alternative energy technologies. Technology innovation in this sector provides a win-win solution to mitigate these issues and alternative (clean) energies, such as wind, solar, geothermal, ocean, or biomass, bring more market certainty and a healthier climate than crude oil does.

Energy prices and government policies are pointed as the two main drivers of technology innovation in the energy area (Kim, 2014; Cheon & Urpelainen, 2012; Dechezleprêtre & Glachant & Haščič & Johnstone, 2011; Johnstone & Haščič & Popp, 2010; Popp, 2005). Rises in the prices of fossil fuels originate incentives to innovate in the generation of electricity from renewable energy sources (Cheon & Urpelainen, 2012; Johnstone et al., 2010). Moreover, Noailly & Smeets (2015) show that higher fossil fuel prices cause a positive and significant impact on alternative energy patenting.

The positive reaction of innovation in alternative energy sources to oil price rises has been documented in several studies. It is now pertinent to investigate whether innovation in alternative energy sources decreases in the face of declining oil prices, and whether the two responses are symmetric. Although periods of oil price declines are not abundant, the recent 2014 oil crisis provides the opportunity to study this. The current paper is a first attempt to analyse the impact of oil price reductions on innovation for alternative energy sources, and to investigate the possible existence of a different magnitude response to either positive or negative oil price changes.

Alternative energy sources are traditionally developed in industrialized countries, with leaders like Japan, the United States of America (USA), China or Germany. These are oil-driven economies, as in 2015 they were among the top 10 global oil consumers[1]. Therefore, these countries were the ones selected to be analysed in the current

1 Source: https://www.eia.gov/tools/faqs/faq.php?id=709&t=6

paper. Together they represent more than 70 per cent of the global number of patents regarding clean energies (average for the period 2000-2017).

Counts of patent applications will thus be modelled for China, Germany, Japan and the USA. An empirical estimation of the relationship between patents for alternative energies, oil prices and other related independent variables will be provided. A positive relationship between patents and oil prices is obtained for all countries. However, we show that the magnitude of the response of innovation in alternative energies is significantly different depending on whether oil prices rise or fall.

The remainder of this article is organized as follows. Section 2 describes the advantages of using counts of patent data as a measure of environmental technological innovation and hence as our dependent variable. Section 3 describes data and presents the methodology employed. Section 4 presents the estimations' results for the four countries selected. Section 5 contains some conclusions and policy implications.

2. Counts of patent data as a measure of environmental technological innovation

There are still very few options available to empirically measure innovation. Many commonly used measures, such as R&D expenditures or the number of scientific personnel, are perceived as imperfect indicators of the innovative performance since their focus is only on inputs and do not give evidence of the output of such investments (Dechezleprêtre et al., 2011; Johnstone et al., 2010).

Yet, according to the literature convention, private innovation, as an indicator that focuses on outputs, can be measured by using counts of patent applications and innovation in environmental technologies has been commonly studied using patents (Kim, 2014; Bayer & Dolan & Urpelainen, 2013; Cheon & Urpelainen, 2012; Johnstone et al., 2010; Popp, 2005).

The principal strength of using patent applications counts as a measure of innovation is that the data is vastly disaggregated to specific technological areas, hence easily subjected to statistical analysis, and is readily available. The easiness of usage of the International Patent Classification (IPC) system provides data with plenty details, that enables identifying advances in specific technological fields straightforward (Noailly & Smeets, 2015; Dechezleprêtre et al., 2011; Johnstone et al., 2010; Popp, 2005).

Other advantage of using patent data over R&D expenditures is that patent data represents more than the investment or the effort done, since it exhibits the actual result or output of R&D activities (Dechezleprêtre et al., 2011; Kim, 2014). For that reason, patent counts serve both as a measure of innovative output, and for an exhibit of the level of innovative activity itself (Popp, 2005). Lastly, it is hard to find any economically significant invention that has not been patented (Dechezleprêtre et al., 2011; Johnstone et al., 2010).

These advantages allow patent data to serve as an acceptable indicator for technology innovation, the best available source of data on innovation, representing the magnitude of knowledge production activities. We use this measure in the analysis that follows.

3. Data and Methodology

The objective of this article is to assess the impact that variations in the price of crude oil have on innovation for alternative energy technologies, especially during periods of declining prices, and to assess whether the magnitude of the response differs depending on the price changes being positive or negative. Counts of patent applications for alternative energies, the dependent variable, are modelled through a negative binomial regression using yearly data between 2000 and 2017.

The set of independent variables essayed for each country are: Oil Prices (series which is common to all countries); Percentage of Oil Reserves; Gross Domestic Product; Electricity Consumption; CO_2 per capita emissions; and Oil Prices×Dummy Price Decreases (series which is common to all countries), a multiplicative variable to identify whether the impact of oil price increases on patents is the same as the effect of oil price decreases. The dummy takes value 1 when prices decrease with respect to the previous year (2001, 2009, 2012, 2013, 2014, 2015, 2016) and 0 when prices increase.

3.1. Data Sources

Statistics of World Intellectual Property Organization (WIPO) were used for Patents, as in Johnstone et al. (2010). The International Patent Classification (IPC) codes collected correspond to the following technological fields: renewable energy technologies (wind power, solar energy, geothermal energy, marine energy, hydro power, biomass energy and waste-to-energy); motor vehicle technologies (electric & hybrid vehicles); energy efficiency in the residential, commercial, and industrial sectors (insulation, heating, lighting and cement manufacturing) and other climate-change relevant technologies (methane capture).

Regarding oil prices data, Imported Crude Oil Real Price, in US$, from the U.S. Energy Information Administration (EIA) Short-Term Energy Outlook (February 2018) was considered. Also, in order to add information about the oil endowments profile of the countries selected, data on oil reserves provided by the U.S. EIA was collected. As in Noailly and Smeets (2015), data on GDP, adjusted by purchasing power parity (PPP), was provided by the U.S. EIA. The variable Electricity Consumption represents the energy needs, and was provided by U.S. Energy Information Administration. The values of total CO_2 emissions per capita were provided by the OECD/IEA report CO_2 Emissions from Fuel Combustion (2017), to add an input concerning the environmental sphere to the model.

3.2. Empirical Methodology

In many economic analyses the variable to be explained is a nonnegative integer or count. In count data contexts, the conditional maximum likelihood estimators are fully efficient when the dependent variable, given the set of independent variables, has a Poisson distribution. The Poisson regression model is thus a common framework for modelling count data. However, in some cases the Poisson distribution presents a major limitation, overdispersion.

The favoured alternative to the Poisson model is the widely-used negative binomial model, which can be considered as a generalization of the Poisson model since it presents the same mean structure but incorporates a dispersion parameter alpha to model and thus accommodate the overdispersion (Cameron & Trivedi, 1986). In fact, a Poisson regression model is one in which alpha is constrained to be zero.

The negative binomial model has two possible parameterizations, the Negbin I and the Negbin II, each implying different assumptions about the functional form of heteroscedasticity. Cameron & Trivedi (1986) showed that the Negbin II is preferred over the Negbin I because the Negbin II is slightly more efficient computationally and the log-likelihood associated with the second parametrization is higher.

The second parametrization of the negative binomial regression model (Negbin II) was thus chosen and applied to data for China, Germany, Japan and the USA. One negative binomial regression model was estimated for each country. Since all the models displayed a dispersion parameter alpha significantly greater than zero, the choice of a negative binomial model over a Poisson model is confirmed to be adequate. As in Bayer et al. (2013), the independent variables were lagged by one year to avoid simultaneity.

4. Empirical Results

We first tested all independent variables for multicollinearity and then performed several iterations where the independent variable with larger Variance Inflation Factor (VIF) was eliminated, until reaching a threshold value of VIF equal to 3. The variables that were not statistically significant were progressively eliminated from the estimations. The results of the country estimations are shown in Table 1.

The negative binomial regression models obtained show a positive relationship between oil prices and counts of patent applications for alternative energies. Given that the USA are an oil producing country, having the lowest oil price beta is not surprising. In turn, the highest betas for China and Japan may be explained by the fact that these countries are the largest oil consumers and importers in the world.

Table 1
Estimated coefficients. Dependent variable: log(number of patents)

Country	China	Germany	Japan	USA
Constant	3.7557***	6.8113***	2.6527*	7.1457***
OilPrices	0.0088***	0.0050***	0.0074***	0.0014**
Dummy	-0.0021**	-0.0011***	0.0052***	0.0006**
Reserves	-0.3922**	-13.262***	-49.830***	-0.1492**
GDP	0.0002***	0.0003*	0.0009*	0.0001***
Elect			0.0039***	
CO_2			-0.2455***	

*** - significant at 1%; ** - significant at 5%; * - significant at 10%

The fact that the oil price dummy is significant for the four countries addressed shows that the response is asymmetric to oil price increases and to oil price decreases. In China patents for alternative energies decrease by 0.0088-0.0021=0.0067=0.67% per one US dollar less in oil prices. Similarly, in Germany patents for alternative energies decrease by 0.39% per one US dollar less in oil prices. On the contrary in Japan and in the USA, the impact is stronger when prices go down than when they go up. In Japan patents decrease by 1.25% per one US dollar less in oil prices. In the USA patents decrease by 0.2% per one US dollar less in oil prices.

We have thus shown that there is asymmetry in the way patents respond to oil prices changes. Variations in the prices of oil impact on innovation for alternative sources of energy, but with different magnitudes whether prices are increasing or decreasing, as we wanted to find out.

As expected, in all countries analysed the percentage of oil reserves that a country possesses has a negative impact on the number of patents. The magnitude of the response in innovation for alternative sources of energy is higher for the countries with less oil reserves and lower for oil producing countries. This impact is weaker in the USA than in China, given that the USA has the highest level of oil reserves, especially since the shale revolution made the exploration of enormous amounts of oil economically viable. Additionally, the reserves impact is considerably stronger in Japan than in Germany, given that Japan currently possesses virtually no oil reserves.

Also, as expected, the models show a positive relationship between GDP (PPP adjusted) and the number of patent applications for alternative energies. The higher the economy's production level, the more resources there are available to invest in clean energies, and the more the country may focus on environmental concerns.

Electricity consumption shows a positive relationship with patents in the alternative sector. However, this relationship is only significant for Japan, a country which possesses zero oil reserves and is one of the largest oil consumers and oil importers in the world. Thus, out of the four economies analysed, Japan is the one with the highest need for increasing energy security. The more consumption the country faces, the more critical the need for alternative solutions becomes. Contrary to what might be expected, CO_2 emissions show a negative relationship with patents for alternative energies. This is true for Japan, whereas in the other three countries this relationship is non-significant.

5. Conclusions

This article investigates the impact of oil prices on innovation for alternative sources of energy, in particular the impact of falling prices. The occurrence of asymmetric effects on innovation, depending on whether prices are rising or falling, is addressed for the first time in the literature. This is a pertinent and timely question, given the sustained low oil price levels recorded since 2014 which call for a public policy re-examination of the energy mix.

We model the counts of patent applications for China, Germany, Japan and the USA, countries which account for 71 per cent of the global patents in the alternative sector. We analyse the period 2000-2017, which includes seven years of falling prices, and provide an empirical estimation of the relationship between patents for alternative energies, oil prices and other related independent variables.

The negative binomial regression models obtained show a positive relationship between oil prices and number of patent applications for alternative energies. China is the country where the impact of oil prices on patents is stronger, followed by Japan, Germany and the USA. This ordering may be related with the fact that China, Japan and Germany import significantly more energy, as a percentage of their GDP, than the USA does. Moreover, the USA, as an oil producing country, proved to be resilient to sustainable low oil prices and able to quickly react and adjust its production to price changes.

We also show that there exists asymmetry in the way innovation on alternative energies reacts to oil price increases or decreases, something that, to the best of our knowledge, had never been studied. The dummy included in each model to capture the effect of declining prices such as experienced during the recent 2014 oil crisis is significant, which means that the mentioned asymmetry has statistical significance. In Japan and the USA the impact is larger when prices go down than when prices go up, whereas in China and Germany the reverse happens. This different behaviour may be associated with the different position of the four countries as concerns oil production and oil dependence.

Since oil prices are one of the main drivers of innovation in alternative energy sources but impact innovation with different magnitudes, policy makers should assess variations differently depending on whether prices are decreasing or increasing, adjusting public support for investment in energy technological innovation, or government regulation and incentives to shift demand towards clean energies. These variations in the prices of oil can be used as a tool to reinforce climate policies and help to reach environmental objectives. However, caution is needed, as different countries present different magnitudes of response, which a global environmental policy should take into account.

This paper contributes to the knowledge on the asymmetric effects of oil price changes on innovation in alternative energy sources by analysing the effect of oil prices incorporating a very recent period of declining prices. These results should be reassessed with a wider time range, as more data becomes available.

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Comparison of Processes and Types of 2nd Generation of Biofuels: An Assessment of the Brazilian and Portuguese Potential

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Abstract

In this paper we analyze the production potential and economic feasibility of the production of biofuels from lignocellulosic resources of the residual biomass of sugarcane straw in Brazil and of the residual forest biomass (RFB) in Portugal. The search for sustainable sources of energy is a topic of great relevance at the present time.

The selected transformation route is the gasification of biomass in a direct fluidizing bed gasifier, and atmospheric air as oxidizing agent. Explored economic indicators such as: internal rate of return (IRR), net present value (NPV) and discounted payback (DPB) were considered with variation of annual interest rates from 12.15, 8 to 6% for Brazil and 2, 4 and 6% for Portugal.

We concluded that in economical terms, the Portuguese scenario is much more attractive than the Brazilian, but from the point of view of availability of raw material the Brazilian territory has a large advantage. However, the transformation of residual biomass to advanced fuels through gasification still lacks research and incentives, a factor that limits private investors to explore such a route.

KEYWORDS
Renewable Energy, Biomass, Second Generation of Biofuels, Gasification, Economic Feasibility.

1. Introduction

The intensive use of fossil fuels has increased our distance from a sustainable situation in terms of energy sources, leading to serious consequences for the pollution of the planet, namely the greenhouse effect.

In Brazil and Portugal, renewable energies amount for 40% (EPE/MME, 2016) and 30% (DGEG, 2016) respectively in terms of their energy matrix. However, renewable resources vary from region to region. Solar energy, wind energy, hydro resources, geothermal resources and biomass are different types of clean energies.

Currently, biomass accounts for 13% of the primary energy sources of the planet, 80% (50 exajoule (EJ)) of renewables. By 2050 it is expected that the biomass will represent 100-300 EJ of the primary energy source (Chum et al., 2011; Immerseel et al., 2014).

The biomass is already explored in many forms of energy conversion (thermochemical and biological routes), and biofuels appear as another piece to balance fossil fuels dependency, as a consolidated route with the first generation of biofuels. However, the second generation has been a route worthy of attention due to its great potential in the conversion of biomass to liquid or gaseous biofuels, without the need to increase planted areas and compete with food production.

2. Literature review

In this section we revised recent studies on specific topics that we believe relevant for the present study.

Overview of biomass resources in Brazil and the potential sugarcane straw.

The Brazilian agricultural sources are very wide, where sugarcane can be highlighted. In 2015/2016 665 million tons (t) were produced, with an huge energy potential to be exploited from this source (Conab, 2016). The observed potential on dry basis is 140 kg of waste for each tonne of sugarcane harvested (Leal et al., 2013).

Overview of biomass resources in Portugal and potentiality

Within the Portuguese territory, the forestry sector, which covers about 35.4% of the planted area of the country, accounted for 3 million hectares (ha), where the species of *eucalyptus globulus* and *pinus* are the largest, to feed the strong paper and pulp industry (MAMAOT/ICNF, 2013).

Second Generation of biofuels

Biofuels play a key role in the diversification of the global renewable matrix. The first generation of biofuels has been heavily questioned recently due to competition with food and indirect land change use (ILCU) areas. The second generation, which deals with biomass residues for the transformation of biofuels, has gained focus in recent years on the balance of impacts generated by the first generation biofuels (Gomez,et al., 2008; Zabaniotou,et al., 2008; Naik et al., 2010).

Gasification and types of gasifier

Gasification consists on the conversion of a solid resource into a synthesis gas with different calorific power. The calorific power depends on the oxidizing agent used (4-40 MJ / Nm^3) through the partial oxidation of the fuel at high temperatures (900ºC) (Natural Resources Institute, 1996; Mckendry, 2002).

Different types of equipment can be used for the gasification process. The most common are fixed bed and fluidized bed (Abreu et al.,2010 apud Oliveira, 2013)the concern about environmental issues in relation to the necessity of economic growth has made the development of new technologies for sustainable development something that cannot be postponed. In this sense, the biomass is presented as the alternative to fossils fuels as a power plant, although, as a solid fuel, its characteristics of poly-dispersion and low density make its direct use with efficiency harder, requiring previous treatments. One of these treatments is called roasting, a soft thermal treatment in temperatures in the average of 225-300°C, producing a fuel with better energy and mechanical characteristics. However, the use of this process for pre-treatment of biomass destined to the energy use is in development and the environmental impacts of this technology are not totally known. This study evaluated the environmental aspects of the impact from the greenhouse gases effects in the lifecycle of the process of biomass toasting as pre-treatment, before the gasification, comparing the gasification of the biomass without the toasting through the balance of carbon dioxide and energetic. This research also used the method of lifecycle assessment (LCA. An alternative that has been attracting the interest of the new researchers is the so-called indirect circulating fluidized bed gasification (ICFBG). This process is characterized by the existence of two different reactors (Zwart, Boerrigter, Deurwaarder, van der Meijden, & van Paasen, 2006)as well as from the point of view of security of supply. The renewable alternative for natural gas is the so-called green natural gas, i.e. gaseous energy carriers produced from biomass comprising both biogas and Synthetic Natural Gas (SNG.

Environmental benefits and carbon credits

Biomass is particularly appealing in terms of Green House Gases (GHG) emissions. Its use generates a zero emission effect, which has been used in many countries to substitute a certain quantity of fossil fuels, thus gaining carbon credits that can be traded as an additional revenue (Basu, 2010).

2. Methodology

The second generation of biofuels, specifically, the production of synthetic natural gas (SNG) through gasification was the path chosen in this work, with the hypothetical plant working alone or integrated in a pulp and paper mill. For the two regions (Brazil and Portugal) five different processing capacities were considered, namely, 10, 50, 100, 200 and 300 thermal megawatt (MWth) and different low heat values (LHV). The technical assumptions to Biomass Forest Residues (BFR) and sugarcane straw are displayed in table 1.

Table 1
Technical Assumptions

Region	Feedstock	LHV (MJ/Kg)	Moisture (%)	Interest Rate (% year)	Reference
Portugal	BFR	15,7	15*	2, 4 e 6	(Morais, 2012)
Brazil	Sugarcane Straw	12,9	15	6, 8, 12.15	(Linero, 2015)
Direct Fluidizing Bed Gasifier (DFBG)/ Oxidizing Agent Atmospheric Air					
Final Product: SNG (35 MJ/Kg)					

For the two biomasses, a cost of 20 € / Ton for sugarcane straw (SUCRE, 2015) and 30 € / Ton for BFR was considered (Morais, 2012).

The value of the SNG gain will be equated with the sale price of natural gas (NG) in Brazil 12,30 €/GJ (BEN, 2016), and 14.87 € / GJ do Portugal (DGEG, 2016).

Given that the biomass availability potential of the two countries is very different, the area required in hectares for the five production scenarios was also calculated.

In terms of economic analysis, we considered the following indicators: net present value (NPV), internal rate of return (IRR) and discounted payback (DPB), with interest rates adjusted to the current values of the countries involved. Thus, the values of 6, 8 and 12,15% per year were taken for Brazil and 2, 4 and 6% for Portugal. In order to make the conversion (gasification) route more attractive, and as a suggestion to decision-makers, a possible subsidy-based incentive policy was identified and discussed.

3. Results

The results obtained are presented in the next chapters. The intention is reach a quantitative basis as support for decision making in a future scenario of investment.

Isolated factory scenario

The construction of a DFBG, amount to an average investment cost of 31.76, 97.99, 159.19, 258.61, 343.48, millions of euros (M€) for each capacity considered*, as show in table 2.

Table 2
Scenario with and without subsidy for sugarcane straw in Brazil

Capacity	MWth	10	50	100	200	300
Investment Cost	M€	31,76	97,99	159,19	258,61	343,48
Unity Cost	€/GJ	10	7,20	6,30	5,60	5,30
Subsidy	€/GJ	2,50	2,50	2,50	2,50	2,50
Revenue plus Subsidy	M€/year	0,90	6,94	15,36	33,11	51,44
Revenue no Subsidy	M€/year	0,47	4,78	11,04	24,47	38,48

In the Brazilian scenario with and without subsidies with the interest rate of 12.15% per year, no capacity would be attractive. With the interest rate of 8%, the capacity with the best results would be 300 MWth with the DPB less than 20 years. Already at the rate of 6% the capacities of 200 MWth and 300MWth are satisfactory results, with DPB less than 20 Years.

In the Portuguese case, with the exception of capacities of 10 and 50 MWth, all capacities were attractive, with DPB less than 20 years. The results can be observed in table 3.

Table 3
Scenario with and without subsidy for RFB straw in Portugal

Capacity	MWth	10	50	100	200	300
Investment Cost	M€	31,76	97,99	159,19	258,61	343,48
Unity Cost	€/GJ	11,6	8,8	7,9	7,2	6,9
Subsidy	€/GJ	2,5	2,5	2,5	2,5	2,5
Revenue plus Subsidy	M€/year	1,07	7,78	17,04	36,46	56,47
Revenue no Subsidy	M€/year	0,64	5,62	12,72	27,82	43,51

Integrated factory scenario

In this chapter, a scenario of replacement of a medium capacity factory is proposed. According to data, from a typical industry the annual expenditure on natural gas (NG) to be used in lime kilns, boiler support and paper machines is about 25 million Nm^3/year. Feasibility calculations was made considering how much would be saved with the substitution if the plant were installed to meet the needs of the NG of a supposed industry, also considering the exploitation of the CO_2 market and the sale of

* Cold gas efficiency considered 60% and additional investment cost of 30% for a system of separation and methanization (Heyne, 2013).

surpluses to the consumer market. The brazilian and portuguese scenario are shown observed in table 4 and 5.

Table 4
Scenario with and without subsidy for Sugarcane straw in Brazil

Capacity*	MWth	10	50	100	200	300
Unity Cost	€/GJ	10	7,18	6,33	5,64	5,30
Subsidy	€/GJ	2,50	2,50	2,50	2,50	2,50
Revenue plus Subsidy	M€/year	0,90	6,94	18,63	41,21	63,49
Revenue no Subsidy	M€/year	0,47	4,78	16,44	39,03	61,31

Table 5
Scenario with and without subsidy for BFR in Portugal

Capacity	MWth	10*	50*	100	200	300
Unity Cost	€/GJ	11,60	8,78	7,93	7,24	6,90
Subsidy	€/GJ	2,50	2,50	2,50	2,50	2,50
Revenue plus Subsidy	M€/year	1,07	7,78	21,67	48,70	75,42
Revenue no Subsidy	M€/year	0,64	5,62	19,48	46,51	73,23

With the addition of subsidies, the larger capacities that would produce surplus would bring gains by replacing and exploiting the surplus between 18.63 and 63.9 million euros per year for Brazil for capacities between 100-300MWth. Again, the Portuguese scenario is more profitable than the Brazilian. Factories with capacities of 100MWth, 200MWth and 300MWth would have profit margins of between 21.67 and 75.42 million euros per year.

According to the assumptions the sugarcane straw in Brazil could represent 12% (149 million barrel of oil equivalent (MBOE)), of non-renewable energy used in the country in 2015, according to Brazilian Energy Balance (BEN, 2016) data. Regarding Portugal, the BFR could represent 3% (3 MBOE) of non-renewable energy.

An advantage of the brazilian scenario is the renewability cycle of sugar cane (12-18 months) (NOVACANA, 2013) when compared with the Portuguese BFR (10-12 years) (Morais, 2012).

4. Conclusion

We can conclude that the Brazilian scenario in terms of availability of biomass and area to be explored is much larger than Portugal, but considering the financial analysis, Portugal has a large advantage for possible investment due to low interest rates. Some important comparisons are made in table 6.

* Do not meet the factory's total requirements

Table 6
Comparisons for the use of residual biomass in Brazil and Portugal

Region	Brazil	Portugal
Lignocellulosic Residues	Sugarcane Straw	BFR
Energy Dependency (%)	7	72,4
Annual Potential (MBOE)	149	3
Logistic Viability	Annual cycle	12 years cycle
NPV/ IRR no subsidy	Disadvantage	Advantage
NPV/IRR with subsidy	Disadvantage	Advantage

Even though the gasification process is an old route of conversion, the process is in a premature stage of development, facing resistance in its development throughout history, every time fossil fuels were cheaper.

There is a necessity of a massive investment in R&D for the insertion of the gasification route into the market, where policies must be outlined for medium and long periods to turn it attractive to a private sector.

Another new pathway to the second generation of biofuels also needs attention due to the huge resource of biomass available, with a high potential in the GHG reduction.

The solutions must be solved before the crisis, in order to assure economic, social and environmental fair conditions for all, ensuring greater and more efficient energy profitability in a planet cleaner for the next generations.

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Gasoline and Diesel Elasticities in Portugal: An Aggregate Approach

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Abstract

Portugal is a small peripheral European country strongly dependent on road transport. Despite its fragile economic conditions, Portugal has one of the highest fuel taxations in Europe. It is, therefore, important to analyze if these high taxes are justifiable on environmental grounds, or if they are mainly revenue sources. In this article, we estimate gasoline and diesel price and income elasticities for Portugal. Our results indicate that gasoline and diesel consumption respond differently to tax changes, hence, the differentiated taxation makes economic sense. Gasoline consumption is significantly more sensitive to price changes than diesel consumption, with a price elasticity of -0.911 when compared to -0.368. On the contrary, diesel consumption is much more sensitive to income changes than gasoline consumption, with an income elasticity of 2.338 when compared to 0.877. Both results can partly be explained by the fact that a large part of diesel consumption occurs for commercial transportation which strongly responds to economic conditions, but is more insensitive to price changes than domestic consumption. Hence, taxes on diesel are not particularly effective to moderate demand while taxes on gasoline can be a little more effective. Economic growth is the main driver for diesel consumption in Portugal.

KEYWORDS
Gasoline consumption; diesel consumption; price elasticities; income elasticities

1. Introduction

The study of fuel demand responses to price and income changes has been a common theme in the literature, especially after the 1970's oil crisis. Higher economic growth and global integration have increased the need for transportation while the access to private cars has also increased, pressuring fuel demand. The connection between fuel demand, emissions and oil dependency further increases the interest of the theme, especially concerning the possibility of environmental policy, through taxation, to affect fuel demand. For example, Sterner (2007) stresses out the extremely important role that fuel taxes have had to moderate fuel demand and emissions particularly in European countries. Other authors argue that, given low own-price elasticities of fuel consumption, fuel taxes are mainly a convenient form to collect public revenues, but are not effective to moderate consumption (González-Marrero *et al.* (2012). The importance of this issue has been reflected in several European legislations, namely the European Union White Paper on Transport (European Comission, 2011) which postulated the goal to reduce oil dependence and polluting emissions.

These problems are particularly relevant for a country like Portugal, which despite its fragile economic situation, is 100 *per cent* dependent on transport fuel imports. In spite of its low economic growth and low average income level, Portugal is one of the European countries with the highest levels of tax fuels. It also has a very high level of taxation over vehicles, which according to Graham and Glaister (2002) is also an important aspect. Sterner (2007) presents the gas tax levels (in Parity of Purchasing Power) for 2005 for several European and non-European countries and it is visible that Portugal is the Western European country with the highest tax level, having higher taxes that e.g., Germany, France or the United Kingdom. Due to the Portuguese peripheral location in the Iberian Peninsula, commercial transport is a fundamental issue and is performed mainly by land, given the limitations of railway and sea transport. In that sense, commercial fuel demand (mainly diesel) is very important for the Portuguese economic activity and the number of commercial vehicles has increased from 152 000 in 1974 to 1 352 600 in 2010. Even in the residential sector a strong increase on private transportation has been observed, with the number of passenger vehicles increasing from 692 000 in 1974 to 4 480 000 in 2010. The weak public transportation network has contributed to this strong dependence on private transport. From the private fleet, an increasing share works on diesel, hence Portugal has witnessed the "dieselisation" process in private transport described by several authors in the literature (e.g., Pock, 2010; González-Marrero *et al.*, 2012). This "dieselisation" process has been associated not only with lower tax levels for diesel but also with CO_2 emissions reduction policies (Barla *et al.*, 2014).

In this study we contribute to the literature by estimating price and income elasticities for both gasoline and diesel for Portugal over a period of 20 years, from 1995 to 2015. We use quarterly data but cover a long period of time. This allows to better capture demand fluctuations while simultaneously covering behavioral and technological changes (especially in terms of fuel efficiency). The long period under analysis covers some important changes, as for example the boom of the internet services which may have, to a certain degree, decreased the need for physical transportations. Fuel elasticities have been rarely calculated for Portugal. One exemption is provided by Sterner *et al.* (1992), who estimate gasoline demand elasticities for 21 OECD countries including Portugal. This study found price elasticities to be -0.13 in the short-run and -0.67 in the long-run, while income elasticities were 0.37 in the short-run and 1.93 in the long run. As far as we know, the simultaneous estimation of gasoline and diesel elasticities has never been performed for Portugal.

2. Literature

As referred before, there are numerous studies that calculate price and income elasticities for fuel demand. This has induced some authors to perform surveys on the existing literature and meta-analysis to understand differences in the results (e.g., Labandeira *et al.*, 2017; Sterner, 2006; Graham and Glaister, 2002; Hanly *et al.*, 2002; Espey, 1998; Dahl and Sterner, 1991). It is widely recognized that estimates for price and income elasticities of fuel demand vary according to the methodology used, the country under analysis, the period of time covered, the variables included in the model, among other things (Graham and Glaister, 2002).

One important distinctive aspect in the literature is the type of fuel under analysis. In generally, it is found that gasoline and diesel have distinct behaviors, mainly due to the fact that gasoline is essentially used for passenger transport while diesel is also used for freight transport. This determines that diesel consumption tends to have a lower price elasticity than gasoline, but a higher income elasticity (Boshoff, 2012; Hanly et al., 2002). According to Frondel and Vance (2014), the majority of the literature calculates elasticities only for gasoline. In this case we find, e.g., Bentzen (1994), Eltony and Al-Mutairi (1995), Pock (2010), Akinboade *et al.*, 2008; Baranzini and Weber (2013), Cheung and Thomson (2004), Ramanathan, (1999). A relatively smaller part of the literature chooses to focus only on diesel demand (e.g., Barla *et al.*, 2014; De Vita *et al.*, 2006). An increasing share of the literature estimates elasticities for both gasoline and diesel. In this group we find Polemis (2006), González-Marrero *et al.* (2012), Boshoff (2012), Danesin and Linares (2015), Bakhat *et al.* (forthcoming).

3. Data and model

3.1. Data

For our model we use data on gasoline and diesel consumption *per capita*, Gross Domestic Product (GDP) *per capital*, and fuel prices. Fuel consumption and prices were retrieved from the Direção Geral de Energia e Geologia (DGEG), while GDP data was from the National Statistics Institute (INE). As referred, we cover the period from 1995 to 2015. As in Baranzini and Weber (2013), we had monthly data on gasoline and diesel demand and on prices, but only quarterly data for GDP. Hence, as those authors, we made the methodological choice to use quarterly data by summing the monthly quantities and averaging the prices. In any case, using data with higher frequency than the usual annual data, increases the available degrees of freedom for the estimation (Boshoff, 2012).

We have not included vehicle stock due to data limitation. Despite the fact that some authors defend the importance of this variable, others, e.g., Bentzen (1994), refer that the inclusion of both income and the vehicle stock may lead to small elasticities for each variable. While that author chooses to include only the vehicles stock in which case, income influences gasoline demand only through that stock, we opt for considering only income.

3.2 Model

With the ARDL bounds testing approach to cointegration, regressors can be either I(0) or I(1) but never I(2) or higher, and the dependent variable has to be I(1) in levels (De Vita *et al.*, 2006). Given the advantages of the ARDL methodology we choose to implement it. Hence, our model takes the form:

Where i can be gasoline or diesel, t is the period, Q is the *per capita* consumption of each fuel, P is the price of each fuel, Y is GDP *per capita*, and **X** represents a vector of the lagged dependent and independent variables. All variables are in natural logarithms. Both the inclusion of the time trend (Bentzen, 1994; Sa'ad, 2009; Polemis, 2006) and the lagged dependent variable (Boshoff, 2012; Bakhat *et al.*, forthcoming) allow controlling for changes in fuel efficiency, technologies, infrastructures, fleet, among other important aspects.

4. Results

As referred by Hughes *et al.* (2008), long run responses are the most important ones for the determination of which policies should be implemented to manage fuel demand and protect the environment. Our results indicate that long-run price elasticity is -0.911 for gasoline and -0.368 for diesel. The lower sensitivity of diesel is according to the literature. Long-run income elasticity is 0.877 for gasoline and 2.338 for diesel.

Our results also show that fuel demand adjusts to its long-run equilibrium within the first year (approximately 25% of the adjustment takes place in the first quarter). This shows the importance of higher frequency data and is in line with, e.g., Ben Sita *et al.*, (2012) who conclude that gasoline consumption in Lebanon only takes two months to adjust to news and shocks. On the contrary, some authors using annual data conclude that only a small part of the adjustment takes place in the first year. For example, in Ramanathan (1999) only 28% of the adjustment of gasoline demand in India to its long run equilibrium occurs in the first year, while in Eltony and Al-Mutairi (1995) the speed of adjustment of 52%.

Our time trend has a negative sign, indicating that technological changes and fuel efficiency have been effective in reducing fuel consumption over time. This is in line with, e.g., Bentzen (1994), Sa'ad (2009). Notwithstanding, the dimension of this effect is smaller than what was found in the refered studies.

5. Conclusions and policy implications

Portugal is a country strongly dependent on road transport and 100 *per cent* reliant on fuel imports. Furthermore, despite its fragile economic situation, this country has very high levels of tax fuels, when compared with other European countries. Our results show that gasoline and diesel consumption have different responses to price and income changes. Accordingly, there is a theoretical justification for the different taxation of these fuels observed in Portugal and in other countries. Diesel is less responsive to price changes than gasoline, but more responsive to income changes. On the other hand, gasoline is more sensitive to price changes than to income changes. Given the estimated elasticities, we can conclude that the current high taxes are not effective to moderate demand, especially for diesel. On the other hand, these taxes can be harmful for the competitiveness of firms which depend on road transport. Diesel consumption is very responsive to income changes, hence, economic growth has a strong influence on that variable.

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Embodied Carbon and Trade Competitiveness in Russia

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Abstract

In this paper emissions embodied in exports and imports of Russia are estimated with the use of inter-country input-output tables from WIOD database. It is revealed that Russia is the second largest exporter of 'virtual carbon'. Additionally, we analysed the trade competitiveness index of the export industries with respect to emissions, and it was found that the industries with strong international competitiveness belong to high-carbon-emission categories. Over the period of 2000-2011 those industries lost some of the competitiveness, which contributed to the decline of carbon content in Russian exports.

KEYWORDS

Input-output approach, emissions embodied in trade, trade competitiveness.

1. Introduction

International climate cooperation that started in the 1990s made necessary to account emissions associated with separate countries. The key issue is how to define, which country is responsible for emissions. In order to fulfill obligations under the Kyoto protocol countries prepare national inventories containing information about the emissions that take place "within national territory and offshore areas over which the country has jurisdiction" (IPCC, 2006). The same practice will be further applied under the new climate agreement adopted in Paris in 2015.

This approach is the most transparent and feasible but has some drawbacks because it ignores international trade flows. Meanwhile, around 30% of global CO_2 emissions are released during the production of internationally traded goods (Sato, 2014). Therefore, an increase in the consumption of carbon-intensive goods in one country may not lead to an increase in its emissions, but will contribute to an increase in emissions in other countries, suppliers of carbon-intensive products.

This is aggravated by the fact that most of the carbon-intensive trade flows are directed from developing to developed countries. Developing countries are not listed in Annex I of the UNFCCC and, therefore, haven't taken quantitative commitments for emissions reduction. This means that the growth in carbon-intensive products consumption in developed countries, which is related to imports from developing countries, is not regulated by the current international climate change regime. Moreover, it induces "emission (carbon) leakage", that is the increase in emissions outside developed countries due to rising imports of carbon-intensive products from developing countries (as a result of the policy to cap emission). Aichele and Felbermayr (2015) calculated that Kyoto protocol commitments had led to growth in embodied carbon imports of committed countries from non-committed ones by around 8%.

Despite substantial reductions, greenhouse gas emissions in Russia are still high (2,643 Mt CO_2 equivalent in 2016, according to UNFCCC data). As described earlier, it is important to account for emissions embodied in trade, especially exports in case of Russia. Moreover, embodied emissions analysis requires identification of trade structure changes underlying the virtual carbon dynamics.

This paper is organized as follows. Section 2 contains the description of main approaches to the estimation of emissions embodied in international trade along with the related literature review. Section 3 describes the methodology of the research. Section 4 provides the estimates of volumes and structure of emissions embodied in Russia's exports and imports and discusses the role of trade competitiveness in embodied emissions dynamics.

2. Literature review

Currently, there are two main approaches to embodied emissions assessment: environmentally extended bilateral trade (EEBT) and multi-regional input-output analysis (MRIO). These approaches differ not only in the data source (national IO tables for EEBT and MRIO tables for MRIO) but also in the manner they account emissions embodied in trade on the different stages of final goods production (Peters, 2008). The difference between two approaches can be illustrated with the following example. Assume country A imports a car from country B. Using EEBT approach, emissions embodied in imports include only emissions related to production of a car itself, whereas emissions from mining of iron ore in country C and smelting of the steel in country D would be imports of country B from countries C and D (The Carbon Trust, 2011). Using MRIO approach, CO_2 emissions associated with the production of the car – mining of iron ore for the steel, smelting of the steel and the assembly of the car – would be considered as imports of the country A from countries B, C, D. MRIO approach, therefore allows analyzing the whole life cycle of a good and most complete assesses "virtual carbon" volumes.

There are more and more studies using IO analysis for accounting emissions embodied in exports of a particular country (primarily for China – the largest emitter and exporter of CO_2 emissions (e.g. Dietzenbacher, Pei, and Oosterhaven, 2012; Liu et al., 2016)) and emissions embodied in global exports. Most developed countries are net importers of emissions, whereas developing countries are primarily net exporters of emissions. Net exports of China and Russia in 1995 was almost equal to net imports of OECD region (Ahmad and Wyckoff, 2003).

Peters and Hertwich (2008) estimated CO_2 emissions embodied in trade of 87 countries in 2001. Global emissions embodied in exports accounted for 5.3 GtCO2. The authors pointed out that current international climate change regime was inefficient because mainly net importers of emissions had taken quantitative commitments under the Kyoto protocol. They suggested including trade effects in national emission inventories and allocating responsibility in accordance with regional groups, not countries, which could lessen the influence of trade on the CO_2 increase.

Davis, Caldeira, and Peters (2011) calculated CO_2 emissions embodied in exports for 113 countries and 57 industries. In 2004, they were around 6.4 GtCO2, and most emissions embodied in trade occurred in exports from China and other developing countries to OECD countries. The authors conclude that the allocation of responsibility between producers and consumers of emissions is important for developing an effective climate agreement. These results indicate that there may be a considerable carbon leakage process – that is, the increase in CO_2 emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries.

There is a number of computable general equilibrium (CGE) models that include carbon emissions data. For example, OECD GREEN Model, GEM-E3 (linked to WIOD and calibrated to the GTAP database) are designed to evaluate distributional and macro-economic effects of environmental policies. These models, among others, can be used to evaluate carbon leakage and therefore the analysis of border tariffs implications.

Boitier (2012) used MRIO method in order to calculate emissions embodied in trade for 40 countries and 35 industries based on WIOD data from 1995 to 2009. The author distinguished "CO_2-consumers" (OECD countries, especially EU-15, where consumption-based emissions exceed production-based emissions) and "CO_2-producers" (developing countries – BRIC and "Rest of the World"). The author suggests implementing not only production-based but also consumption-based CO_2 accounting, which would allow elaborating more objective targets for climate change mitigation policy. Moreover, it is assumed that for most countries, that didn't sign Annex I UNFCCC, using consumption-based CO_2 accounting for determining national reduction targets would be preferable and probably stimulated taking quantitative commitments for emission reductions (Boitier, 2012).

Most studies devoted to the calculation of emissions embodied in trade include assessment of emissions embedded in exports and imports of Russia (Boitier, 2012; Peters and Hertwich, 2008; Davis, Caldeira, and Peters, 2011). But there are few studies discussing in detail carbon content of Russia's trade (apart from indicating total values).

Emissions embodied in Russia's exports and imports were estimated in 2011 by the research group that used EEBT method and IO tables of Russian statistical service (Rosstat) for 2002, trade statistics and carbon intensities of industries. Emissions embodied in exports in 2002 accounted for 373 Mt, emissions embodied in exports were about 203 Mt. The authors concluded that the largest importers of emissions from Russia are European countries and China, which is related to the high value of exports of mineral resources (Mehra et al., 2011). It was assumed that the technology (and hence carbon intensity) of Russian exports is equal to the imports technology, which leads to some bias.

Piskulova, Kostyunina, and Abramova (2013) analyzed exports of Russian regions concerning possible changes in Russian trade partners' climate policies. The authors showed that carbon intensity of a large number of Russian regions is quite high and hence the implementation of border carbon adjustment (BCA) by Russian trade partners could be damaging. This study did not include quantitative assessment of emissions embodied in Russian exports. For the discussion on importance of embedded carbon for Russian climate policy see Makarov and Sokolova (2017).

3. Methodology

This study employs standard MRIO methodology for estimation of emissions embodied in exports. MRIO adapted for WIOD tables is described in Boitier (2012) and is the basis for this study. The key idea of assessing emissions embodied in exports using IO tables is combining of (monetary) data about flows of resources and goods (between countries and industries) and CO2 emissions data (in physical units). An IO table for MRIO analysis can be represented by (1) or in terms of final consumption by (2):

(1) $x = Ax + f$

(2) $x = \sum_m (I - A)^{-1} f_m = \sum_m y_m$,

where m, v – country indices, x – output vector, A – the inter-industrial matrix, I – identity matrix, f_m – a vector of the final demands in country m, y_m is a vector of the output of country m, necessary to meet the final demands in country m and its trade partners.

In order to calculate the CO_2 emissions related to the production of , it is multiplied by the carbon intensity coefficient. Thereafter, matrix E represents intercountry flows of "virtual carbon". In particular, CO_2 emissions embodied in exports from country m:

(3) $E^{exp} = \sum_{v \neq m} E_{m,v} = e_m y_{m,v} = e_m (I - A_{m,v})^{-1} f_{m,v}$

CO_2 emissions embodied in imports to country m:

(4) $E^{imp} = \sum_{m \neq v} E_{v,m} = e_v y_{v,m} = e_v (I - A_{v,m})^{-1} f_{v,m}$

4. Results and conclusions

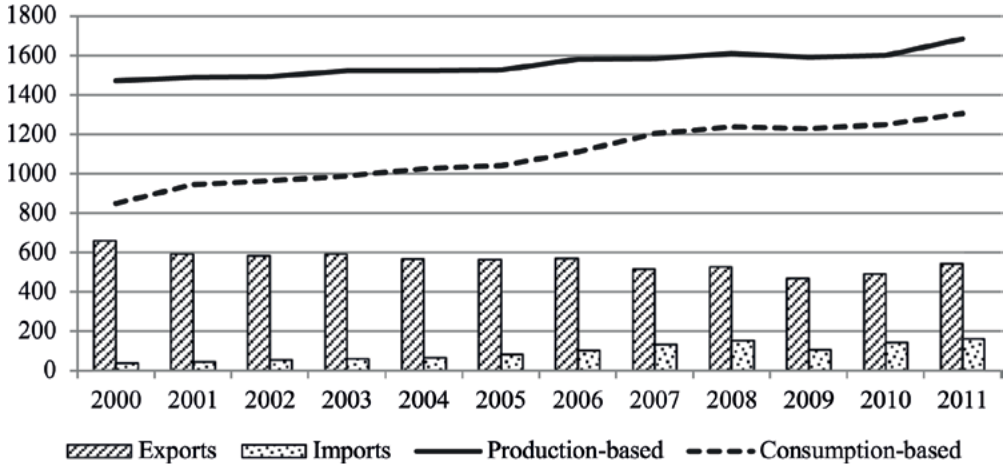
4.1. Emissions embodied in Russia's exports

It could be expected that dynamics of emissions embodied in Russia's exports coincides with dynamics of total emissions. However, it was revealed that it is not true. In 2011 Russia exported 541 Mt of CO_2 (Fig. 1). It is the highest value since 2007, but it is 18% lower than in 2000. In 2000 Russia exported 45% of total emissions, in 2011 – only 32%.

This tendency could seem odd because the export value (US dollar, current prices) rose 5-fold from 2000 to 2011 and production-based emissions (according to UNFCCC national inventories) increased by 11%. However, export volume index, reflecting export natural volumes, reached only 140% by 2011 compared to 2000 (according to World Development Indicators). 40%-increase of commodity exports was compensated, on the one hand, by technological improvement, and on the other hand by simplification of export structure (production of final goods, which requires burning large volumes of domestic fossil fuel, is associated with higher emissions volumes than selling raw mineral fuels).

Emissions embodied in Russia's imports increased 4.4-fold from 2000 to 2011 (see Fig. 1). The reasons were rising commodity imports volume and substitution of imports of European goods by more carbon-intensive Chinese goods. However, emissions embodied in imports in 2011 accounted for only 161 $MtCO_2$ – 3.4 times less than emissions embodied in exports.

Figure 1
Production-based and consumption-based CO2 emissions, CO2 emissions exports and imports, $MtCO_2$, 2000-2011)*



4.2. Trade competitiveness and policy implications

Large volumes of emissions embodied in Russia's exports are primarily explained by its commodity structure of exports, which is mainly represented by fuels and energy-intensive industries. Using emissions embodied in Russia's trade data, we now compare trade competitiveness indices by industry in 2000 and 2011 (see Fig. 2).

Trade competitiveness (TC) is measured as net exports divided by the trade turnover. When TC = 1, it indicates that the industry only exports without import and the competitiveness is strong. We calculate analogous index using embodied emissions data in order to identify exports structure changes which contributed to the dynamics of embodied emissions in 2000-2011.

* Production-based CO2 emissions: $E^{prod} = E_{m,m} + E^{exp} + E^{H}$, and consumption-based CO2 emissions: $E^{cons} = E_{m,m} + E^{imp} + E^{H}$, where E^{H} – emissions from final consumption of households (for example, from burning car fuel in country m); $E_{m,m}$ - CO2 emissions of country m for domestic consumption

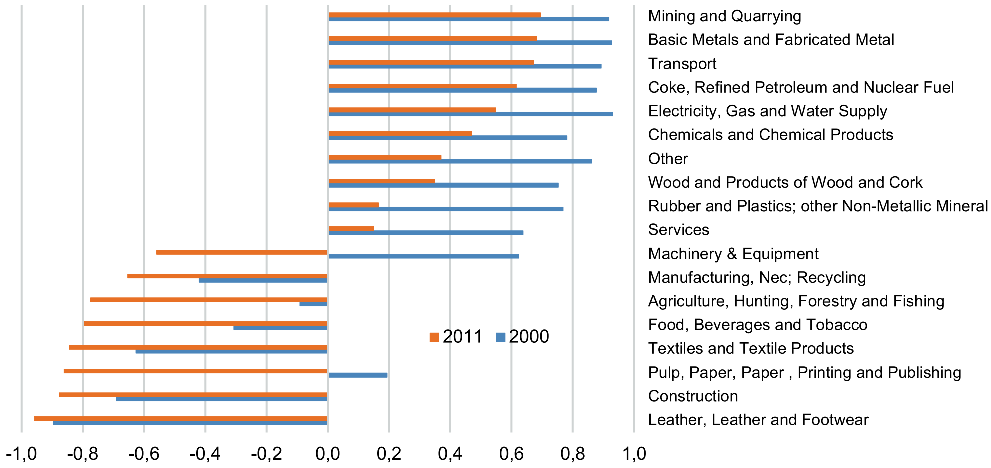


Figure 2
Trade competitiveness index (emissions equivalent), 2000 and 2011. Strong competitiveness (TC = 1), weak competitiveness (TC=-1).

All major high-carbon industries (Electricity, Gas and Water supply, Basic metals and fabricated metal, Transport, Mining and Quarrying) demonstrate significant loss in "emissions competitiveness", which contributes to the decline in carbon emissions in Russia's exports. The most dramatic change in competitiveness is seen in machinery and equipment as well as pulp and paper categories, which experienced a change from strong to weak competitiveness. The main contributing factor was the change in export market power between Russia and its trading partners.

The fact that the most carbon intensive exporting industries become less competitive in terms of emissions exports could provide some policy insights. Recently Russian trade partners have discussed potential implementation of border carbon adjustment (BCA) (e.g. Euractiv, 2018). BCAs is often considered as a tool to reduce "carbon leakage" and to stimulate emission reduction in developing countries (Branger and Quirion, 2014). Taking into account potential border tariffs implementation, decline in embodied carbon in exports may be seen as a sign of reduced vulnerability, as less exports would be subject to such tariffs.

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Conventional Energy Taxes vs. Carbon-Based Incentive Instruments in Emission Regulation

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Abstract

As a useful tool of climate mitigation strategies, carbon-based incentive instruments are becoming an increasingly popular subject of academic discussion. At the same time, the conventional energy taxes which do not directly target carbon content of fossil fuels but may still have a significant impact on emissions level, due to wide economic coverage, are often placed outside of such discussion. This research is dedicated to fulfilling this gap – it aims to estimate the relative impact of conventional energy taxes, carbon tax and cap-and trade system on the basis of feasible GLS regression model on panel data for European countries in 1995-2016. The results indicate that the impact of conventional energy taxes on carbon intensity is twice as high as the impact of either carbon tax or cap-and-trade.

KEYWORDS
Energy taxes, carbon tax, EU ETS, carbon dioxide emission regulation, climate change.

1. Introduction and Research Puzzle

Climate change is rapidly gaining momentum as a global problem with severe implications for domestic economies hereby raising the importance of mitigation strategies centered around emission regulation measures. Being responsible for nearly two thirds of global emissions, energy sector has been a subject of fiscal regulation since the first half of the XXth century [Speck, 2008]. Starting from the early 1990-s, conventional energy taxation (excise fuel taxes, extraction taxes, and many others) has been complemented by carbon-based incentive instruments providing stronger price signals for decreased use of fossil-fuel based energy.

According to a wide pool of theoretical and empirical studies, carbon-based incentive instruments (carbon tax, cap-and-trade or emission trading system, hybrids, etc.) have proven to be efficient mitigation tool against the backdrop of command-and-control instruments due to the ability of the former to equalize marginal abatement costs among emitters and sources of emission [Goulder, Parry, 2008]. At present, these instruments are quickly gaining popularity in both developed and developing countries and jurisdictions around the globe – around 40 of them now put price on carbon either through carbon tax or emissions trading scheme [World Bank, 2017].

European countries have always stayed at the forefront of environmental policy initiatives. The first carbon tax appeared in Finland in 1990, while the first and the largest emissions trading system (ETS) was launched on the basis of European market in 2005. European ETS now includes 31 countries while 16 European countries also use carbon tax (or close equivalent). Despite the growing popularity of carbon-based incentive instruments that help the countries effectively frame their climate and energy policy, coverage of the instruments is still on average relatively small. Even the most advanced and comprehensive European emissions trading scheme covers less than a half of all emissions [EU, 2018].

Focused mostly on carbon-based economic instruments, academic literature often neglects the role which conventional energy taxes play in carbon dioxide emissions dynamics. At the same time, conventional energy taxes which do not directly target the carbon content of fossil fuels may also have a significant influence on the emission level. Ultimate carbon price signal for the economy of an instrument is determined not only by the rate but also by the extent it is used: number of sectors under regulation, share of emissions covered, etc. In this regards, even though direct instruments (carbon tax or cap-and-trade) which usually use carbon content of the fuel as a tax base, are considered to have a greater marginal impact on the emission level, the indirect ones (conventional energy taxes) may play comparable role in emissions dynamics due to the wider scope of their application. Therefore, changes in indirect carbon regulation can potentially bring significant price effects which can even outstrip these from changes in the level of direct price signals since the later are playing growing but yet comparatively modest role in the fiscal framework.

In this regard, the main objective of this study is to identify the relative role of direct and indirect instruments in emission changes. The paper is organized as follows. Section 2 describes the methodology and the general approach of the study. Then, Section 3 describes the model and main inputs. Finally, Section 4 highlights main results of the analysis.

2. Methodology and Framework of the Analysis

Methodologically, the analysis is based on calculation of implicit carbon price – fiscal burden of a ton of carbon dioxide emissions which consists of three types of price signals: indirect price signal (created by conventional energy taxes), price signal of carbon tax and price signal of ETS. In order to make price signals comparable, data on tax revenues in energy sector were used for calculation of energy taxes price signal and carbon tax price signal. The ratio of tax revenues to volume of annual carbon dioxide emissions served as an indicator of price signal for both of them. Such an approach helped avoid the issue of differences in coverage and specifications of fiscal regulation (various tax rates for different sectors or sources of energy) in different countries. ETS price signal was calculated based on the volume of verified emissions and the average annual allowances price. The implicit carbon price for country *i* looks as **(1).**

$$ICP = \frac{1}{E} * (\underbrace{CT^{REV} + P^{ETS} * E^{VER}}_{\text{«Direct» price signals}} + \underbrace{\textstyle\sum_k ET_k^{REV}}_{\text{«Indirect» price signal}}) \quad (1)$$

where $\boldsymbol{E}$ – carbon dioxide emissions from combustion of fossil fuels;

$\boldsymbol{ET_k^{REV}}$ – energy tax revenue from the energy tax of k-type;

$\boldsymbol{CT^{REV}}$ – carbon tax revenue;

$\boldsymbol{P^{ETS}}$ – average annual allowances price at EU ETS;

$\boldsymbol{E^{VER}}$ – verified emissions under EU ETS.

In order to better shape the research objectives the following research hypotheses are formulated:

Hypothesis 1 (H1). *Carbon dioxide emissions are inversely related to implicit carbon price*. This is a general hypothesis to check if all three price signals within implicit carbon price are strong enough to incentivize the reduction of carbon dioxide emissions.

Hypothesis 2 (H2). *Carbon dioxide emissions are inversely related to each of the three components of the implicit carbon price, i.e. price signals of conventional energy taxes, carbon tax, and ETS.* Each of the three price signals potentially has a meaningful effect on the level of emissions.

Hypothesis 3 (H3). *Direct price signals (carbon price and ETS) have less impact on the level of carbon dioxide emissions in comparison to indirect ones (conventional energy taxes).* This is the main hypothesis to answer the research question of the present paper. The task is to evaluate the relative role which each of the three price signals plays in emissions reduction.

Hypothesis 4 (H4). *ETS has bigger impact on carbon dioxide emissions level in comparison to carbon tax*. There is a lot of discussion in academic literature on which of the carbon-based incentive mechanisms is better in terms of achieving greater level of emissions reduction. Since seminal paper of Weitzman, 1974 tax is often compared with cap-and-trade regulation both in purely theoretical setting and in empirical studies. The central is issue is which of the two instruments is more cost efficient. The answer usually depends on the framework of analysis: following Weitzman's tradition, some papers highlight carbon tax to be more cost efficient in the presence of uncertainty of marginal abatement costs [Pizer, 2002; Hoel, Karp, 2001]; alternatively, some papers indicate that cap-and-trade performs better when it comes to political dynamics and when stakeholders can influence the policy framework [Stavins, 2007]. Finally, some authors highlight the importance of the design of the instruments and argue that if properly designed both types of instruments gain equal cost-efficiency [Goulder, Schein, 2009]. Even though the present paper is unable to measure relative-cost efficiency and marginal impact of each of the three price signals (due to lack of data on the coverage of energy taxes and carbon tax in all countries and in all time periods) it provides useful insights on the ultimate impact of each of the three price signals on emissions.

3. Model Design and Key Input Variables

The causal relationship between implicit carbon price as well as each of the three price signals and the level of carbon dioxide emissions is estimated on the basis of regression model on panel data for 25 European countries* and 22 time-periods (1995-2016). Feasible OLS regression with fixed-effects is used to account for heterogeneity and spatial and time correlation as well as to consider different properties of regulatory instruments and individual characteristics of countries. Carbon intensity which shows the amount of carbon dioxide emissions per GDP is used as a proxy of the level of emission. Additionally, two control variables are used, namely, the share of fossil fuel energy in primary consumption and the share of manufacturing in gross value-added.

* The sample includes Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Lithuania, Luxemburg, Malta, Netherlands, Norway, Portugal, Romania, Slovakia, Spain, Sweden, and the UK. The sample does not cover some of the European countries for which it is statistically hard to distinguish energy taxes revenue and carbon tax revenues. Finland is one of the examples; in the middle of the 1990-s the country combined energy and carbon tax in a single one with the common tax base calculated for carbon content and the amount of the fuel consumed.

Equations **(2)** and **(3)** depict two operational models, while **Table 1** provides detailed description of both dependent and independent variables included into analysis.

$$lnCarbonIntensity_{it} = C1 + \alpha_1 * lnICP_{it} + \alpha_2 * FFshare_{it} + \alpha_3 * MANshare_{it} + \sum_k^K \alpha_4 * Country_k + e_{it} \quad (2)$$

$$lnCarbonIntensity_{it} = C2 + \alpha_1 * \ln EnergyTaxes_{it} + \alpha_2 * \ln CarbonTax_{it} + \alpha_3 * \ln ETS_{it} + \alpha_4 * FFshare_{it} + \alpha_5 * MANshare_{it} + \sum_k^K \alpha_6 * Country_k + u_{it} \quad (3)$$

Table 1
Description of Input Variables

Variable Name	Dimension	Description	Source
$CarbonIntensity$	tons per thousand US dollars	Carbon intensity - carbon dioxide emissions from the combustion of fossil fuels per unit of GDP at PPP	Calculations based on *Euromonitor International*
ICP	thousand euros	Implicit carbon price - sum of all tax revenues withdrawn from the taxation of energy use (excluding electricity use) per ton of carbon dioxide emissions from the combustion of fossil fuels	Calculations based on *Eurostat*
$EnergyTaxes$	thousand euros	Price signal of conventional energy taxes - sum of all tax revenues (excluding carbon tax) withdrawn from the taxation of energy use (excluding electricity use) per ton of carbon dioxide emissions from the combustion of fossil fuels	Calculations based on *Eurostat*
$CarbonTax$	thousand euros	Price signal of carbon tax – carbon tax revenues per ton of carbon dioxide emissions from the combustion of fossil fuels	Calculations based on *Eurostat*
ETS	thousand euros	Price signal of ETS – amount of verified emissions multiplied by annual average allowances price per ton of carbon dioxide emissions from the combustion of fossil fuels	Calculations based on *EU Emissions Trading System (ETS) data viewer*
$FFshare$	%	Share of fossil fuels in primary energy consumption	Calculations based on IE*A World Energy Statistics and Balances*
$MANshare$	%	Manufacturing as a share of gross value added	*Euromonitor International*

4. Results and discussion

Table 2 summarizes the results of the coefficient estimation in regressions **(2)** and **(3)**. Both regressions are significant at 1% significance level and so do all the coefficients of the variables. The results of the estimation allow to support **H1 –** implicit carbon price which represents the effect of all three types of price signals reunited has an inverse impact on the dependent variable. At the same time, according to the results **(Table 2)**, carbon intensity is inversely related to all three price signals (conventional energy taxes, carbon tax and ETS) separately which allows to support **H2**. As for relative impact of each of the three price signals, conventional energy taxes have turned to have the largest impact on the emissions level – 1% increase in the overall level of energy taxes on average lead to 2,21% decrease in carbon intensity levels. This is approximately twice as much as the average effect of each of the direct carbon-based incentive instruments (thus, **H3** is supported). The two direct instruments of emissions regulation show close to equivalent effect on carbon intensity. Although carbon tax price signal is slightly higher (-1.06 against 0,99) the difference is not statistically significant (standard errors around 0,3-0,4), therefore, **H4** cannot be supported.

Table 2
Results of the Regression Analysis

Variables	**Regressions**	
	(2)	**(3)**
lnICP	-1,8217*** (0,1332)	-
lnEnergyTaxes	-	-**2,2114*** (0,1511)
lnCarbonTax	-	-**1,0623*** (0,3719)
lnETS	-	-**0,9875*** (0,3162)
FFshare	0,3825*** (0,0345)	0,3646*** (0,0347)
MANshare	0,5678*** (0,0719)	0,5779*** (0,0717)
Country°	...	...
Intercept	-0,0736* (0,0378)	-0,0399 (0,0379)

Significance level: * p<0,1; ** p<0,05; *** p<0,01

°The models also include 24 country-specific dummy variables

The results indicate that other energy taxes play an important role in carbon dioxide emissions changes against the background of direct instruments of emission control. At the same time, there is no statistical difference between two direct types of instruments – carbon tax and cap-and-trade – the emissions level. Being created primarily not for climate-related purposes, other fiscal instruments in the energy sector have a profound impact on the emissions level which is twice as high as the effect of either carbon tax or cap-and-trade system. It highlights the importance of broader economic analysis when it comes to assessing impact of climate and energy policy and optimal instrument design.

Emission dynamics highly depends on conditions of inter-fuel competition which varies in accordance to comparative prices for different types of energy in the economy. In this regard, level of price is just the half of the story – scope and the coverage of an emissions regulation instrument makes a critical difference. The results indicate that the effect of direct carbon price signals can be easily offset by contrary changes in indirect carbon taxation due to the wider scope of its application, i.e. emissions coverage.

Analysis highlights the importance of existing fiscal framework when it comes to introduction of new incentive-based instruments targeting greenhouse gas emissions.

It draws additional attention that the fact that new carbon regulation policies should take a strong notice of the impact of existing fiscal instruments on the level of emissions. Furthermore, when the role of existing fiscal regulation is substantial, new carbon policies based on the market regulation should not neglect the possible tax-interaction effect which may undermine the efficiency of recently launched instruments.

Finally, the efficiency of carbon regulation and its overall impact on the emission level to a large extent depends on property rights allocation, transaction costs in the economic system, level of uncertainty of economic growth and technological development and other institutional factors. All of them may overstate the administrative costs of managing economic instruments of carbon regulation. Thus, high monitoring, verification and enforcement costs may further undermine the efficiency of carbon-based regulation making simple command-and-control regulatory measures a better alternative.

This is a burning issue especially for developing countries which are yet to develop mature market institutions. Introduction of new carbon-based incentive instruments without consideration of existing fiscal framework and specific features of institutional environment may bring no added value. In fact, it may even hurt the economy. In contrast to carbon tax, which often can be embodied into existing fiscal infrastructure, launch of the cap-and-trade system requires creation of new institutes (platforms and for trade and allowances distribution, etc.) leading to higher corruption risks. For the sake of sustainable use of carbon-based incentive instruments, their introduction should be gradual while their development should be synchronized with the existing set of fiscal measures.

Alternatively, if the institutions and market environment are too weak to manage these instruments cost-efficiently, the possible solution could be to modify the existing price signals towards their higher environmental efficiency. In particular, gradual increase of carbon component in the tax base of the existing energy taxes may help make energy policy more environmentally focused. In developing economies, such an approach may, on the one hand, help avoid high administrative costs of newly-launched instruments, and, on the other hand, help better consider the role of the existing set of fiscal regulatory measures contribution to a higher effectiveness of climate policies.

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Exploratory Study on Consumer Demand for Organic Personal Care Products

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Abstract

Our study focuses on the contrasting motivations for choosing biocosmetics and personal care products in general and on misperceptions as to what is an organic Personal Care Product (PCP). We design a questionnaire to study consumers' motivations when purchasing these types of goods and recruit a convenience sample of University students in Portugal. We consider attitudes towards the environment as well, to address the importance of private and social benefits. To explore potential market behaviour, we apply a stated preference approach to a hypothetical market scenario involving biocosmetics to elicit the value of the organic feature in PCPs. We hope to contribute to the literature on the demand for organic PCPs, as few studies have explored empirically its determinants.

KEYWORDS
Bio Personal Care Products, Consumer´s motivations, stated preferences approach.

1. Introduction

Green goods are nowadays a reality in many consumer markets including personal care products (PCPs henceforth). Consumers have at their disposal organic or biologic products which propose advantages in several dimensions in comparison to conventional alternatives (Arbenz et al. 2016). On the one hand, it is often claimed that organic products are better for consumer's health, and in that sense the benefit is mostly private. On the other hand, organic products are inherently less environmentally damaging than conventional alternatives. As such, their consumption reduces the societal burden caused by environmental damage. If consumers are motivated by environmental concerns in their purchases, they value the public good in relation to that benefit.

Our study focuses on these contrasting motivations for choosing biocosmetics and personal care products in general and on misperceptions as to what is an organic PCP. We design a questionnaire to study consumers' motivations when purchasing these types of goods. We consider attitudes towards the environment as well, to explore the importance of private and social benefits. To explore potential market behaviour, we apply a stated preference approach to a hypothetical market scenario involving bio-cosmetics to elicit the value of the organic feature in PCPs. We expect to contribute to the literature on the demand for organic personal care products, as few studies have explored empirically its determinants.

This short paper is organized as follows: we first discuss briefly the literature on organic consumption and present the methodology. The following section presents the results in terms of sample characteristics and stated willingness to pay for specific organic PCPs and finally, discuss preliminary conclusions from this study.

2. Literature review

When it comes to green consumption of food, several studies have identified that consumer values concerning environmental issues play a key role in explaining intentions and behavior. Furthermore, health concerns are also important determinants (e.g. Chryssohoidis and Krystallis 2005; Janssen 2018). Price is however a barrier from intentions to actions (Aschemann-Witzel and Zielke 2017).

Liobikienė and Bernatonienė (2017) review the literature on green consumption and highlight the fact that this phenomenon is often studied in aggregate without considering the details of specific types of consumption. The authors argue that determinants of green consumption will vary with the type of good, while suggesting specific criteria for the study of green cosmetics. In fact, few empirical studies have studied the determinants of consumption of PCPs that are either green in general or specifically organic. Noteworthy exceptions are Kim and Chung (2011), Ghazali et al. (2017), Hsu et al. (2017). These studies use the framework of the Theory of Planned

Behaviour by Ajzen (1985, 1991) and identify, amongst other factors, health and environmental concerns as important determinants for organic PCPs. On the contrary, Matic and Puh (2016) find that health concerns have no impact.

On the other hand, Cervellon and Carey (2011) argue there is a lack of understanding by consumers of what it means for a personal care product to be organic. We explore consumers' definitions of "natural" and "organic".

For the purpose of this paper we consider personal care products to include face, hair, body and intimate care, dental hygiene and make-up. These is also commonly referred to as cosmetics, although the latter's interpretation can be slightly less encompassing. To ensure respondents shared the same definition, there was a note in questionnaire at the start of the section on consumption of PCPs claryfing the definition in terms of what it includes.

3. Methodology

We use a stated preference method to explore the willingness to pay for different organic PCPs. Two questions are formulated concerning a more common and less expensive good (soap) and also a common but more expensive item (shampoo). Additionally, we also included a cosmetic item, a foundation cream, to capture a more specific luxury item. The prices used as references in the questions follow from an analysis of the more common prices for branded items at the time the questionnaire was designed. The formulation is as follows:

- *Consider a shampoo for your type of hair from a well-known brand, for sale in a supermarket for €4.00 (250 ml). Consider a shampoo for the same purpose, but with organic certification from the same brand, at sale in the same supermarket. What is the maximum price you would be willing to pay for this organic alternative?* Alternatives range from "I would not buy this alternative", €4.00 till €9.00 in €0.50 increments, and finally "more than €9.00".

- *Consider a bar of soap from a well-known brand, for sale in a supermarket for €0.70 (100 gr.). Consider a bar of soap for the same purpose, but with organic certification from the same brand, at sale in the same supermarket. What is the maximum price you would be willing to pay for this organic alternative?* Alternatives range from "I would not buy this alternative", €0.70 till €5.00, and finally "more than €5.00".

- *Consider a foundation cream for your skin type from a well-known brand, for sale in a supermarket for €7.00 (30 ml.). Consider a foundation cream for the same purpose, but with organic certification from the same brand, at sale in the same supermarket. What is the maximum price you would be willing to pay for this organic* *alternative?* Alternatives range from "I would not buy this alternative", €7.00 till €16.00, and finally "more than €16.00".

Besides the contingent valuation questions, the questionnaire included several questions about generic attitudes towards the environment, food choices, and habits concerning PCPs. Another covered topic concerned the associations consumers make relative to the terms "natural" and "organic".

4. Results

We use a convenience sample of university students from 18 to 35 years old. Recruitment was done via a university mailing list and online via social media, using a snowball system for a total of 379 complete questionnaires during June and July 2017. There are about 80% of female respondents and 70% of respondents are younger than 25.

In terms of environmental attitudes, we observe that almost all respondents agree that protecting the environment is important to them (35% agree with the statement and 64% totally agree). As for behaviours, we mostly follow the Eurobarometer question about actions undertaken in the previous month to compare the sample responses to the EU and Portuguese average (European Commission 2014). The results are in Table 1. Furthermore, roughly 35% of respondents indicate they have chosen organic products in the past month. Finally, as for paying higher prices for goods that are more environmentally friendly, 54.9% indicate their willingness, 20% neither agree nor disagree and 12.6% disagree. Overall, sample respondents appear more environmentally engaged than the Eurobarometer results.

Table 1
Environmental behaviours

"In the last month, have you undertaken any of the following actions for environmental reasons?"	EU	PT	Sample
cut down energy consumption	52%	60%	79.7%
separated most of waste for recycling	72%	71%	72.3%
cut down water consumption	37%	63%	60.4%
chosen a more environmentally friendly way of travelling	35%	25%	54.4%
chosen local products	35%	20%	27.4%
chosen organic products			34.6%

Source: European Commission (2014) and sample calculations.

Concerning PCPs, although the student status and age of respondents could potentially impact their direct influence in terms of PCPs products, 90.5% indicate they are responsible for the choice of products they use. The majority of purchases of PCPs are done in supermarkets (for hair, body, intimate care, dental hygiene), split between supermarkets and pharmacies (and akin) for face and solar products and mostly done in fragrance shops for make-up and fragrances.

In the literature, there is evidence that consumers misperceive the characteristics of products, partly from label misunderstanding and partly due to some misleading marketing strategies (Cervellon and Carey 2011). To explore perceptions as to the environmental characteristics of PCPs, we ask respondents to indicate if they have heard of "natural" PCPs and "organic" PCPs and about which features they consider to be attached to each definition. 80% and 74.4% of respondents had previously heard of these types of products, respectively.

Table 2 shows that half of the sample makes associations with the label "natural" such as a product only having natural ingredients. Based on the literature, this is an association that is not necessarily true. As for the organic definition, we see that 60% of respondents associate the designation with organic farming and 58% with the absence of genetically modified ingredients. In both cases, and again based on the literature we consider these last associations correct.

Table 2
Associations made by the respondents to the meaning of "natural" and "organic"

"Which statement(s) do you associate with the expression … personal care products?"	**"natural"**	**"organic"**
only natural ingredients	55.9%	49.3%
high percentage of natural ingredients	41.7%	21.9%
no chemical ingredients	49.6%	54.1%
to have ingredients from organic farming	-	60.2%
no GMO ingredients	43.0%	57.8%
cruelty-free	52.2%	43.5%
no negative damage to the environment	61.2%	56.5%
no ingredients damaging users	44.6%	40.6%

In the questionnaire, before further exploring attitudes towards organic PCPs, there is a short description of what organic PCPs are to ensure all respondents understand the characteristics and base their responses in a truthful assessment as to the objective advantages and disadvantages of these products. Then we explore the reasons why respondents use or would use organic PCPs (Table 3) and find the most cited reason are health concerns with 84% of responses, followed by environmental concerns with 56% of responses. Also concerns about animal testing seem to play a role for a significant part of the sample. Social influences from the inner circle of acquaintances or social media are negligible reasons in this sample.

Table 3
Reasons to choose organic PCPs

"Which reasons (would) make you choose organic PCP in detriment of conventional products?"	
health concerns	83.9%
environmental concerns	56.2%
concerns about animal testing	43.8%
because friends and acquaintances use them	3.7%
bloggers and youtubers suggestions	2.6%
it is indiferent to me	9.8%

We ask respondents to indicate if their use of organic PCPs is hindered by any external factors. The factor most frequent is price followed by availability (Table 4). Additionally, 36% to 44% indicate that they would use more if the advantages for the user or for the environment were clearer. We included two possibilities that are related to trust, namely the place of sale being a pharmacy (or akin) and the brand, but these factor were seldom chosen.

Table 4
Factors hindering consumption of organic PCPs

"I would use organic PCPs more actively, or, in the case I don't use them, I would start using them if:"		
they were the same price as conventional products	371	73.2%
they were more widely available	355	70.0%
the advantages for users were clearer	221	43.6%
the advantages to the environment were clearer	183	36.1%
they were available in pharmacies and parapharmacies	94	18.5%
they were produced by better known brands	56	11.0%

Concerning the stated willingness to pay (WTP) for the three organic alternatives, we plot the distribution of the additional WTP relative to the benchmark price. The frequency of responses is in the three graphs in Fig.1. The more common items of shampoo and soap have similar patterns of some positive additional WTP for the organic alternative. For soap there are two frequent values of €0.30 and €0.80, which in the second case more than doubles the original price. As for the makeup item, it is much less popular, with 45.6% of respondents saying they would not buy (21) or use the item (128).

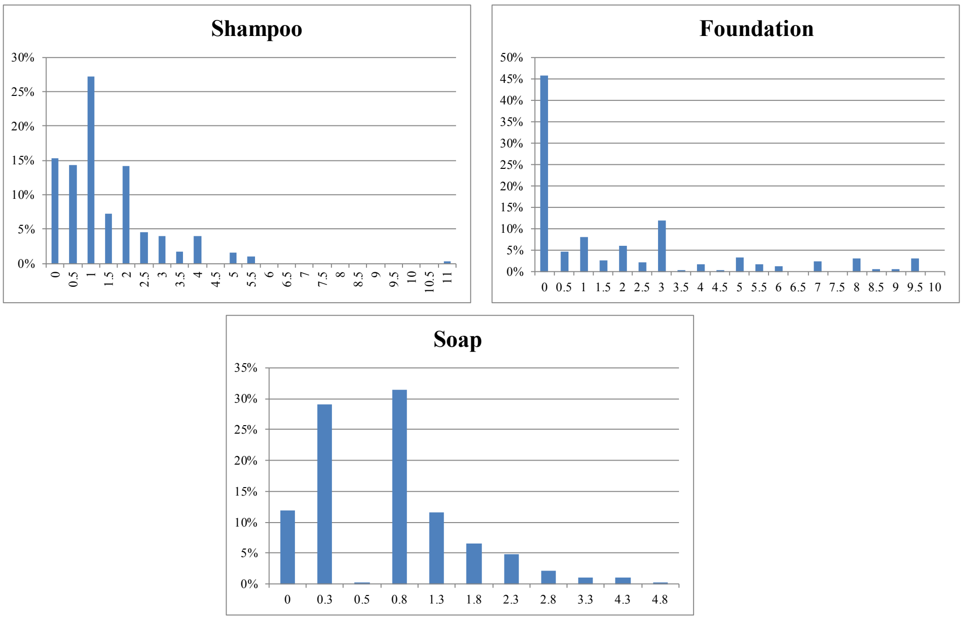

Fig. 1
Additional willingness-to-pay for organic products

Note: 379 observations; responses of non-purchase are coded as zero (respectively 10, 8 and 149 for the shampoo, soap and foundation cream).

Furthermore, we explore which factors condition the willingness to pay additionally for organic PCPs, namely concern for personal health issues and concern for the environment. We run a Tobit regression model on the additional WTP for the organic shampoo, soap and (makeup) foundation. We include the two types of concerns that would make respondents more actively buy organic PCPs and control for gender, given that prices are mentioned by the majority of respondents as an important factor affecting the choice of organics, we include a self-assessment of financial hardship as well.

Table 5
Tobit regression of the additional WTP for organic PCPs

dependent variables	**(1) Shampoo**	**(2) Soap**	**(3) Foundation**
Health reasons	0.745***	0.429***	0.464
	(0.221)	(0.132)	(0.653)
Environmental concerns	0.327**	0.153	0.178
	(0.159)	(0.0960)	(0.462)
Financial hardship	-0.298***	-0.0983	-0.654**
	(0.107)	(0.0644)	(0.308)
Woman	0.300	0.217*	7.795***
	(0.194)	(0.117)	(0.975)
Constant	0.847***	0.394**	-5.360***
	(0.317)	(0.191)	(1.210)
Observations	379	379	379

Notes: Standard errors in parentheses; significance levels *** p<0.01, ** p<0.05, * p<0.1; Health reasons, Environmental concerns and Woman are indicator variables; Financial hardship is measured on a 1 (I live comfortably financially) to 4 (I have many financial difficulties) scale.

Both in the cases of shampoo and soap, health concerns positively affect the willingness to pay. Furthermore, in the case of shampoo, the coefficient on environmental concerns is also statistically significant and positive. None of these factors affect the willingness to pay for makeup. In terms of controls, being a woman has a positive effect in the last two regressions but not on the purchases of shampoo. Finally, the variable that captures financial hardship is statistically significant in regression 1 and 3 and negative, as expected; this means that all else being equal the less financially comfortable the respondent feels, the less (s)he is willing to pay for the item.

5. Conclusions

Personal care products include a range of products that are frequently purchased by consumers and which are increasing being innovated with greener alternatives. While firms appear to have been using adjectives such as “natural” for a long time, there is still confusion on the side of consumers as to what a greener or more natural product is. The case of organic PCPs is noteworthy as objectively all ingredients need to come from organic farming. While much research has been devoted to studying factors affecting organic food consumptions, much less attention has been focused on PCPs. As argued by Liobikienė and Bernatonienė (2017) green purchases are not understood equally by consumers and depend on the category of product.

Using a convenience sample of Higher Education students we observe that different types of products, more or less common, more or less expensive are valued differently. In terms of understanding purchasing intentions and willingness to pay for an organic product, health and environmental concerns interact to shape consumers’ attitudes and behaviours. The majority of respondents agree that health concerns would be the main reason for buying organic but say they would be more willing to buy organic if prices were similar to conventional products and there was more availability. These factors seem to be dampening demand for organic PCPs. Additionally, there seems to be some confusion as to the definition of organic and we also find that consumers would potentially be more receptive to these products if the advantages in terms of health and the environmental were clearer.

Looking at the willingness to pay results, both for soap and shampoo, most respondents would be willing to pay a higher price for the organic product. However, at the time of conducting this survey, prices for organic products were substantially higher than the observed stated price premia. This means, that while respondents in this sample are susceptible to these products, a lower price is required to turn intentions into feasible choices.

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Global Cost and Optimal-Cost of Nearly Zero Energy Cities

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Abstract

The economic evaluation of a simplified Nearly Zero Energy City (nZEC) model which exploits the solar resource for Photovoltaic (PV) self-consumption of Barcelona (Spain) is presented here. This work seeks to contribute to the study of energy self-sufficiency of cities: urban areas that demand a high amount of energy resources, causing the emission of greenhouse gases. The evaluation procedure used is novel and is based on calculating at the city scale of Global Cost and Optimal-Cost indicators, originally proposed in the Energy Performance of Buildings Directive (EPBD) of the European Union. Based on several investment hypotheses in which Consumers, through self-consumption, and energy Producers share part of the electricity generation of the city, the results indicate that these two agents could participate in the energy supply with the aim of reducing the consumption of fossil primary energy and its associated costs.

KEYWORDS
Nearly Zero Energy Cities, Global Cost, Optimal-Cost.

1. Introduction

The substantial energy consumption of cities is responsible for a high percentage of the world's greenhouse gas emissions. Within these urban centres, as in the case of Barcelona, buildings have a high participation in the generation of these negative externalities (Barcelona Energia, 2014). In order to take advantage of the local renewable energy resources of the cities, the Distributed Generation (DG) is presented as a technological solution. At a building level, energy self-sufficiency is evaluated with the Nearly Zero Energy Building concept (nZEB): buildings in which Consumers reduce their energy demand with Energy Efficiency Measures (EEM) and cover part of the remaining demand with energy generated in situ. Energy self-sufficiency has been extended to the scale of cities, as presented in (Carlisle, Geet, & Pless, 2009; IRENA, 2016), to evaluate Nearly Zero Energy Cities (nZEC). Taking advantage of the advantages of the DG, in this type of urban areas the traditional electric energy Producers can participate in the supply of electric energy in cities. In this sense, the objective of this paper is to offer an approximation to the calculation of the costs of energy self-consumption of cities through the use of a nZEC model in which Consumers and Producers interact. The case study was Barcelona (Spain), a city that has been focusing on developing specific plans for its energy self-sufficiency (Agència d´Energía de Barcelona, 2011; Barcelona Energia, 2017). The results provided here help to understand the process of energy self-sufficiency in cities, their associated costs and the participation of Consumers and Producers in the supply of electricity to cities.

2. Methodology

In a nZEC model of Barcelona, this work evaluates several investment hypotheses by Consumers and Producers in Photovoltaic (PV) systems installed on the rooftops of buildings of this city, and in EEM by Consumers, to calculate the economic indicators Global Cost (CG(T)) and Optimal-Cost. The data of PV generation capacity of the city have been obtained by its City Council. The CG(T) and the Optimal-Cost belong to the Energy Performance of Buildings Directive (EPBD) of the European Union, and both have been adapted for their application in energy self-consumption systems at a city level in the *Economic Assessment Tool of Energy Projects* (EATEP), presented at (Villa-Arrieta & Sumper, 2018)in hourly time steps, technical and economic variables that can determine the functioning of energy systems and the profitability of the investment required for their implementation. The economic calculation procedure, as described in the European standard EN 15459:2007, of the Energy Performance of Buildings Directive (EPBD. This tool works by integrating the energy simulation software *TRaNsient System Simulation Tool* (TRNSYS) and allows for dynamic linking of technical and economic variables that determine the behaviour of energy systems in hourly time steps. The following the procedure for calculating the indicators and the model used is described.

2.1 Global Cost and Optimal-Cost

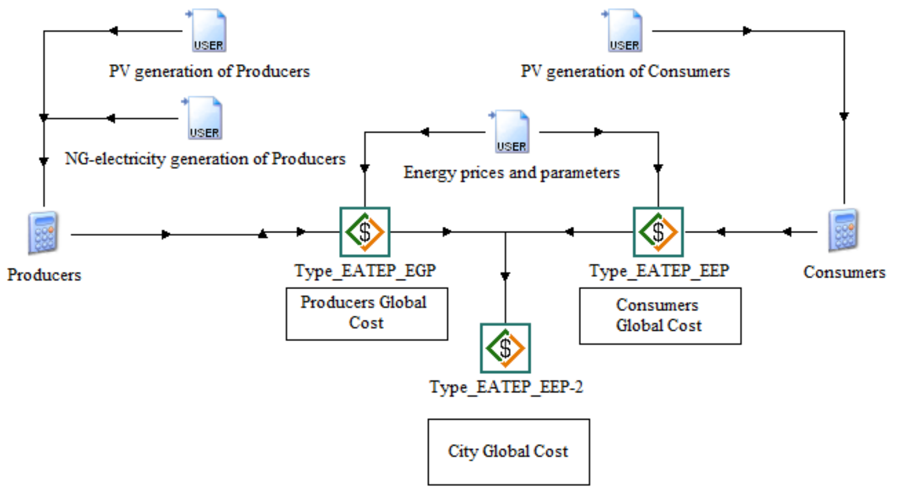
The Optimal-Cost is the lowest CG(T) among several combinations, called Packages, of EEM and energy self-consumption measures, called Components, which allows reducing the consumption of primary energy with respect to the building without energy investment, called Reference Case. The CG(T) is the present value of the annual costs of investment and replacement of Components, of energy and environmental costs, and of maintenance costs in a period of economic evaluation (T) (see eq. (1)). Each annual cost is the sum of the future value of the initial costs, calculated from a specific evolution rate (RX) for each Component and energy price used. To update these costs to the initial year of T, a Discount rate (Rd) is used that depends on a Real Interest Rate, calculated from a Market Interest Rate (R) and an Inflation Rate (RI) (European Union, 2010, 2012). The CG(T) subtracts from the total of the annual costs, the Final Value of the Components (VF(T)) in the year T. In the EATEP, the equation (1) is the one used to calculate the CG(T). Here, the costs are divided into four groups of global costs for Consumers and Producers: Investment Cost (CIG(T)), Running Cost (CRG(T)), Energy Cost (CEG(T)), and Environmental Cost (CMG(T)). The first and second of these costs are calculated from the investment and maintenance of Packages, and the third and fourth from the external energy consumed by the nZEC.

$$CG(T)_{Csr,Pdr} = CIG(T)_{Csr,Pdr} + CRG(T)_{Csr,Pdr} + CEG(T)_{Csr,Pdr} + CMG(T)_{Csr,Pdr} \qquad (1)$$

2.2 Model nZEC evaluated

In the model NZEC evaluated the energy balance corresponds to the equality between the demand of electrical energy of the domestic and non-domestic buildings of the city, and the PV energy generated by Consumers and Producers in the rooftops of these buildings, and the external energy generated by the Producers in a hypothetical combined cycle power plant. Figure 1 presents the scheme of the nZEC model built in TRNSYS; where the Type EATEP_EEP corresponds to the tool to calculate the CG(T) of the Consumers, the Type EATEP_EGP to calculate this indicator in the Producers and the Type EATEP_EEP-2 to calculate the CG(T) of Consumers and Producers.

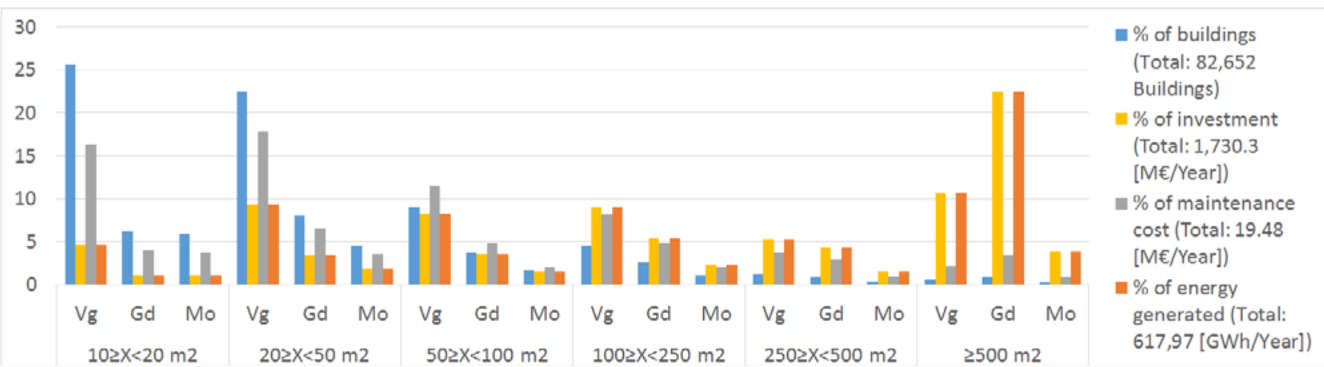
Figure 1
Construction in TRNSYS of the nZEC model (by Consumers and Producers) of Barcelona (Spain)



Initial data

The data on the PV generation on the rooftops of the buildings of Barcelona have been taken from the Map of renewable energy resources of the City Council of Barcelona (Barcelona Energia, 2016a, 2016b). These data are classified into groups of suitable surfaces with classifiers "Very good", "Good", "Moderate" and "Limited" of the rooftops with surfaces in square meters between ≥10 and <20, ≥20 and <50, ≥50 and <100, ≥100 and <250, ≥250 and <500, and ≥500. For the scope of this study, only the data of the Very good (Vg), Good (Gd) and Moderate (Mo) groups and surfaces that have a continuous insolation of 95-100%, 80 -94% and 70-79% respectively have been used. According to these data, as shown in Figure 2, 25.53% of the buildings in the city have a generation capacity of less than 5% of the electric power, with low initial investment costs (4.62%) and high maintenance costs (16.33%). Likewise, the buildings with rooftops of more than 500 m^2 with radiation of category Gb, which represent just 0.96% of the total of buildings, have the capacity to generate 22.45% of the electrical energy of the total capacity of the rooftops.

Figure 2
Summary of the PV generation of Barcelona (Spain). Source: (Barcelona Energia, 2016a, 2016b).



Hypothesis evaluated

The calculation of the CG(T) was made with the evaluation of 53 Packages, each corresponding to an investment hypothesis on the part of Consumers and Producers. The real investment in EEM and energy self-consumption depends on the return of the investment made, which in turn depends on the economic and financial conditions that the markets provide. In this paper, to give an approximation to the costs of the nZEC model of Barcelona, four groups of hypotheses have been established, presented in Table 1: by suitable radiation groups, scenarios B and C; by groups of rooftop surfaces, scenarios D, E and F; by percentages of buildings, scenarios G and H; and by selection of generation capacity of the rooftops surface groups, scenario I.

Table 1
Investment hypothesis of Consumers and Producers in each scenario (Sc).

Sc	Investment
A	Reference case
B	Csr: 1) Vg. 2) Gd. 3. Mo. 4). Vg and Gd. 5) Vg and Mo. 6) Gd and Mo Pdr: They do not invest
C	Csr: 1) Vg. 2) Gd. 3. Mo. 4). Vg and Gd. 5) Vg and Mo. 6) Gd and Mo Pdr: Mirror investment
D	Csr: 1) 10≥X<20. 2) 20≥X<50. 3) 50≥X<100. 4) 100≥X<250. 5) 250≥X<500. 6) ≥500 Pdr: They do not invest
E	Csr: 1) 10≥X<20. 2) 20≥X<50. 3) 50≥X<100. 4) 100≥X<250. 5) 250≥X<500. 6) ≥500 Pdr: 1) ≥20. 2)10≥X<20 and ≥50. 3) 10≥X<50 and ≥100. 4) 10≥X<100 and ≥250. 5) 10≥X<250 and ≥500. 6) <500
F	Csr: Mirror investment of Pdr in E Pdr: Mirror investment of Csr in E
G	Csr: 1) 10%. 2) 20%. 3) 30%. 4) 40%. 5) 50%. 6) 60%. 7) 70%. 8) 80%. 9) 90%. 10) 100% Pdr: They do not invest
H	Csr: 1) 10%. 2) 20%. 3) 30%. 4) 40%. 5) 50%. 6) 60%. 7) 70%. 8) 80%. 9) 90% Pdr: 1) 90%. 2) 80%. 3) 70%. 4) 60%. 5) 50%. 6) 40%. 7) 30%. 8) 20%. 9) 10%
I	Csr: 1) and 2) Buildings with the greatest generation capacity of each area group. 3) Buildings with the second and third largest generation capacity of each area group Pdr: 1) They do not invest. 2) Buildings with the second and third largest generation capacity of each area group. 3) Buildings with the greatest generation capacity of each area group

General data and calculation of initial costs and prices

Barcelona has an area of 102.159 km^2. The initial data on energy consumption and energy prices have been from 2016. In this year, the city consumed 6,659.757 GWh of electricity in its domestic and non-domestic buildings (Departament d'Estadísitca de la ciutat de Barcelona, 2017). The economic evaluation period used was 35 years (2015-2050), with an R of 4% and an RI of 2%. The price of electricity paid by Consumers was built as the average of the regulate access charges (Spain) of low tension and power connection to the grid less than 10kW, presented in (IDAE, 2016). The power charge used was 38.043426 €/kW-Year, assuming a contracted power of 4.6 kW. The energy charge used was 0.037082 €/kWh, and an energy price equal to 0.046109 €/kWh (REE, 2017). The income received by Producers for energy sold is calculated using only the price of electricity. Regarding natural gas (NG), a conversion factor (FX) was used to primary energy (PE) with a value of 2,007 kWh_Primary/

kWh_Final (Ministerio de Industria, 2016) with an evolution rate (RX) of -0.001%, an FX of CO_2 emissions with a value of 0.357 kgCO2/kWh_Final (Ministerio de Industria, 2016), and an RX of -0.3%, and finally a price for this energy vector of 0.0209975 €/kWh (MIBGAS, 2018). To calculate the hypothetical cost of CO_2 emissions by Producers, the CO_2 price value of 5.35 €/TonCO2 (Sendeco2, 2018) was used. In the prices of energy and CO_2, an RX of 2% was used, obtained from (AENOR, 2008).

In the solar resource of Barcelona map, PV modules of 270 W and 2 m^2 were used, with an average value of energy generated of 1,250 kWh/kWp·Year. A lifespan of 25 years for these modules was considered in this paper, with which the future value of its replacement was calculated, using a RX of 2% for its investment cost and maintenance cost. The cost of the investment in the EEM and the value of their expected energy efficiency, considering only the placement of insulation on the façade of the buildings (expanded polystyrene of 6 cm), was calculated as average values among all the categories of buildings presented in (ICAEN, 2017): for buildings of 1 and 2 floors (single-family building) a value of 23.775% was used for the achievable energy efficiency, an initial over cost of investment of €2,948.45 and maintenance cost 140 €/Year; for buildings of >2 floors (multi-family buildings) a value of 26.9% was used for the achievable energy efficiency, an initial over cost of €39,722.46 and a maintenance cost of €1,700. Finally, to calculate the maintenance cost of the hypothetical Producers combined cycle plant, the 1% of 300 €/kW was used.

Results and discussion

All the investment hypotheses of the Packages evaluated in the nZEC model of Barcelona, allow to reduce the consumption of primary fossil energy (external) and the Global Cost (CG (T) with respect to the Reference Case. This reduction in primary energy consumption is between the range of 27.7-35%, and that of the CG(T) between the range of 5.3-24.1%. Within these economic results, the energy cost represents more than 50% in each Package. The Optimal-Cost, as indicated in Graph 1 of Figure 3, is obtained with the Package D5, which corresponds to the investment hypothesis of Consumers on rooftops surfaces between 250 and 500 m^2 without the investment of the Producers. This Package, as detailed in Graph 4, allows to reduce 25.69% of the primary energy consumption and 24% of the CG(T). This economic result is obtained because the initial investment of this PV generation surface is low (see Figure 2). Continuing with Figure 3, the best result in terms of reducing primary energy consumption is the Package E1, which corresponds to the investment of the Consumers in the group of rooftops surfaces (between ⩾10 and <20 m^2) with the greatest number of buildings (approx. 40%), and the Producers invest in the other number of buildings (rooftops surfaces ⩾20 m^2). This indicates that the individual investment of the Consumers in each of their rooftops, together with the investment of the Producers in the rooftops of larger surfaces, is favourable in the reduction of the city's energy consumption.

Between the Packages F1 and E1, as indicated in Graph 3, a selection of 28 results with the lowest primary energy consumption is located. Except for the Package G10 (100% of the investment by Consumers), all of results belong to hypotheses in which the investment is made by Consumers and Producers. The results of Packages 1 to 9 of the hypothesis H are kept in the same line of primary energy consumption because the proportional distribution of the buildings does not influence the equivalence of the amount of external energy imported; on the contrary, if it influences the CG(T). Graph 5 presents a selection of the best results in terms of lower ECG(T) and CG(T), obtained in each group of hypotheses. Among these, those that consider the investment of Producers allow a greater reduction of the primary energy consumption because they cover all the rooftops of the nZEC model.

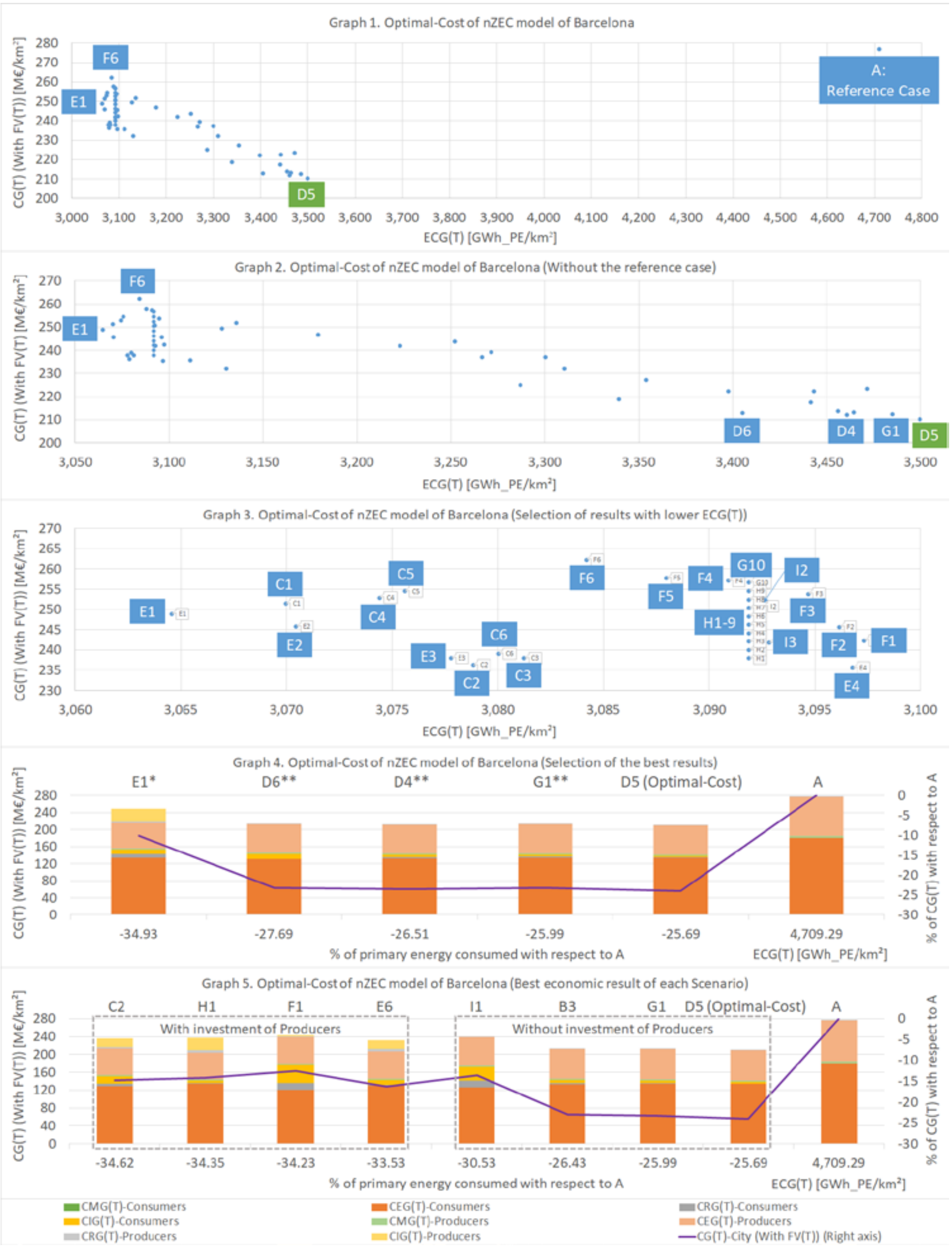


Figure 3
Results of nZEC model of Barcelona (Spain). Note: *Greater saving of Primary Energy (PE); ** Results close to the Optimal-Cost and with greater energy savings.

Conclusion

The Optimal-Cost of the economic calculation procedure of the EPBD in its version adapted for the evaluation of nZEC is interpreted as the lowest net present value (Global Cost) of the sum of the environmental, energy, operation and investment costs of a Package of EEM and energy self-consumption technologies that reduce the consumption of primary energy of a city. The calculation of this indicator in the nZEC model of Barcelona evaluated in this work has meant that it has been possible to provide an approximation to the costs of the use of the rooftops of the buildings domestic and non-domestic of the city for PV self-consumption in total terms for the city and in specific terms for Consumers and Producers.

All the combinations of investment hypotheses of Consumers and Producers in EEM and PV modules in the evaluated model allow to reduce the consumption of primary energy of fossil origin (external) and the Global Cost (CG (T) with respect to the Reference Case. In this sense, the use of local renewable energy resources through energy self-sufficiency reduces the consumption of fossil energy resources and, therefore, the emission of greenhouse gases. From the point of view of the calculation of the Optimal-Cost, Barcelona has a high capacity to reach a level of energy consumption nearly to zero; in which energy Consumers and Producers can interact in its energy supply. The hypotheses evaluated give an approximation to the distribution that according to commercial agreements of the rental of the rooftops of the city (not included in this work), could be made between these two economic agents. Finally, due to these results, this paper encourages the representatives of city administrations to continue or increase plans to promote investment in energy self-consumption systems.

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