UNIVERSIDADE DA BEIRA INTERIOR
Ciências Sociais e Humanas

Energy transition and economic growth: Evidence from countries with barriers to diversification of their electricity mix

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Tese para obtenção do Grau de Doutor em

Economia

(3º ciclo de estudos)

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Covilhã, maio de 2020

Ackowledgments

Completing a PhD thesis is never an easy task, because it is not possible to conclude it alone.

I would like to express my sincere thanks to Professor António Cardoso Marques. I am extremely grateful to him for having shared the experience and encouragement and, above all, for his patience.

A special thanks to Professor José Alberto Fuinhas for his availability and support.

I also thank to my family, especially to my parents and my girlfriend, for their reluctant encouragement in this adventure.

I want to thank my friends and colleagues for their support. I would also like to thank those who have contributed something to the accomplishment of this work.

Resumo

Num contexto global de transição energética, os países começaram a desenvolver esforços para reduzirem as emissões de gases poluentes. A diversificação do *mix* de eletricidade tem vindo a progredir com a introdução de fontes de geração renovável intermitente. Com o propósito de melhorar a compreensão da transição de fontes fósseis para fontes renováveis é necessário analisar os constrangimentos e os fatores da transição energética. Neste sentido, a presente tese tem como objetivo analisar empiricamente o comportamento da interação entre fontes, considerando a existência de fontes dominantes e a dimensão do mercado, tendo ainda em conta o compromisso com o crescimento económico. Esta tese é constituída por quatro ensaios. O primeiro ensaio aborda o papel das energias renováveis no crescimento económico, considerando o contexto da existência de uma barreira inocente à diversificação. A dominância de uma fonte de geração no *mix* de eletricidade, quer pela abundância de um recurso natural ou por opção estratégica, pode dificultar a entrada ou o desenvolvimento de novas fontes no *mix* de eletricidade. Utilizando estimadores de dados em painel para uma frequência anual, os resultados mostram uma evidência empírica para uma relação negativa das energias renováveis para o crescimento económico. Os países com uma fonte dominante possuem uma vantagem comparativa e, portanto, enfrentam um *trade-off* entre continuar a produzir através da fonte dominante, promovendo o crescimento económico, ou introduzir fontes alternativas, podendo comprometer a atividade económica.

O mercado de eletricidade é uma ferramenta importante na acomodação de fontes renováveis, permitindo alocar os excessos e importar o défice de produção, dependendo da dimensão do mercado. Esta está relacionada não só com a extensão geográfica, mas também com a profundidade, integração de fontes, diversidade do *mix* de eletricidade dos membros e fluxos de eletricidade. Portanto, a dimensão do mercado pode ser uma potencial barreira ao desenvolvimento de renováveis ou um fator determinante. No segundo ensaio são analisadas as interações entre fontes de geração de eletricidade e a atividade económica no contexto de um grande mercado de eletricidade. Utilizando modelos autorregressivos de desfasamento distribuídos em séries temporais, com frequência mensal para uma amostra de dois países no Nord Pool Spot, os resultados mostram que os recursos naturais endógenos estão a promover a atividade económica. No terceiro ensaio é estudada a interação de fontes de eletricidade com o preço do mercado grossista num contexto de pequeno mercado. Os dois membros que constituem o mercado ibérico foram analisados recorrendo a um modelo vetor autorregressivo com séries temporais de frequência diária. Os resultados mostram que os dois países, Espanha e Portugal, não interagem com o mercado da mesma forma. A escala de geração de eletricidade é muito diferente nos dois sistemas elétricos. Recomenda-se o estabelecimento de critérios na admissão a um mercado de eletricidade, como a diversidade do *mix* em relação aos membros já existentes.

A diversificação do *mix* de eletricidade pode ser utilizada para diminuir a dependência energética e promover a transição energética. No quarto ensaio são abordados dois conceitos de transição energética, concretamente a transição energética limpa e a transição energética de baixo carbono. Dois indicadores foram construídos e propostos para mediar os dois tipos de transição. Na transição energética limpa as renováveis foram consideradas como parte da transição. Enquanto que na transição energética de baixo carbono foram consideradas as fontes renováveis e nuclear como parte da transição. Vários estimadores de dados em painel foram aplicados nas duas subamostras, produtores não nucleares e nucleares. A eficiência energética e a abertura da economia são fatores determinantes na transição das duas abordagens utilizadas. Como tal, são recomendadas medidas de promoção de eficiência energética e a abertura da economia para o desenvolvimento das fontes renováveis

Palavras-chave

Transição Energética Limpa, Transição Energética de Baixo Carbono, Crescimento Económico, Barreiras à Diversificação, Fontes Dominantes, Mercados de Eletricidade, Mercado Nórdico, Mercado Ibérico

Resumo alargado

A transição energética de fontes fósseis para fontes renováveis tem sido um fenómeno transversal em vários países. A necessidade de cumprir os acordos ambientais internacionais e também as ambiciosas metas nacionais levou a que se avançasse rapidamente para a eletrificação dos vários setores da economia e, consequentemente, para a introdução de energias renováveis intermitentes no *mix* de eletricidade. O aumento da procura de eletricidade traz um desafio para a transição energética e para a segurança energética. Neste sentido, para além da substituição de fontes existentes é necessário satisfazer a procura crescente.

As energias ou fontes renováveis intermitentes são caracterizadas por um preço marginal baixo, mas com um elevado investimento inicial. Os desenvolvimentos destas fontes intermitentes vieram trazer desafios ao sistema de geração, nomeadamente, em termos de flexibilidade. Quando os recursos naturais, sol e vento, não estão disponíveis é necessário recorrer ao uso de fontes flexíveis não intermitentes, como por exemplo o gás, os recursos hídricos ou então a aquisição de eletricidade no mercado.

Os recursos renováveis intermitentes estão disponíveis geograficamente de forma menos concentrada do que os combustíveis fósseis. Contudo, o desenvolvimento de renováveis ainda enfrenta alguns constrangimentos, como barreiras naturais e técnicas. As barreiras naturais estão relacionadas com a existência de fontes com uma grande quota no *mix* de geração de eletricidade. Esta dominância constitui-se como uma barreira inocente que pode ocorrer devido à abundância de um determinado recurso natural, como por exemplo o carvão. Para além da abundância de recursos naturais, os elevados investimentos num tipo de geração, por exemplo a energia nuclear, constituem-se como uma barreira estratégica para a introdução ou desenvolvimento de outras fontes no *mix* de eletricidade. Os países com uma ou mais fontes dominantes têm uma vantagem comparativa na geração de eletricidade nesse tipo de fonte. O custo de oportunidade que decorre dos elevados investimentos executados pode dificultar a transição de fontes fósseis para fontes renováveis ou de baixo carbono, sem comprometer o crescimento económico.

O problema da intermitência nas fontes renováveis ainda não está totalmente mitigado. Neste aspeto, o mercado de eletricidade pode fornecer o suporte necessário para a acomodação deste tipo de fontes. O mercado de eletricidade tem de ou deve? operar de forma instantânea na compensação da escassez de geração de eletricidade das fontes intermitentes, portanto, as insuficiências nas interligações transfronteiriças podem constituir-se com uma barreira técnica à diversificação de fontes. A dimensão do mercado também pode influenciar a transição energética. Esta dimensão do mercado está relacionada com a extensão geográfica, número de países participantes, eletricidade comercializada, capacidade das interligações e diversidade do *mix* de eletricidade. O mercado de eletricidade permite que os países se especializem na fonte de geração na qual possuem uma vantagem comparativa e com isto promover o crescimento económico.

Esta tese tem como objetivo avaliar empiricamente o comportamento da interação de fontes de eletricidade num contexto de fontes dominantes no *mix* de eletricidade, e também no acesso ou não a um grande mercado de eletricidade, considerando o compromisso com o crescimento económico. Esta tese é constituída por quatro ensaios, em que no primeiro é estudado o papel das fontes fósseis e renováveis no crescimento económico em países com fontes dominantes no *mix* de eletricidade. O segundo ensaio está focado na análise das interações entre fontes de geração de eletricidade e a atividade económica em dois países que pertencem a um grande mercado de eletricidade como o Nord Pool Spot. No terceiro ensaio é analisada a interação entre as fontes de geração de eletricidade e o preço do mercado grossista em países que pertencem a um pequeno mercado de eletricidade, como o mercado ibérico. O quarto ensaio evidencia os determinantes da transição energética considerando duas abordagens, a transição energética limpa e a transição energética de baixo carbono.

A dominância de fontes no *mix* de eletricidade foi analisada, no primeiro ensaio, para um conjunto de países que pertencem aos dez maiores produtores num tipo de fonte. Foi utilizada uma estrutura de dados anuais em painel para 28 países, desde 1995 até 2013. Tendo em conta as características dos países foram testados estimadores heterogéneos e estimadores homogéneos. Uma vez que a heterogeneidade não foi comprovada, utilizou-se um estimador Driscoll-Kraay com uma abordagem autorregressiva de desfasamento distribuído para capturar a dinâmica de curto e longo prazo. Os resultados mostram que o consumo de energia de fontes renováveis inibe o crescimento económico para o longo prazo, já as fontes fósseis estimulam o crescimento económico no curto prazo. Portanto, os países enfrentam um *trade-off* entre continuar a consumir energia gerada através de fontes fósseis, contribuindo para o seu crescimento económico, ou consumir energia gerada através de fontes de origem renovável, podendo comprometer o crescimento económico. Neste ensaio são discutidas medidas de forma a atenuar e reverter o efeito das fontes renováveis no crescimento económico.

O grande mercado de eletricidade, no segundo ensaio, tem como amostra a Estónia e a Suécia. Recorrendo a séries temporais com frequência mensal, os dois países foram analisados separadamente através da aplicação de modelos autorregressivos de desfasamento distribuído. A Estónia é abundante em xisto betuminoso, enquanto que a Suécia tem como fontes dominantes no seu *mix* a energia hídrica e nuclear. Os resultados mostram que o crescimento económico tem como suporte as fontes fósseis. Os recursos naturais podem sustentar o desenvolvimento das fontes renováveis. A análise do pequeno mercado de eletricidade, no terceiro ensaio, tem como amostra os dois países que constituem o mercado ibérico de eletricidade, Espanha e Portugal. Estes dois países apresentam semelhanças no seu *mix* de eletricidade com exceção da energia nuclear em Espanha. Recorrendo a séries temporais com frequência diária (dias úteis) desde a criação do mercado foi estudada a interação das fontes de eletricidade e o preço do mercado grossista. Os dois países têm padrões de consumo idênticos devido à proximidade cultural e geográfica, pelo que ambos beneficiam com o acesso a um mercado de eletricidade diversificado.

No quarto ensaio foram analisados os determinantes da transição energética limpa e da transição energética de baixo carbono. De forma a medir a transição energética limpa foi criado um indicador de peso relativo entre as fontes renováveis e as fontes fósseis. Enquanto que para a transição energética de baixo carbono o indicador foi criado pela relação entre a soma de renováveis e nuclear com a fontes fósseis. Para este estudo foi utilizado um painel constituído por países membros da Organização para a Cooperação e Desenvolvimento Económico para o horizonte temporal de 1971 a 2016. A amostra foi dividida em países produtores de energia nuclear e países não produtores. Foram aplicados vários estimadores de forma a garantir a robustez dos resultados. Os resultados mostram que a eficiência energética e a abertura da economia são impulsionadoras nas duas abordagens de transição energética analisadas. É recomendada a implementação de políticas de promoção da eficiência energética de forma a contribuir para a substituição de fontes fósseis por renováveis, e não uma adição das renováveis às fontes fósseis.

Abstract

In the global context of energy transition, many countries are trying to reduce their greenhouse gas emissions. The diversification of the electricity mix has been achieved with the development of intermittent renewable generation sources. To improve the understanding of the transition from fossil sources to renewable sources, it is necessary to analyse the constraints and drivers of this transition. With this in mind, this thesis is aimed at empirically analysing the behaviour of the interacting of sources, considering the existence of dominant sources, and the market size, while taking into account the commitment to economic growth. This thesis consists of four essays. The first essay addresses the role of renewable energies in economic growth, considering the context of an innocent barrier to diversification. The dominance of a generation source in the electricity mix, such as the abundance of a natural resource or by strategic option, may obstruct the entry or development of new sources in the electricity mix. Using panel data estimators for an annual frequency, the results show empirical evidence for a negative relationship of renewable energies to economic growth. Countries with a dominant source have a comparative advantage, so they face a trade-off between continuing to produce using the dominant source, promoting economic growth, or introducing alternative sources that may compromise economic activity.

An electricity market is an essential tool in the accommodation of renewables, it distributes the excesses, and imports the production deficit, depending on the market size. The market size is related, not only to the geographical extent, but also to the depth, integration of sources, electricity mix diversity of the members, and flows of electricity traded. Therefore, the market size may be a potential barrier to the development of renewables. The second essay analyses the interactions between electricity generation sources and economic activity in the context of a large electricity market. Using autoregressive distributed lag models in time series with monthly frequency for a sample of two countries in the Nord Pool Spot, the results show that endogenous natural resources are supporting economic activity. In the third essay, the interaction of electricity sources with the wholesale market price in a small market context is considered. Using a vector autoregressive model with daily frequency time series, the two members of the Iberian market were analysed. The results show that the two countries, Spain, and Portugal, do not interact with the market in the same way. The scale of electricity generation is very different in the two electrical systems. The establishment of admission criteria to an electricity market, such as the diversity of the mix in relation to existing members, is recommended.

Energy transition and economic growth: Evidence from countries with barriers to diversification of their electricity mix

Diversification of an electricity mix can be used to reduce energy dependency and promote energy transition. The fourth essay addresses two concepts of energy transition, specifically clean energy transition and low carbon energy transition. Two indicators were computed and proposed to measure both transition approaches. In clean energy transition, renewables were considered as part of the transition, while in low carbon energy transition, both renewable and nuclear sources were considered as part of the energy transition. Some panel data estimators were applied in two sub-samples, non-nuclear and nuclear producers. Energy efficiency and trade openness as a supporter of energy transition are a common feature in both approaches. As such, energy efficiency promotion measures are necessary for the development of renewables.

Keywords

Clean Energy Transition, Low Carbon Energy Transition, Economic Growth, Barriers to Diversification, Dominant Sources, Electricity Markets, Nord Pool, Iberian Market

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Acronymous list

ARDL	Autoregressive Distributed Lag
CO_2	Carbon Dioxide Emissions
ECT	Error Correction Term
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	Eurpean Union
FE	Fixed Effects
FGLS	Feasable Generalized least Squares
GDP	Gross Domestic Product
MG	Mean group
MIBEL	Iberian Electricity Market
NPS	Nord Pool Spot
OECD	Organisation for Economic Co-operation and Development
PCSE	Panel Corrected Standard Error
PMG	Pooled Mean Group
RE	Random Effects
RES	Renewable Energy Sources
RESI	Intermittent generation by Renewable Energy Sources
STL	Seasonal Trend Decomposition
TSO	Transmission System Operator
VAR	Vector Autoregressive
VIF	Variance Inflation Factor

Chapter 1

Introduction

Over the years, there has been growing concern about the consequences of economic activity on the environment. With this, governments and international institutions have been proposing various programs to minimize the emissions of pollutant gases into the atmosphere. Electrifying sectors of the economy could be an effective way to execute their low carbon plans. As a result of environmental concerns, and limited availability of fossil resources, countries have begun to diversify their electricity mix, taking into account issues such as energy supply, energy independence, and energy poverty. The development of renewable energy has brought some challenges for electric power systems, namely, the way they operate in terms of flexibility.

The potential of intermittent renewable energies is usually evenly available across countries, although still conditioned to the seasons. In contrast, the economically feasible exploitation of fossil fuels is much more concentrated in specific areas of the globe. The social acceptance of renewables is practically taken for granted, so issues that may affect their development are mainly the technical and natural barriers of the flexibility of the power system. An electricity market makes it possible to export surplus electricity and import the same during periods of low generation, so it is a good tool to manage the intermittency of renewable sources. Storing large-scale electricity is impractical, so the market must operate instantly; hence the importance of cross-border interconnections which, when insufficient, can constitute a technical barrier. In turn, natural barriers are associated with the abundance of an endogenous resource that prevails in the electricity mix. They are also associated with sizeable investments made in large-scale generation sources such as nuclear power. Beyond these barriers to the diversification of the electricity mix, there are challenges for the balance of the electricity system with the growing demand for electricity. From the vast set of potential barriers to the diversification of the electricity mix, this thesis focuses on the analysis of two: the dominance of generation sources, and the size of the electricity market.

In the context of energy transition, and with the need to increase the development of renewables to meet international agreements, namely renewables share and emission levels, countries have implemented renewable support schemes. These measures were established without considering the complexities of their impact on economic activity. This is what inspires this thesis.

This thesis aims to empirically evaluate the behaviour of energy source interactions focusing on the context in which at least one source is dominant in the electricity mix, such as nuclear or coal, and whether or not there is access to a large electricity market, taking into account the commitment to economic growth. The dominance of existing energy sources can constitute an innocent barrier to the entry (or effective development) of new RES. In turn, the lobbying effect of fossil sources could be a potential intentional barrier to the diversification of sources. The market size can also be an innocent/technical barrier and or a driver, depending on the market characteristics. A large electricity market is characterized by various member countries with different electricity mixes. A small electricity market is constituted of a limited number of countries and a limited electricity mix. Therefore, this thesis addresses the barriers and drivers of the transition in the following contexts: the dominance of sources in the electricity mix generation; countries participating in a large electricity market; countries belonging to a small electricity market; and determinants that promote energy transition.

To meet the objective of this thesis, several econometric techniques were applied, as well as different data frequencies and different countries/groups of countries. Panel data techniques were used on an annual basis to obtain as many observations as possible. Long-term relationships between variables were also considered to ensure robust results. Time series models were applied with high-frequency data, namely monthly and daily (5 weekdays) to better understand how the power systems operate, and to separately analyse country specificities. The samples used in this thesis are composed of countries within the Organization for Economic Cooperation (OECD), together with European Union (EU) countries sharing common policies. In the case of the European Union (EU) countries, energy policy sharing is further developed. OECD and EU members are the countries that together are putting the most effort into the transition from fossil to renewable energy.

There have been many energy transitions throughout history, with the most recent transition being from fossil fuels to renewable sources of electricity generation. Figure 1.1[1] shows the development of the share of fossil fuels (coal, peat, shale oil, oil, and natural gas), nuclear power plants and renewable energies (hydroelectricity, geothermal, solar, wind, ocean, biofuels and renewable waste) in the electricity mix for the OECD for the time-span 1971-2018.

[1] Figure 1.1 was constructed taking into account the data available from IAE Headline Energy Data available at: https://www.iea.org/media/statistics/IEA_HeadlineEnergyData.xlsx (accessed on November, 8th 2019)

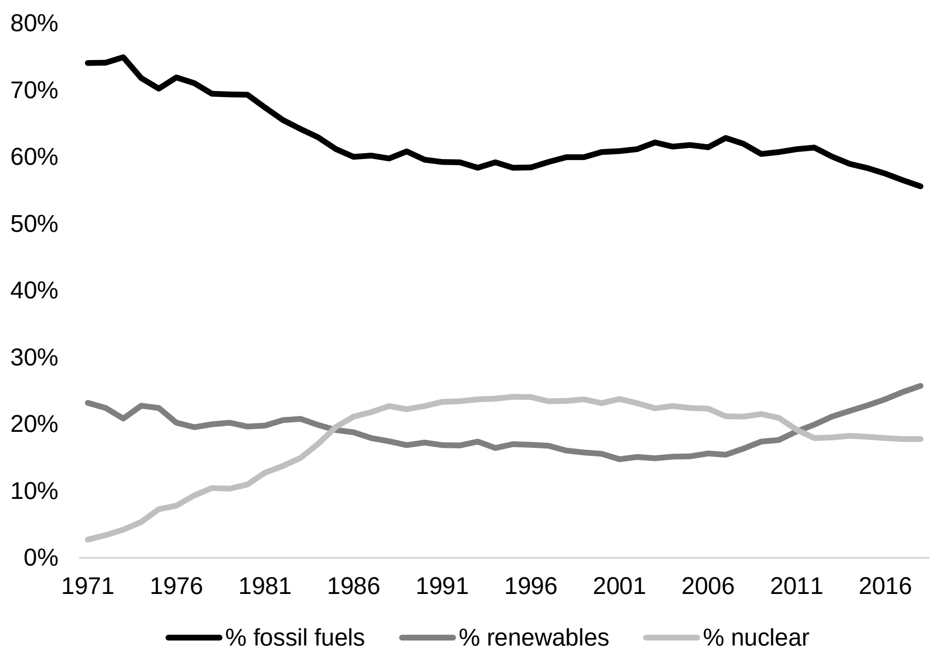

Figure 1.1 - Share of the electricity generation sources

Looking at the figure, the role of fossils has been losing share. In the opposite direction are the renewables that have an increase in participation after 2011. The figure also shows a large increase in the nuclear quota until 1986, and a slight decline after due to the phase out that some countries are applying. Although the cost of nuclear installations is high, some countries have taken different paths in nuclear policy. Social acceptance and security issues are the main reasons for that. Figure 1.2[2] shows the evolution of the sources of electricity generation in absolute value. The dotted line represents the ratio of energy efficiency of electricity (EF). The ratio was calculated by dividing gross domestic product by total electricity generation (Matraeva, Solodukha, Erokhin, & Babenko, 2019). High values of this ratio mean a greater efficiency.

[2] Data for electricity generation sources were collected from IAE database at the link: https://www.iea.org/media/statistics/IEA_HeadlineEnergyData.xlsx (accessed on November, 8th 2019). GDP data were collected from the World Bank's World Development Indicators database at: https://databank.worldbank.org/source/world-development-indicators (accessed on November, 8th 2019).

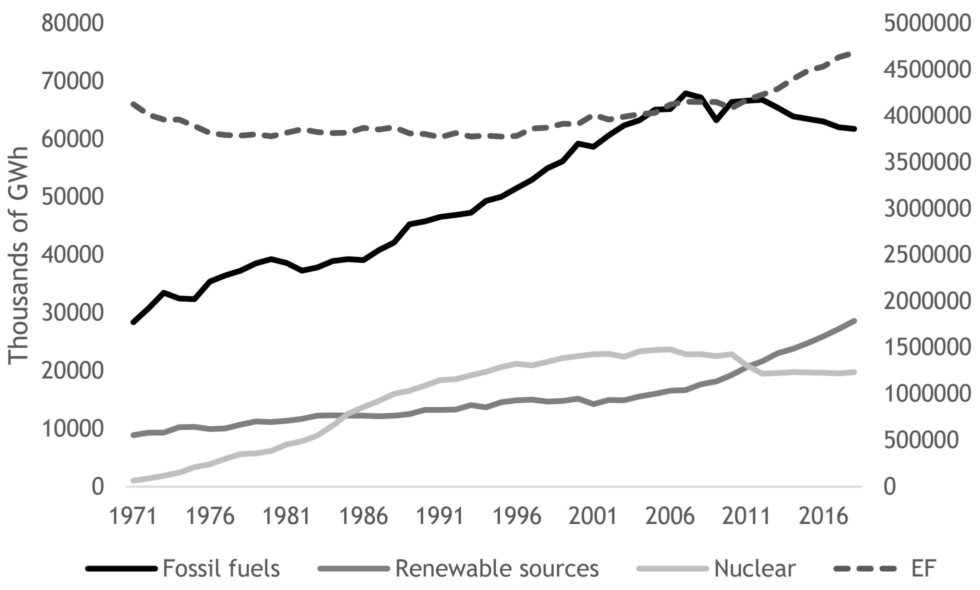

Figure 1.2 - Absolut values of electricity generation sources and electricity efficiency ratio

It is worthwhile to note that, although the share of fossil fuel use has an increasing trend for the period examined, in absolute terms, the trend has a positive slope during almost all periods. Therefore, the increasing demand for electricity, due to the increasing electrification of some industrial equipment and sectors of the economy, has been accompanied by an increase in the use of fossil sources, alongside the increase in nuclear and renewable sources. This trend was interrupted from 2007. After that year, electricity generated from fossil fuels began to decrease, a fact which coincides with the financial crisis. This overall increase in fossil use may have several causes, such as the persistence of the lobbying effect, or the abundance of natural resources.

This thesis is composed of 4 essays. The first essay, in Chapter 2, analyses the role of renewable and non-renewable electricity production in countries with a dominance of one type of source in the energy mix. In other words, this chapter is focused on the analysis of the energy transition in countries where the intensive use of one source stands out in relation to the use of the other sources. The subject of entry barriers has been well, and long-time, identified in the literature of industrial economics (Mukoyama & Popov, 2014), and they relate to market failures. One of the best known is the use of market power, or abuse of a dominant position, to weaken the competition. The barriers to the diversification of renewable energy sources (RES) are also documented in the literature, such as by Hu, Harmsen, Crijns-Graus, Worrell, & van den Broek (2018). So, Chapter 2 intends to respond to the following central question:

(i) What is the role of renewable energy sources in economic activity in countries with a dominant energy source?

To answer this question, a regression of economic growth was estimated as a function of energy consumption and other control variables; variables such as RES, non-renewable energy sources, economic variables such as gross fixed capital formation, exports of goods and services, and finally, carbon dioxide emissions. Considering the data characteristics and the existence of long-term relationships, the Autoregressive Distributed Lag (ARDL) approach was applied. The nature of the countries under analysis was also considered and, consequently, heterogeneous estimators were confronted with homogeneous estimators, and the latter prevailed. The effects of both the short and long-run were also explored.

Answering the central question of Chapter 2, renewables are undermining long-term economic growth for the countries examined. In other words, an increase in energy production through renewable sources decreases economic growth. Contrariwise, fossil sources encourage economic growth in the short run. Consequently, such as is proved in this chapter, countries with dominant sources in the energy mix face a trade-off between energy production through renewable sources for the purpose of reducing emissions, and economic growth.

Once the consequences of the presence of dominant sources in the energy mix diversification and economic growth are analysed, this chapter innovates by including an analysis of the size of the internal electricity market. In Chapter 3, two countries that belong to a large electricity market, the Nord Pool Spot (NPS), were studied. These countries also have the particularity of having dominant sources in their electricity mix. The two countries analysed are Estonia and Sweden. Estonia has a large abundance of shale oil, so electricity generation from this source has a large share in the electricity mix. In this sense, diversification is bound by a natural barrier. In the case of Sweden, the electricity mix is quite different; the predominant sources of generation are nuclear and hydroelectricity. Hydroelectricity has some degree of dominance due to the availability of this natural resource. The nuclear plants are part of a strategic option, even with uranium being imported.

In the context of low carbon energy transition, Sweden is well on its way. Over 90% of the energy mix is made up of electricity generated using low carbon technologies. NPS member countries have a remarkably diverse energy mix, which, with a significant integration of the market, makes for constant balances. Because of this market integration, it is also important to understand how sources interact with each other and how they relate to economic growth. The second essay of this thesis seeks to answer the following questions:

(ii) What sources of electricity contribute most to economic activity in countries that have access to a large electricity market?

(iii) How do the sources of electricity generation interact in each of these countries?

Both Estonia and Sweden were studied separately to answer the previous questions. Time series techniques with monthly frequency data were used because the time period was short, and thus it was possible to increase the number of degrees of freedom in the models we studied. Due to the properties of the data collected, the ARDL approach was applied to distinguish short- and long-term effects and to evaluate cointegration. The analysis of both countries follows the same framework: (i) to estimate a model for economic activity as a function of the electricity generation sources; and (ii) to estimate a regression for each type of electricity generation source as a function of the other sources and economic activity. With this approach, it is possible to verify the existence of bidirectional relationships among all the variables used.

In Chapter 3, the results show a bidirectional causality between fossil sources and economic activity for Estonia. Intermittent renewable energy sources with intermittent generation (RESI) have no effect on economic activity, but economic activity is necessary for the development of RESI. Therefore, Estonia can support an energy transition based on the generation by fossil fuel sources. For Sweden, the results were quite different. RESI has a negative impact on economic activity; hence, access to a substantial and diversified electricity market may not be enough to assist in the energy transition.

One expects that the larger the maturity and the development of an electricity market, the more significant the advantages in accommodating the diversification of the electricity sources. Most developed electricity markets allocate surpluses of electricity generated because of the immediate availability of natural resources, meanwhile allowing for compensation when renewables resources are unavailable. Renewables introduce volatility in the wholesale electricity market (Clò, Cataldi, & Zoppoli, 2015), due to their intermittent generation. Countries with a high commitment to the development of renewables, but without access to a developed electricity market, can face a barrier to the energy transition process.

The integration of electricity markets with different energy mixes positively influences market integration (Gugler & Haxhimusa, 2019), although a substantial investment in interconnections is required. Chapter 4 focuses on the barriers within countries with access to a small electricity market, as is seen with the electricity mix of Spain and Portugal, which constitute the MIBEL (Iberian Electricity Market). The biggest difference in the electricity mix between the two countries within MIBEL, is the presence of nuclear power plants in Spain. The availability of RESI is similar in both countries due to geographical proximity. That is, the interaction between energy sources and their role in the electricity market is important when understanding how countries with access to a small electricity market can make progress in energy transition. The third essay of this thesis has the following research questions:

(iv) What is the role of the wholesale market price in intermittent generation?

(v) What is the role of generation sources in the wholesale market price?

To deal with the objectives of this chapter, time series data with high frequency were used to answer the research questions. Some changes were made to the data due to the large number of observations and the presence of noise in the time series. Once the properties of the data were appraised, the autoregressive vector model (VAR) was carried out, since it is a suitable method to cope with endogeneity. It also makes it possible to analyse the interaction between all variables. The model was estimated using the time series of each source of electricity generation, the market price, and the net exports of electricity.

In Chapter 4, the results show that at the level of interaction of generation sources, the two power systems are similar, but the way they interact with the market is different. In the case of Spain, nothing affects the market price, but the price affects the sources of generation. This means that the generation sources are sensitive to the market price. In the Portuguese case, the results show a bidirectional causality between the sources of generation and the market price.

Due to the difference in scale size between the two systems, Spain has no incentive to interact with the market due to the low capacity of the Portuguese system to absorb large excesses of electricity produced by the Spanish system. Still, the Spanish system always tries to economically recover any surplus. Portugal has a greater interest in participating in the market, as it manages to dispose of all its extra production and acquires in the market when the price is advantageous. The electricity market proves to be a valuable tool for the management of the system as a whole, even managing the availability of renewables, namely hydro, with its differing generation over time. The electricity market can be used to accommodate renewables up to a certain level but gains from trading are strongly conditioned with the market size.

Energy transition is already on-going. Most countries have been implementing measures to promote RES and reduce fossil sources. But have countries made progress in their energy transition? To contribute with an answer to this question, two different concepts of energy transition are discussed in Chapter 5. In low carbon energy transition, electricity generation through renewable and nuclear is considered as part of that transition. An energy transition index has been computed for OECD countries that have nuclear power in their electricity mix. The index is a ratio between the sum of electricity generated by RES and nuclear, and the electricity generated from fossil sources. Some results of the Low Carbon Energy transition ratio are presented[3] in Table 1.1[4].

Table 1.1 - Low Carbon Energy Transition

Country	1971	1980	1990	2000	2010	2017
Belgium	0.00	0.33	1.63	1.50	1.44	2.28
Canada	3.03	3.51	3.45	2.65	3.31	4.28
Finland	0.96	0.73	1.84	1.92	1.42	4.25
France	0.61	1.04	7.85	9.78	9.11	7.81
Germany	0.07	0.20	0.46	0.57	0.66	0.85
Italy	0.60	0.39	0.20	0.23	0.35	0.56
Japan	0.32	0.43	0.56	0.68	0.55	0.25
Korea	0.14	0.17	1.28	0.64	0.45	0.42
Mexico	0.86	0.36	0.37	0.31	0.23	0.24
Netherlands	0.01	0.09	0.06	0.08	0.15	0.22
Spain	1.26	0.47	1.13	0.78	1.16	1.16
Sweden	3.66	8.45	43.42	31.00	19.10	89.81
United Kingdom	0.14	0.17	0.29	0.34	0.31	1.05
United States	0.22	0.29	0.44	0.39	0.42	0.58

High index values mean a greater evolution in transition. Comparing the values of the first available year (1971), with the values of the last available year (2017), it is possible to see that all countries have made some progress, except for Italy, Mexico, and Spain. Looking at other years, it is possible to observe some advances and reoccurrence in the index. This may not mean that the effort to increase RES has lost momentum. Increasing demand for electricity has been a more significant driver than replacing fossil sources with low carbon technologies.

A second energy transition index has been calculated for countries that do not have nuclear plants. The Clean Energy transitory index is the ratio of electricity generated by RES and electricity generated by fossil fuels. Some values of this index can be seen in Table 1.2.

[3] The values shown can only be applied between years for the same country and not between countries.
[4] Data for electricity generation sources are collected from IAE database at the link: https://www.iea.org/media/statistics/IEA_HeadlineEnergyData.xlsx (accessed on November, 8th 2019).

Table 1.2 - Clean Energy Transition

Country	1971	1980	1990	2000	2010	2017
Australia	0.29	0.16	0.11	0.09	0.09	0.18
Austria	1.40	2.31	1.97	2.67	2.01	3.24
Chile	1.34	2.11	1.17	0.94	0.67	0.78
Denmark	0.00	0.00	0.03	0.19	0.48	2.61
Greece	0.30	0.18	0.05	0.08	0.23	0.33
Ireland	0.08	0.09	0.05	0.05	0.15	0.41
Israel	0.00	0.00	0.00	0.00	0.00	0.03
Luxembourg	0.04	0.14	0.16	0.79	0.09	2.71
New Zealand	13.01	9.41	4.04	2.52	2.76	4.34
Norway	223.48	610.31	1379.07	486.66	23.45	52.99
Portugal	3.99	1.21	0.53	0.43	1.13	0.65
Turkey	0.40	0.97	0.68	0.33	0.36	0.42

As in the low carbon energy transition index, values greater than 1, mean a greater weight in the use of RES compared to the use of fossil fuels in the production of electricity. Observing the table, some countries have been regressing due to the electrification of some sectors and consequently an increase in electricity consumption. In the case of countries with nuclear energy, this increase in demand was partly met by this type of source. In non-nuclear countries, the demand for electricity was met by generation through fossil fuels such as coal, oil, and natural gas. Considering these two indicators, the following research question was approached in two ways:

(i) What can drive an energy transition?

This chapter is focused on several countries, and as such, panel stationary data techniques have been applied to annual data over a long period of time to provide an answer to the research question by evaluating the characteristics of the data and some potentially unobserved phenomena and heteroscedasticity. Considering the data characteristics, two estimators were applied; namely, the Panel Corrected Standard Error (PCSE) and the Feasible Generated Least Squares (FGLS) estimators. Models were estimated to explain what determines a low carbon transition and a clean energy transition. The six potential drivers tested were: energy security, carbon economy of the economy, the carbon intensity of energy consumed, energy efficiency, economic openness, and gross fixed capital formation.

In Chapter 4, the findings show that energy efficiency contributes to the two types of transition addressed. Looking at clean energy transition, the carbon intensity of the economy is slowing this transition. In the determinants of low carbon transition, energy security and the carbon intensity of the energy consumed are slowing the transition

1.1 Contribution to the literature

This thesis contributes to the literature by improving the understanding of the complexity of the relationship between economic growth and energy transition by carrying out an analysis of both barriers to transition, as well as the determinants of energy transition. In the first essay, countries with a large share of one or more kinds of energy sources in their electricity mix are analysed. Despite the analytical framework being based on the energy consumption – economic growth nexus, the objective was not to test the traditional hypotheses of causality between energy and growth. Indeed, Chapter 2 aims to examine the role of renewable energies in the economic growth in countries with an innocent barrier to diversifying the electricity mix. Chapter 2 provides empirical evidence for the negative effect of renewable sources on economic growth, considering a sample of countries with dominant sources. Moreover, this essay also contributes with an extensive discussion of strategies for making renewables compatible with economic growth.

The contribution to the literature from the essay in Chapter 3 is twofold. The first contribution is the analysis of the interaction between electricity generation sources and economic activity in two countries with dominant sources, but with the advantage of having access to a large electricity market with a wide range of members participating in it. The second concerns the detail provided in the empirical framework to allow replicability and application in other cases, namely in controlling critical points with the use of dummy variables.

In Chapter 4, empirical evidence using high frequency data is provided for the interaction between sources of electricity generation for countries that have access to only a small electricity market. Usually, in the literature, the merit order effect is analysed; that is, the role of renewables in the electricity price of the wholesale market. This essay innovates by following an entirely different approach, which is the analysis of the influence of the electricity market price on electricity sources. In a small electricity market, countries seek to recover investments in installed capacity and thus respond to the market price.

Finally, Chapter 5 provides empirical evidence of the determinants of energy transition. This essay innovates by considering two approaches to energy transition, namely clean energy transition (from fossil to renewables) and low carbon energy transition (from fossil to renewables and nuclear). The essay also innovates by offering a new measure for energy transition. Instead of the traditional share of renewables in total energy production, a ratio between renewable electricity generation and electricity generation from fossil fuels was constructed to assess countries' performance during energy transition and their drivers and barriers.

1.2 Structure and outcomes

This thesis consists of a collection of four articles, from Chapter 2 to Chapter 5. Each chapter begins with a brief summary of what is covered in each topic. Chapter 2, is devoted to exploring the role of renewables in economic growth, considering the existence of dominant energy sources. Section 2.1 sets out the motivation and objectives of the study. In Section 2.2, a brief literature review on the topic studied is presented. The description of the data used in the empirical analysis is set out in Section 2.3. The econometric procedure is described in Section 2.4. The results are presented in Section 2.5. In Section 2.6, the discussion is presented, while the conclusion is displayed in Section 2.7. A preliminary version of Chapter 2 was presented at a conference:

- Afonso; T. L.; Marques, A. C.; Fuinhas, J. A. (2015) Renewable energy is causing economic growth? An empirical study upon countries with a barrier to diversify energy sources. Proceedings of the 2nd International Meeting on Energy and Environmental Economics. ISBN: 978-972-789-459-8, Aveiro, Portugal, 30 September

A journal article was also published, entitled Strategies to make Renewable Energy sources compatible with Economic Growth, as follows:

- Afonso, T.L., Marques, A. C., & Fuinhas, J. A. (2017). Strategies to make renewable energy sources compatible with economic growth. Energy Strategy Reviews, 18. https://doi.org/10.1016/j.esr.2017.09.014. Impact factor 1 year/5year - 2.633/2.838; SJR – Q1

In Chapter 3, the interaction between generation sources and economic activity is analysed for countries with access to a large electricity market. Section 3.1 presents the introduction and a brief description of the Nord Pool Spot energy mix. In Section 3.2 a brief literature review on the relationship between energy sources and economic growth is divulged, as well as the development of renewables. Section 3.3 presents the operation of the Estonian and Swedish electricity systems, which are the countries under analysis. The data and the methodology applied are presented in Sections 3.4 and 3.5, respectively. Results for both countries are shown in Section 3.6 and discussed in Section 3.7. Section 3.8 presents the conclusion on the interaction of sources and economic activity for Estonia and Sweden. Two previous versions of this chapter were presented at the following conferences:

- Afonso, T.L., Marques, A. C., Fuinhas, J. A., & Saldanha, M. M. The interaction between electricity generation sources and economic activity: evidence from Estonia and Sweden, VII Conference of the Spanish-Portuguese Association of Natural Resources and Environmental Economics, Aveiro, Portugal, 5-7 September 2016

- Afonso, T.L., Marques, A. C., Fuinhas, J. A., & Saldanha, M. M. (2017). The Interaction Between Electricity Generation sources and economic activity: Evidence from Estonia and Sweden 30th International Congress on Applied Economics, 30th-June - 2nd July: Valencia. ISSN: 2174-3088

A journal article was published entitled Interactions between electricity generation sources and economic activity in two Nord Pool systems. Evidence from Estonia and Sweden.

- Afonso, T.L., Marques, A. C., Fuinhas, J. A., & Saldanha, M. M. (2017). Interactions between electricity generation sources and economic activity in two Nord Pool systems. Evidence from Estonia and Sweden. Applied Economics. https://doi.org/10.1080/00036846.2017.1418074. Impact factor-0.968; SJR – Q2

Unlike Chapter 3, Chapter 4 is focused on small markets, and this option allows us to confront and compare the consequences of the internal electricity market in the transition of sources. Thus, Chapter 4 is structured as follows: the introduction is presented in Section 4.1; the literature review is set out in Section 4.2; the data and method used are presented in Section 4.3; Section 4.4 is devoted to the presentation of results; the discussion and conclusion are shown in Sections 4.5 and 4.6, respectively. This chapter resulted in three outputs. A preliminary version resulted in a poster:

- Afonso, T.L., Marques, A. C., Fuinhas, J. A. Is the Iberian electricity market too small to accommodate renewables? Evidence from the interactions of sources within Portugal and Spain. Poster presented at Fórum/conferência "Desafios da Gestão Ativa da Procura de Energia: Eficiência e Resposta – GAPEER'17", 20-21 April, 2017, University of Beira Interior

A previous version resulted in a conference presentation:

- Afonso, T.L., Marques, A. C., Fuinhas, J. A. Spanish and Portuguese electricity generation systems: an empirical approach with high frequency data, Energy Economics Iberian Conference, Lisbon, Portugal 4-5 February 2016

It also resulted in a scientific article entitled, "Accommodating renewable energy sources in a small electricity market: An analysis considering the interactions of sources within Portugal and Spain". The reference is as follows:

- Afonso, T.L., Marques, A. C., Fuinhas, J. A. (2019). Accommodating renewable energy sources in a small electricity market: An analysis considering the interactions of sources within Portugal and Spain. Heliyon, 5. https://doi.org/10.1016/j.heliyon.2019.e02354. SJR – Q1

After analysing the barriers, the drivers of energy transition are the focus of Chapter 5. An introduction to energy transition and a brief approach to the concept of transition is presented in Section 5.1. In Section 5.2, a brief literature review is presented. Empirical procedure is described in Section 5.3. The data used are set out in Section 5.4. In Section 5.5, the results of the variable tests are shown. Estimated models are presented in Section 5.6. The discussion of the results is presented in Section 5.7. Section 5.8 concludes. A preliminary version of this chapter was presented at an international conference, and an article is currently under review in the International Journal of Sustainable Energy Planning and Management.

- Afonso, T.L., Marques, A. C., Fuinhas, J. A. (2019). Determinants of the energy transition: Empirical evidence for OECD countries. Proceedings of the 4th International Conference on Energy & Environment: bringing together Engineering and Economics. 16-17 May. Guimarães, Portugal. ISBN: 978-989-97050-9-8, ISSN: 2183-3982

On a final note, it is important to emphasize that each chapter contains its own section of the bibliographic references used. Finally, the last chapter, Chapter 6, presents the conclusion of this thesis, highlighting the major findings and the contributions this thesis brings to the literature. This thesis ends with future research ideas, some of which are already in course, with some scientific outputs already published.

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Chapter 2

Strategies to make Renewable Energy sources compatible with Economic Growth

This chapter focuses on the relationship between economic activity, and renewable and non-renewable energy consumption for the set of countries with the largest usage of each energy source. The dominance of one type of energy source could raise an unintentional barrier to a strategy of energy mix diversification. A panel of 28 countries was studied, using annual data for the time span 1995-2013. The ARDL approach was used to capture the short- and long-run effects. The Driscoll-Kraay estimator was used to attain robust results given the presence of the phenomena of heteroscedasticity, contemporaneous correlation, first order autocorrelation and cross-sectional dependence. Results suggest that renewable energy has not contributed to economic growth, while non-renewable energy has contributed. This finding should be incorporated in the definition of energy strategies, specifically by making renewable energy compatible with economic growth.

2.1 Introduction

Fossil fuels remain the main sources in the global energy mix and are associated with the increase of carbon dioxide (CO_2) emissions. The deployment of renewable energy sources (RES) can play a crucial role to reduce both (CO_2) emissions and fossil fuel dependency (Lind et al., 2013). Thus, there is a worldwide trend to promote the use of renewable energy sources. Even so, these sources face severe entry barriers, mostly associated with market failures.

The entry barriers are widely analysed in the literature of industrial economics (McGowan, 2014; Mukoyama & Popov, 2014). In fact, there are several kinds of entry barriers, namely: (i) initial investment; (ii) inelastic demand; (iii) restrictive practices; and (iv) research and development. The barriers to the diversification of energy sources, particularly RES, are also common and are analysed, for example, by Luttenberger (2015). According to general studies regarding entry barriers, both intentional and “innocent” entry barriers to RES can also be observe. This chapter uses one of these entry barriers, which is a great dependence on, or even dominance by, a single source, to define the countries under analysis. This barrier could come from substantial domestic availability of the resources (innocent barrier), or it could come from an intentional strategy to intensively use a specific source, namely fossil fuel, often due to lobbying by stakeholders in that source.

As such, a country's presence in the top ten of world electricity production by source, was the criterion used to select the countries under analysis, using the year 2012 as a reference. This criterion was based on the data available as of July 2015. When a country is present in the list of more than one energy source, then it is considered only once. Annual data for the period 1995 to 2013 was used. Following the literature, energy variables (non-renewable and renewable energy consumption), economic variables (gross fixed capital formation, export of goods and services, and employment) and an environmental variable (carbon dioxide emissions) were used to explain economic growth. The Autoregressive Distributed Lag (ARDL) approach in panel data proved to be suitable to detect the dynamics of the adjustments between the short- and long-run.

This chapter contributes to the literature by revealing the relationships between energy sources and economic growth for this set of countries. Moreover, the chapter provides support to the process of defining energy strategies, particularly those aiming to combine RES and economic growth. In the short-run, non-renewable energy has a positive impact on economic activity, while in the long-run, RES has a negative impact on economic activity. Energy strategies should enhance the economic rationality for the use of renewables, specifically by adopting demand-side measures to address their characteristics of intermittency.

2.2 Literature Review

The analysis of the causal relationship between energy consumption and economic activity has received much attention in the literature. Within this energy-growth nexus, four traditional hypotheses have been exhaustively tested (Ozturk, 2010; Payne, 2010), namely: (i) the *growth hypothesis*, which predicts a unidirectional causality, running from energy consumption to economic growth; (ii) the *feedback hypothesis*, which predicts a bidirectional causality between economic growth and energy consumption; (iii) the *neutrality hypothesis*, when there is no causality relationship between economic growth and energy consumption; and (iv) the *conservation hypothesis*, which consists of a relationship running from economic growth to energy consumption.

Although literature focusing on the nexus is abundant, there is no consensus on the outcomes. Indeed, dissimilar samples and econometric techniques can explain this lack of consensus (Ozturk, 2010). The study of the nexus has evolved, from an aggregate perspective using primary energy consumption towards electricity consumption only. Moreover, the energy-growth nexus has also evolved from considering the energy sources as a whole, towards the analysis of each source individually, giving rise to several different nexuses. A summary of the results of the energy-growth nexus can be seen in Ozturk (2010) and Menegaki (2014). This chapter accompanies this trend, and focuses on energy consumption, by dividing the energy into renewable and non-renewable according to its origin.

Diverse relationships between renewable energy consumption and economic growth can be found in the literature. A positive relationship (Al-mulali, Fereidouni, & Lee, 2014), the lack of any link (Chang, Huang, & Lee, 2009), as well as, a bidirectional relationship between renewable energy consumption, non-renewable energy consumption and economic growth (Apergis & Payne, 2012), are examples of these relationships. We will return to the nature of these relationships, in the discussion section.

2.3 Data

As stated before, the countries under analysis were chosen according to a single criterion: that the share of the country's electricity production by a specific source is present in the top ten of the countries for that source. According to the data available, the 28 countries selected, for the period 1995-2013, are the following: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, South Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, the United Kingdom, and the United States of America. The countries Estonia, Iceland, Israel, Luxembourg, Slovenia and Turkey were excluded due to the lack of data for the entire period under analysis. The data analysis was performed by using the software STATA 13.1.

The source of the variables was the World Bank, for: gross domestic product (constant 2005 US$); exports of goods and services (constant 2005 US$); population (number of people); unemployment (% of total labour force); labour force (total); and for gross fixed capital formation (constant 2005 US$). The BP Statistical Review of World Energy was the data source for (CO_2) emissions and for each energy source, namely: oil consumption (in tonnes); gas consumption; coal consumption; nuclear energy consumption, hydroelectricity consumption; solar energy consumption; wind energy consumption; geothermal, biomass; and other renewables sources. All variables obtained by BP Statistical Review of World Energy, June

2015 are in million tonnes oil equivalent, except oil consumption and (CO_2) emissions. The variables gross fixed capital formation, exports of goods and services, CO_2 and employment, are used as control variables (Cai, Mu, Wang, & Chen, 2014; Azam, Khan, Bakhtyar, & Emirullah, 2015; Özbuğday & Erbas, 2015).

The variables used in the estimated models are as follows: (i) *GDPPC* (Gross Domestic Product *per capita*) – The ratio between Gross Domestic Product and total population; (ii) *NRESPC* (non-renewable energy consumption *per capita)* – Is computed in two steps. The first step consists of the sum of oil consumption, gas consumption, coal consumption and nuclear energy consumption. The second step consists in dividing the above sum by the total population; (iii) *RESPC* (renewable energy consumption *per capita*) – This variable is also computed in two steps. The first step consists of the sum of hydroelectricity consumption, solar energy consumption, wind energy consumption and geothermal, biomass and other renewable sources consumption. The second step consists in dividing the above sum by the total population; (iv) *XPC* (exports of goods and services *per capita*) – Ratio of exports of goods and services, and total population; *(v) GFCFPC* (gross fixed capital formation *per capita*) – Obtained by dividing the gross fixed capital formation by the total population. *(vi) CO2PC* (carbon dioxide emissions *per capita*) - Carbon dioxide emissions divided by the total population; and (vii) *EMP* (employment) – This variable is obtained in three steps. The first step consists of dividing unemployment by 100. In the second step, the first result is multiplied by labour force, in order to obtain an absolute value for unemployment. In the third step, unemployment was subtracted from labour, in order to obtain the employment value.

2.4 Method

To study the relationship between economic growth, renewable and non-renewable energy consumption in countries with a dominant energy source, it is useful to analyse the dynamic effects in the short- and long-run. The ARDL (Shin & Pesaran, 1999) model allows analysing these effects separately. It also allows different integration order of variables, i.e. I(0) and I(1) but not I(2), and different lag-lengths for the variables within the model. The dependent variable is *DLGDPPC*. The general specification of the ARDL model is the following:

$$LGDPPC = f\,(LNRESPC;\ LRESPC;\ LGFCFPC;\ LCO2PC;\ LXPC;\ LEMP) \qquad (2.1)$$

In Equation 2.2, the short- and long-run dynamics can be observed, where the prefixes “L” and “D” denote natural logarithm and first difference of the variables, respectively. The subscripts t, I and j denotes the time period, country and lag length, respectively. α denotes the intercept, β_{ij} and λ_i the estimated parameters, and ε_{it} the error term.

$$DLGDPPC_{it} = \alpha_i + \sum_{j=1}^{k} \beta_{1ij} DLGDPPC_{it-j} + \sum_{j=0}^{k} \beta_{2ij} DLNRESPC_{it-j} + \sum_{j=1}^{k} \beta_{3ij} DLRESPC_{it-j}$$
$$+ \sum_{j=1}^{k} \beta_{4ij} DLGFCFPC_{it-j} + \sum_{j=1}^{k} \beta_{5ij} DLCO2PC_{it-j} + \sum_{j=1}^{k} \beta_{6ij} DLEXPPC_{it-j} + \qquad (2.2)$$
$$\sum_{j=1}^{k} \beta_{7ij} DLEMP_{it-j} + \lambda_{1i} LGDPPC_{it-1} + \lambda_{2i} LNRESPCPC_{it-1} + \lambda_{3i} LRESPCC_{it-1}$$
$$+\lambda_{4i} LGFCFPC_{it-1} + \lambda_{5i} LCO2PC_{it-1} + \lambda_{6i} LEXPPC_{it-1} + \lambda_{7i} LEMP_{it-1}$$

In studies on panel data, it is necessary to analyse the characteristics of the series and the cross sections. As such, a battery of tests was carried out to check the order of integration of the series and the eventual presence of cross-sectional dependence and collinearity. Table 2.1 shows the descriptive statistics and CD-test to test cross-sectional dependence. Cross-sectional dependence was detected, which could be related mainly to geographical proximity or to the dependency of countries sharing common shocks (Eberhardt, 2011). Overall, the characteristics of the data determined the battery of econometric techniques used.

Table 2.1 - Descriptive statistics and cross section dependence

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

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

Variance Inflation Factor (VIF) was performed (Table 2.2), to check the multi-collinearity between variables. The absence of multi-collinearity is verified by low VIF statistics values.

Table 2.2 - VIF statistics

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

To check the stationary properties of the variables first and second generation unit root tests were made. The traditional first generation teste are: LLC (Levin, Lin, & Chu, 2002), where H0: unit root (common unit root process); ADF-Fisher (Maddala & Wu, 1999) and ADF-Choi (Choi, 2001), where H0: unit root (individual unit root process). Taking into account the presence of cross-sectional dependence, the second generation unit root test CIPS (Pesaran, 2007) was made, this unit root test is robust to heterogeneity and H0: series are I(1). Table 2.3 shows the results of unit root test.

Table 2.3 – Panel unit roots test

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

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

Pursuing the objective of detecting the most efficient estimator to deal with the characteristics of the panel data, the presence of individual effects was tested. Fixed effects (FE) against random effects (RE) were tested by the Hausman test, where the null hypothesis is that random effect model is the appropriate one. The null is rejected (x^2= 95.64) at a significance level of 1%, supporting the use of a fixed effect estimator.

Considering the order of integration of the series, the heterogeneous panel data, the presence of dynamic effects, and the cross-sectional dependence, the second generation co-integration test developed by Westerlund (2007) was performed, using bootstrapping to obtain robust critical values. The results of the Westerlund co-integration test, for all variables, can be seen in Table 2.4.

Table 2.4 - Westerlund co-integration test

Statistic	**Value**	**Z-value**	**Robust P-value**
Gt	-2.610	1.245	0.400
Ga	-2.523	8.653	0.178
Pt	-7.860	5.364	0.446
Pa	-2.474	6.374	0.121

Notes: The null hypothesis of Westerlund's co-integration test is no co-integration; the bootstrapping regression with 800 reps was performed; Gt and Ga test the cointegration for each country individually, and Pt and Pa test the cointegration of the panel as whole; and the Stata command *xtwest* (with the constant option) was used.

The results show that the null is not rejected and as such they support no co-integration in both statistics. In the next section the results are presented.

2.5 Results

Considering the sample under analysis and taking into account the dominance of a single type of energy source, the possibility of being faced with a heterogeneous panel should be considered. In this case, the Mean Group (MG) and the Pooled Mean Group (PMG) estimators ought to be used and tested. The MG estimator is more flexible than PMG (Shin, Pesaran, & Smith, 1999). This MG estimator is efficient when the long-run coefficients are heterogeneous, whereas the PMG estimator allows for heterogeneous short-run coefficients and homogeneous long-run coefficients. In order to test the adequacy of PMG and MG estimators against FE estimators, the Hausman test was performed once again. The PMG, MG and FE estimators, as well as the results of the Hausman test can be observed in Table 2.5.

Table 2.5 - Heterogeneous estimators and Hausman test

Models	**PMG(I)**	**MG(II)**	**FE(III)**
Constant	1.2913***	3.0724**	0.9459***
DLNREPC	-0.0098	0.0358	0.0469***
DLREPC	-0.0054*	-0.0075	0.0002
DLGFCFPC	0.1968***	-0.1751***	0.1818***
DLCO2PCC	0.0453	0.0010	0.0012
DLEXPPC	0.1708***	0.2171***	0.1555***
DLEMP	0.1425**	0.1135	0.1773***
ECT	-0.1737***	-0.6928***	-0.1603***
LNREPC	-0.0103	0.0921	0.0628
LREPC	-0.0115**	-0.0449	-0.0326***
LGFCFPC	0.3520***	-0.6540	0.2476***
LCO2PCC	0.0371***	1.7041	0.0324***
LEXPPC	0.2150***	0.3142	0.2773***
LEMP	-0.1384***	0.9896	0.0189
Models	**PMG vs FE**	**MG vs PMG**	**MG vs FE**
Hausman tests	Chi2(7)=0.00	Chi2(7)=0.61***	Chi2(7)=0.00

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

The results confirm that the FE model is the most suitable model, and as such it is appropriate to consider the cross sections as a group sharing common coefficients. Taking into account the presence of fixed effects, in order to select the robust estimator, additional specification tests were made, specifically for the presence of heteroscedasticity, autocorrelation and contemporaneous correlation among cross sections. To check heteroscedasticity, the modified Wald test was performed. Following this, the Wooldridge test to verify the existence of serial correlation was used. The Pesaran test was performed to appraise contemporaneous correlation among cross sections. The specification test results are presented in the Table 2.6.

Table 2.6 - Specification tests

	Statistics for III, V and VII	Statistics for IV, VI and VIII
Modified Wald test	491.23***	486.57***
Wooldridge test	75.911***	75.911***
Pesaran test	5.417***	5.417***

Notes: *** denotes significance at 1%; the results of the Modified Wald test, Wooldridge test and Pesaran test, are based on Chi-squared distribution, F distribution and standard normal distribution, respectively. The null hypothesis of the modified Wald test, Wooldridge test and Pesaran test is homoscedasticity, no first-order autocorrelation and cross-sectional independence, respectively.

The specification test results show the rejection of the null hypothesis for the modified Wald test. The data has first order autocorrelation according to Wooldridge test. The existence of contemporaneous correlation was confirmed by the Pesaran test.

Following the results of the specification tests, the Driscoll and Kraay (1998) estimator was used, given that standard errors of this estimator are robust in the presence of cross-sectional dependence. The error structure is assumed to be heteroskedastic and auto correlated. The FE model, and FE model with robust standard errors, were also estimated to control the heteroscedasticity. The results are compared and displayed in Table 2.7.

Table 2.7 - Estimation results

Dependent variable *DLGDPPC*	FE (I)	FE (II)	FE Robust (III)	FE Robust (IV)	FE D.K. (V)	FE D.K. (VI)
Constant	0.9460***	0.8232***	0.9460***	0.8232***	0.9460***	0.8232***
DLNRESPC	0.0469***	0.0427***	0.0469***	0.0427***	0.0469***	0.0427***
DLRESPC	0.0002		0.0002		0.0002	
DLXPC	0.1555***	0.1558***	0.1555***	0.1558***	0.1555***	0.1558***
DLGFCFPC	0.1818***	0.1850***	0.1818***	0.1850***	0.1818***	0.1850***
DLCO2PC	0.0012		0.0012		0.0012	
DLEMP	0.1773***	0.1732***	0.1773**	0.1732***	0.1773***	0.1732***
LGDPPC(-1)	-0.1603***	-0.1599***	-0.1603***	-0.1599***	-0.1603***	-0.1599***
LNRESPC(-1)	0.0101		0.0101		0.0101	
LRESPC(-1)	-0.0052***	-0.0059***	-0.0052***	-0.0059***	-0.0052**	-0.0059***
LXPC(-1)	0.0444***	0.0446***	0.0444***	0.0446***	0.0444***	0.0446***
LGFCFPC(-1)	0.0397***	0.0429***	0.0397***	0.0429***	0.0397***	0.0429***
LCO2PC(-1)	0.0052***	0.0050***	0.0052***	0.0050***	0.0052***	0.0050*
LEMP(-1)	0.0030		0.0030		0.0030	
Diagnostic statistics						
N	502	502	502	502	502	502
R^2	0.8632	0.8625	0.8632	0.8625	0.8632	0.8632
R^2 adjusted	0.8513	0.8518	0.8595	0.8599		
F	F(13.461)= 223.74***	F(9.465)= 323.99***	F(13.27)= 272.86***	F(9.27)= 168.31***	F(13.17)= 17792.94***	F(9.177)= 2072.46***

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

The results reveal great consistency. There is no signal change and level of significance remains unchanged, except the variable *LCO2PC* lagged once in the model VI. Following the parsimonious principle, the reduced forms of the models I, III and V were estimated. The models in reduced form can be seen in Table 2.8, as well as the specification tests. In order to assess the magnitude of the effects, both semi-elasticities and elasticities were performed.

Table 2.8 - Semi-elasticities, elasticities and adjustment speed

Models	coefficients	FE(VI)	FE Robust (VII)	FE D.K. (VIII)
Semi-elasticities		Statistical significance level		
Constant	0.8232	***	***	***
DLNRESPC	0.0427	***	***	***
DLXPC	0.1558	***	***	***
DLGFCFPC	0.1850	***	***	***
DLEMP	0.1732	***	***	***
Elasticities				
LRESPC(-1)	-0.0366	***	***	***
LXPC(-1)	0.2788	***	***	***
LGFCFPC(-1)	0.2683	***	***	***
LCO2PC(-1)	0.0313	***	***	**
ECT	-0.1599	***	***	***

Notes: *** and ** represent a significance level of 1% and 5%, respectively; ECT means Error Correction Term.

Regarding Table 2.8, one result deserves particular attention. The positive effect from *NRESPC* to economic growth in the short-run contrasts with that observed for RES in the long-run. Indeed, in the long-run, an increase of 1% in *RESPC*, decreases economic growth by 0.03%. This outcome justifies further discussion in the next section.

The results also reveal that *GFCFPC,* as well as *XPC,* have a positive effect in both the short- and long-run. Regarding the environmental variable, the CO_2 emissions, it has a positive effect on economic activity in the long-run. In fact, this is not a surprising outcome, and it is consistent with a productive structure that remains very dependent on fossil fuels.

2.6 Discussion

The main findings of this chapter are summarized in Figure 2.1. Some of these deserve to be discussed in greater depth, namely the dissimilar effects of *RES* and *NRES* on economic growth, highlighting potential strategies capable of overcoming the undesirable observed effects. First of all, one of the central features of the analysis used in this chapter is its impartiality regarding the nature or source of the energy a country should use when its objective is to guarantee economic growth. Indeed, results suggest that renewable energy has hampered economic growth, but conversely, non-renewable energy has fostered it. While it may be unexpected, this negative effect of *RES* on economic growth has already been detected by various authors but remains scarce in the literature (e.g. Ocal & Aslan, 2013, Dogan, 2015, Bhattacharya, Paramati, Ozturk, & Bhattacharya, 2016), which is focused on the analysis of the traditional energy-growth nexus, regardless of the source.

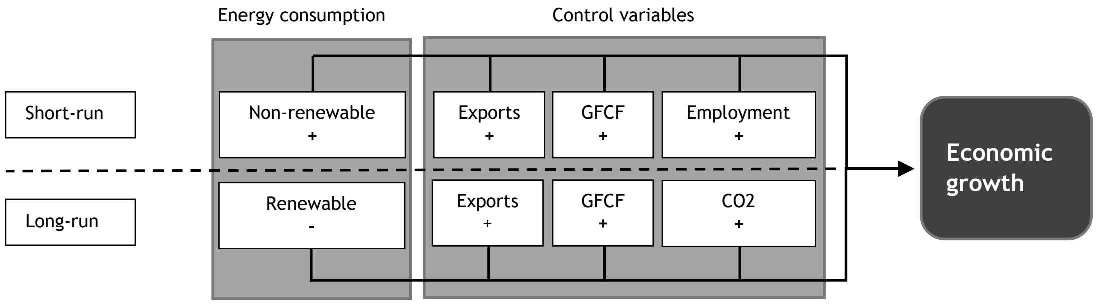

Figure 2.1 - Main results. Authors' elaboration

Some literature, such as Marques & Fuinhas (2012) advances that the promotion of *RES* could be placing a heavy burden on the economy. Indeed, the strategy to increase the penetration of RES has been pursued through public policies that have an implicit cost, which is transferred to the economy and society as a whole. Moreover, considering the intermittent nature of these sources, some of the installed capacity could be idle, either due to the absence of instantaneous renewable resources, or even the lack of demand when the availability of the resource is higher. As such, several strategies could be defined and implemented. The first step should be the deployment of demand-side management programmes. It is time to address the energy mix of consumers. Their pattern of consumption is shown to be essential to accommodate renewables, specifically by increasing consumption when larger renewable resources are available and decreasing consumption when the source of generation is conventional fossil sources. This strategy could imply a penalty for consumption during the peak periods, thus preventing the overload of the energy system. Alternatively, a benefit in the form of a discount could be attributed to consumption in off-peak periods, in periods with plentiful availability of solar or wind energy, for instance.

The most successful strategies will be those that can handle the intermittent nature of renewable generation. Indeed, in the near future, those strategies will be essential to change the observed negative effect of *RES* on economic activity. Accordingly, the electrification of economic activities ought to be quickly augmented and those activities that are more intensive in capital and less in labour should be increasingly adapted to function during traditionally off-peak periods or, whenever larger renewable resources are available. E-mobility also needs to be reinforced, by incentivising self-consumption of energy, i.e. household's generated, which can then serve as storage reservoir in vehicles, contributing to the electricity grid (V2G strategy) when there is a lack in generation from *RES*.

One of the most used tools worldwide for the promotion of renewables is a minimum quota of renewables. An alternative strategy could be the definition of maximum quotas for conventional sources, namely fossil sources. Initially, it could be viewed as the same strategy as the renewable's quotas, but it is definitely not. The renewables quotas have been achieved with massive resources of backup capacity from controllable fossil generation. This fact could be the origin of the negative effect of renewables on economic growth observed in the literature. The alternative strategy that we are proposing here, prevents the installed capacity of fossil sources from only registering a few hours of use, and as such, leaving a large capacity idle. This fact has induced severe economic inefficiencies that hamper the economic growth in national economies. Another strategy, closely linked with the former, is the measure of diversification of the energy mix. The use of the diversity index could be a useful support for policy design as it promotes the effective diversification of the energy mix. The Shannon-Weaner index is a good example that could provide additional information, because it takes into account the dominance of one energy source. Regarding the diversification of the energy mix, it is worthwhile to note that diversification by itself does not have to be the main strategic energy policy of a country. However, looking not only at the countries under analysis, but also at the current worldwide pressure to became part of the fight against climate change, it is an increasingly hard task for a country to avoid a strategy of energy mix diversification.

This worldwide trend of integration of policies is clearly proved in the analysis. One can argument that the unit of analysis should be only a single country instead of a group of countries. However, the presence of phenomena of cross-section dependence and contemporaneous correlation would be related with the stronger dependency of countries, sharing common shocks. By other words, countries are increasingly integrated into their policies and strategies. The countries under the same policy guidance execute identical (imposed) strategies and there is a worldwide effect of contagion, such as is the case of left behind feed-in-tariffs in favour of market-oriented policies. Overall, the battery of tests support that countries should be studied together, as long as the cross-section dependence effect is taken in consideration.

Another relevant factor is to ensure the stability of the strategies being pursued. In other words, the strategy of promoting RES has to be made and focused on the long term and should not be easily reversed by taking one step forward and then one or even two backward. This sector requires large investment costs, which are usually more efficient when advantage is taken of scale economies. As such the stakeholders in the generation markets need to know about policies that take into account the payback of the investment in generation infrastructure. This practice reduces the risk and consequently leaves room to lower prices, given that lower uncertainty provokes lower premium risk.

2.7 Conclusion

This chapter is centred on the analysis of the relationships between renewable and non-renewable electricity sources and their relationship with economic activity. The focus is centred on a set of countries, whose electricity generation by source is in the top ten of the countries using that source. The panel data was subject to an exhaustive battery of tests with the objective both to analyse the properties of the data series, as well as to guarantee the use of appropriate estimators. Once the presence of cross-sectional dependence was detected, the Driscoll-Kraay with fixed effects estimator was used, and the ARDL approach allowed the short- and long-run effects to be determined.

This research uses the GDP per capita to measure economic growth, following the vast majority of literature focused on the energy-growth nexus. However, for future research, it could be of special relevance to assess whether the conclusions remain consistent when the focus is placed on sustainable development and not just on economic growth.

Overall, the results reveal great consistency both with the literature and with the economic theory. The results corroborate the well-known positive effect of non-renewable energy on economic growth, unlike renewable energy, which constrains economic growth in the long-run. This finding is extensively discussed, and several strategies are proposed in order to make the accommodation of renewables within the energy system not only easier, but also to help reverse this negative effect. A critical success factor of the integration of renewables in the energy system, without compromising the objective of economic growth, should involve enhancing the economic rationality of using renewables. Policymakers should promote measures on the demand side, particularly by giving consumers a more hands-on role, in order to adapt their consumption to the availability of renewable sources.

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Chapter 3

Interactions between electricity generation sources and economic activity in two Nord Pool systems. Evidence from Estonia and Sweden

The interactions between electricity sources and economic activity are analysed here in this chapter, in a context of a large electricity market. The availability of data defines the time spans, from January 2010 until September 2015 for Sweden, and from April 2010 until December 2014 for Estonia. These countries are particularly interesting to study because of their dissimilar generation mix. Estonia's generation mix is based on oil shale, while Sweden's is based on nuclear plants and hydroelectricity. In short, both countries' energy mixes are based on endogenous natural resources. The ARDL model was applied, allowing the long-run and short-run effects to be captured. The results prove that economic growth is sustained by natural endogenous resources. Estonia should continue to improve the usage of renewable energies, using fossil sources in support, in order to reduce emissions and to meet international environmental commitments. Sweden should promote the efficient usage of various renewable sources.

3.1 Introduction

The study of the relationships established between electricity generation and the economic growth nexus is not a recent theme in the literature. Traditionally this relationship has been analysed from the perspective of the energy consumption – economic growth nexus. More recently, this framework has been evolving by analysing both the complexities and the adjustments of several sources of generation within national electricity generation systems, without neglecting the consequences of the energy mix on economic activity. Some authors have analysed the relationship between primary energy consumption and economic growth (Payne, 2010). More recently, energy consumption has been analysed separately for renewable and non-renewable energy and compared with economic growth (Apergis & Payne, 2012). The complexity of the relationship between energy and growth often requires the consideration of other factors, such as the environmental perspective (Alshehry & Belloumi, 2015; Cerdeira Bento & Moutinho, 2016).

The energy industry, and particularly electricity generation, operates on a large scale in order to accommodate high investment and fixed costs. Consequently, large-scale production allows costs to be shared and, as large-scale electricity storage is not possible, market integration has proven to be an effective management tool to meet demand. The Nord Pool Spot (NPS) is a good example of this interaction between national electricity systems. Due the amount of electricity transacted and the number of member states, the NPS is the largest electricity market in Europe. It pioneered the first cross-border electricity exchange. This market operates in the Nordic and Baltic countries of Norway, Denmark, Sweden, Finland, Estonia, Latvia and Lithuania, but also has links with Germany, the Netherlands, Belgium and the United Kingdom. Its importance is revealed by the fact that the majority of energy consumption in these countries is transacted through NPS.

The NPS is characterized by a variety of electricity mixes (Ergemen, Haldrup, & Rodríguez-caballero, 2016). In Norway the main electricity generation source is stored water, while in Sweden and Finland there is a combination of hydro, nuclear and thermal electricity generation. Denmark uses predominantly thermal electricity generation, although wind power has been increasing. In Estonia and Lithuania, electricity generation is mainly based on fossil fuels. In dry years, the Nordic countries are becoming more dependent on electricity imported from central European countries, such as the Netherlands and Germany. NPS has proven to be quite complex in terms of negotiations and transactions (Imran & Kockar, 2014), the deployment of intermittent generation sources brings more complexity to the market (Zipp, 2017). Even some countries are divided into different areas, which make individual analysis of the NPS's countries difficult. This chapter aims to analyse this mix diversity, by focusing on two quite dissimilar electricity systems, those of Estonia and Sweden. These countries are very dependent on their endogenous natural resources, which are oil shale in Estonia and hydro/nuclear power in Sweden. Both the Estonian and Swedish electricity systems are analysed and compared. We are confident that the analysis of this diversity adds significant value to the burgeoning study of the complex interactions between generation sources and economic activity.

The main goal of this chapter is twofold: (i) to assess which sources contribute to economic activity; and (ii) to appraise the nature of the interaction between sources within the electricity mix. As such, this analysis was performed with recourse to electricity generation sources and economic activity proxy and control variables, such as electricity prices, carbon monoxide emissions and electricity exchanges. In order to carry out the analysis of the interaction between electricity generation sources, the ARDL (Autoregressive Distributed Lag) was used to discover both the short- and long-run adjustment effects. The results reveal a bi-directional causality between economic activity and electricity generated from fossil fuels, the main electricity generation sources in Estonia. In the case of Sweden, a negative effect running from renewable generation (excluding hydro) to economic activity was found, in both the short- and long-run[5], and a substitution effect was discovered between hydroelectricity and nuclear energy. The usage of abundant resources in electricity generation is supporting economic activity in both Estonia and Sweden.

The rest of this chapter is organized as follows: Section 3.2 presents a review of the literature about the energy-growth nexus; in Section 3.3 there is a brief description of the Estonian and Sweden electricity generation systems, Section 3.4 and 3.5 contain the data and the econometric method, respectively; Section 3.6 shows the results, in Section 3.7 the discussion is presented; and Section 3.8 contains the conclusions.

3.2 Energy-growth nexus – the debate

There are many studies focused on the relationship between energy consumption and economic growth. Some papers seek to summarize the results of those studies (Omri, 2014; Payne, 2010). The conventional framework for analysing relationships between energy and economic growth is grounded on four hypotheses (Le, 2016) that define causality relationships: (i) the *feedback hypothesis*, which is characterized by a bidirectional causality between energy consumption and economic growth; (ii) the *conservation hypothesis* which is validated by a unidirectional causality running from economic growth to energy consumption, meaning that the implementation of energy conservation policies are not able to influence growth; (iii) the *growth hypothesis* is supported by a unidirectional causality running from energy consumption to economic growth; and (iv) the *neutrality hypothesis* is supported by the non-causality between economic growth and energy consumption.

The integration of new renewable energy sources, such as wind power and solar photovoltaic, brings new challenges to the generation system due to their characteristic of intermittent generation. Generation by new renewables is dependent on the weather and cannot be adjusted as it can in conventional plants (Hirth & Ziegenhagen, 2015). As such, the penetration of inconstant renewable electricity requires higher flexibility in the power system (Genoese & Genoese, 2013; Alizadeh, Parsa Moghaddam, Amjady, Siano, & Sheikh-El-Eslami, 2016). The power system's flexibility options in the integration of renewables (Kondziella & Bruckner, 2016) are supply side and demand side. The flexibility options are: plants with

[5] Due the small time span of the data, the long-run adjustment referred to the effects not considered in the short-run.

quick generation adjustment; electricity storage on a large-scale; demand side management programmes, and interconnections with other power systems. A review of energy system flexibility can be found in the reference section (Lund, Lindgren, Mikkola, & Salpakari, 2015).

There is no consensus on the energy-growth nexus. Sebri (2015) for instance, maintains that the diverse findings are a consequence of a number of features, including model specifications, data characteristics, estimation techniques (cointegration tests and causality tests) and the level of development of the country. This conclusion can be supported by another study (Omri, Ben Mabrouk, & Sassi-Tmar, 2015) where the nexus hypotheses were tested for different kinds of energy and countries, and the results showed different outcomes.

Regarding the countries under analysis, Sweden and Estonia, studies of the nexus in these countries are scarce or even non-existent. Indeed, while there are a few studies focused on Sweden, there are none on Estonia. A study of nuclear energy and economic growth in Sweden was conducted (Wolde-Rufael & Menyah, 2010), in which the economic growth was found to cause increased production by the nuclear plants. The neutrality hypothesis (Lee, 2006), as well as the conservation hypothesis (Akkemik & Göksal, 2012) were found to be confirmed for Sweden.

3.3 Estonian and Swedish electricity generation systems

The Estonian transmission system operator (TSO) is Elering and the Swedish TSO is Svenska Krafnät. The market operator for both countries is NPS. As stated before, despite their geographical proximity, Estonia and Sweden have quite different mix compositions. Regarding Estonia, the main electricity generation source is shale oil. In contrast, Sweden's electricity generation system is characterized by high generation by nuclear and hydro-electric plants, and the other sources are wind power with a small percentage of fossil fuels. In Estonia's electricity generation system, fossil fuels are used in both base load and backup roles, and due the intermittent generation by renewable energy sources (RESI), hydro has a small share. In the Sweden's electricity generation system, one expects that nuclear plants are used for the base load, such is expected where nuclear power is used, due to its low marginal cost.

Figure 3.1 shows the aggregated evolution of the use of hydro, fossil fuel and RESI sources for generation. Figure 3.1 clearly shows the dominant use of oil shale source in Estonia, and also the use of nuclear and hydro in Sweden.

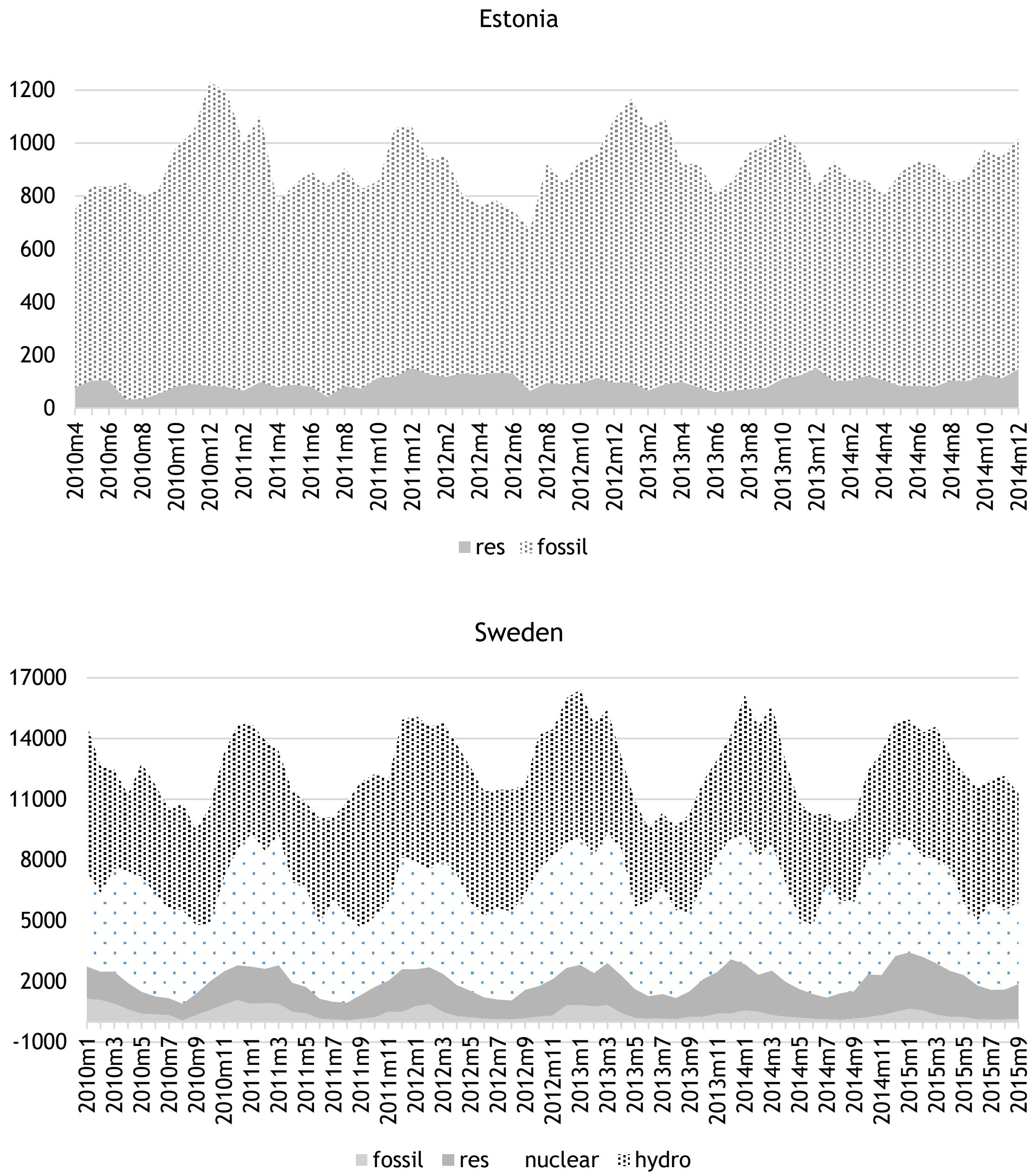


Figure 3.1 - Electricity generation for Estonia and Sweden (GWh)

Wind power in Estonia is the main renewable energy source and plays an important role in renewable generation, due to its proximity to the Baltic Sea (Pacesila, Burcea, & Colesca, 2016). Hydroelectricity is not generated on a large scale, due to the geographical and environmental conditions of the country, and the country's small plants. Feed-in tariffs are the main policy support tool, playing an important role in the increase of wind power generation.

Weather conditions, rainfall distributed throughout the year and the Sweden's geographical features have enabled the development of hydroelectric plants. Sweden has several incentives for renewables, such as green certificates, renewable quota systems, subsidy schemes, tax exemptions and even research programmes funded by the Government (Pacesila et al., 2016).

3.4 Data

Monthly data was used, for the time span April 2010 to December 2014, for Estonia, and January 2010 to September 2015 for Sweden. The time span for Estonia was chosen according to when it became a member of NPS (April 2010) and the data availability for carbon monoxide emissions (December 2014). For Sweden, the availability of data for electricity generation sources was the sole criterion for the time span used.

Usually the literature uses the Gross Domestic Product (GDP) as the measure of economic growth. However, when working upon higher frequency data such as monthly data, GDP is not available and the literature uses a proxy of economic activity, such as the Industrial Production Index (IPI) (e.g. Bilgili, 2015 and Sun & Anwar, 2015). This chapter follows that literature, and uses IPI, for both countries. Awake to the possible existence of a seasonality pattern in output, it is worthwhile to note that the IPI seasonal adjusted is the used variable. In order to achieve the goal of this study, the variables of IPI, electricity generation sources, electricity imports and exports, electricity market price and carbon monoxide emissions are used. Carbon monoxide emissions are only used in the models estimated for Estonia, because this data is unavailable, in monthly frequency, for Sweden. Please note that the environmental variable could be of particular relevance for Estonia given that the electricity generation system in this country is very dependent on fossil fuels, namely shale oil, the dominant generation source. With regard to Sweden, the main generation sources are nuclear and hydroelectric plants, with no greenhouse gas emissions. The electricity market price was used in the models estimated for Estonia. Regarding the market price for Sweden, the Swedish market is divided into four zones. The average of these prices was tested in the econometric models, but it was not significant in any of them. Table 3.1 presents the variables considered in this study and their definitions.

Table 3.1 - Variables' definition

Variable	Definition
LIPI	Seasonally adjusted industrial production index
LFOSSIL	Electricity generated from fossil fuels (GWh)
LRESI	Electricity generated from intermittent renewable energy sources (GWh)
LHYDRO	Electricity generated from hydroelectricity (GWh)
LNUC	Electricity generated from nuclear plants (GWh)
LRXM	Rate of coverage of imports by exports
LPRICE	Elspot market price (€/MWh)
LCM	Average concentration of carbon monoxide emissions (μg/m^3)

Note: all variables are in natural logarithms; μg/m^3 means micrograms per cubic meter.

The data for electricity generation sources and electricity exports and imports were extracted from the European Network of Transmission System Operators for Electricity (ENTSO-E). The electricity price market data was extracted from the NPS database. The industrial production index data was extracted from Eurostat with the code sts_inpr_m., and the carbon monoxide emissions data was extracted from the Statistics for Estonia with the code EN45.

As stated above, the variable *LIPI* was used as a proxy for economic activity, given that the shortest available frequency for GDP data is quarterly. When interpreting the results it should be remembered that the IPI does not include all sectors of economy and, as consequence, is an imperfect proxy for economic activity (Sari, Ewing, & Soytas, 2008). The variables *LPRICE* and *LCM* are used as control variables. In the literature, carbon dioxide emissions are usually used as environmental variables (Chaabouni, Zghidi, & Ben Mbarek, 2016; Saidi & Ben Mbarek, 2016), but these variable are not available in a monthly frequency for Estonia. Fortunately, however, carbon monoxide emissions are available on a monthly frequency. As Estonia has a high share of oil shale, and carbon monoxide is caused by fuel combustion when there is insufficient oxygen, this proxy was used.

3.5 Method

The analysis of the relationship between the variables was based on the ARDL model. This econometric procedure is a robust structure in the presence of endogeneity. The electricity generation system is managed in order to meet electricity demand (Di Giacomo, 2012), and, as such, the presence of endogeneity must be considered. The ARDL approach offers some other advantages for the analysis, specifically allowing for a different integration order of variables, different lag-length, and the ability to handle small samples (Shin, Pesaran, & Smith, 1999).

In order to detect the stationary properties of the variables, conventional unit root tests were carried out. The conventional tests are: ADF (Augmented Dickey-Fuller), PP (Phillips-Perron) and KPSS (Kwiatkowski-Phillips-Schmidt-Shin). The results of these tests do not take into account the existence of structural breaks in the series, so the results may be unsuitable. Taking into account the data frequency and the characteristics of the variables, the system can be subject to shocks. As a consequence, the unit root test with structural breaks, of Zivot and Andrews (1992), was also carried out. This test allows the identification of a break point with intercept, trend or both. Potential structural breaks can be controlled with dummy variables in the ARDL model. Nonetheless, these dummy variables should be used as sparingly as possible.

To test the long-run relationship between variables, the ARDL Bounds test (Pesaran, Shin, & Smith, 2001) was performed. This approach has econometric advantages over other methods (Hamdi, Sbia, & Shahbaz, 2014). Indeed, the Johansen cointegration test assumes that all variables have the same order of integration, but the ARDL Bounds test allows for different orders of integration. The dynamic unrestricted error correction model (UECM) incorporates short-run dynamics with long-run equilibrium.

A general ARDL model is specified (Katusiime, Agbola, & Shamsuddin, 2016) as follows:

$$\phi(L,p)y_t = \beta_i(L,q_i)x_{it} + \alpha' z_t + \varepsilon_t \quad (3.1)$$

where L is the lag operator; $\phi(l,p) = 1 - \phi_1 L - \phi_2 L^2 - \phi_2 L^3 - \ldots - \phi_p L^p$, $\beta_i(L,q_i) = B_{i0} + \beta_{i1}L + \beta_{i2}L^2 + \ldots + \beta_{iq}L^{qi}$ and z is a vector of deterministic variables including the constant, trend and exogenous variables with fixed lags. p and q_i are the lag lengths, α' represents the coefficient on the deterministic variables, and ε is the error term. y_t is the dependent variable and x_{it} represents the explanatory variables. The error correction model is shown in Equation (3.1). An Equation (3.2) for variables *LIPI, LHYDRO, LFOSSIL, LNUC* and *LRESI* was estimated.

$$\Delta y = \sum_{i=1}^{k} \beta_{i0} \Delta x_{it} + \alpha' \Delta z_t - \sum_{j=1}^{\hat{p}-1} \theta_j^* \Delta y_{t-j} - \sum_{i=1}^{k} \sum_{j=1}^{\hat{q}i-q} \beta_{ij}^* \Delta x_{i,t-j} - \theta(1,\hat{p}) ECT_{t-1} + \varepsilon_t . \quad (3.2)$$

The coefficients θ_j^* and β_{ij}^* relate to the short-run dynamics of the model's convergence to equilibrium. The long memory of the variables is characterized by the statically significant Error Correction Term (ECT). According with Jouini (2014), if the ECT is significant at 1% level and has a negative signal, the presence of Granger causality can be confirmed. The ARDL bounds test (Pesaran et al., 2001) was performed in order to test the significance of long-run coefficients. In order to test the quality of the estimations, residual diagnostic tests were performed to detect the econometric properties. The Autoregressive Conditional Heteroscedasticity (ARCH) test was used to test the presence of conditional heteroscedasticity, and the null hypothesis was: the residuals are homoscedastic. The Breusch-Godfray serial correlation LM test had a null hypothesis of no serial correlation. The Jarque-Bera normality test verified that the error term follows normal distribution. The Ramsey Regression Equation Specification Error Test (RESET) confirmed the correct model specification. The coefficients stability test CUSUM and CUSUM squares (Garbade, 1977) tested parameter stability for all equations.

3.6 Results

The results are shown separately for the two countries under analysis, in order to make them easier to read. The traditional unit root tests were performed in both cases. The unit roots for Estonia are presented in Table 3.2 and 3.3. While the unit root tests for Sweden are displayed in Tables 3.4 and 3.5.

Table 3.2 – ADF and PP unit root tests - Estonia

		ADF			PP		
		CT	C	None	CT	C	None
LIPI	Level	-3.2459*	-3.1841**	2.1940	-3.2395*	-3.8699***	2.2609
	1st dif	-9.8408***	-9.3354***	-8.7433***	-10.237***	-9.3742***	-8.6468***
LFOSSIL	Level	-3.8276**	-3.8856***	-0.1962	-4.0614**	-4.1098***	-0.2068
	1st dif	-9.1001***	-9.1496***	-9.2291***	-9.0836***	-9.1388***	-9.2192***
LRESI	Level	-4.2434***	-3.3526***	0.2224	-4.2471***	-3.9029***	1.3157
	1st dif	-8.8860***	-8.9788***	-9.0353***	-18.585***	-19.396***	-16.159***
LHYDRO	Level	-3.8015**	-3.7255***	-1.9076*	-3.5829**	-3.5262***	-1.6573*
	1st dif	-6.7762***	-6.8698***	-6.9320***	-9.8400***	-10.086***	-10.260***
LRXM	Level	-5.2372***	-4.7454***	-1.9769**	-5.2577***	-4.7347***	-1.6926*
	1st dif	-8.2963***	-8.3736***	-8.4410***	-18.118***	-17.973***	-16.098***
LRPICE	Level	-4.7225***	-4.0901***	-0.0599***	-4.6957***	-4.1755***	-0.0293
	1st dif	-7.5855***	-7.5936***	-7.6685	-10.339***	-10.361***	-10.460***
LCM	Level	-5.2439***	-5.2906***	-0.2787	-5.2439***	-5.2906***	-0.2680
	1st dif	-10.774***	-10.825***	-10.921***	-11.401***	-11.458***	-11.566***

Notes: ADF stands for Augmented Dickey Fuller test; PP stands for Philips Perron test; CT stands for constant and trend; C stands for constant; ***, ** and * represent significant level for 1%, 5% and 10%, respectively.

Table 3.3 - KPSS unit root tests - Estonia

		KPSS	
		CT	C
LIPI	Level	0.1634**	0.8422***
	1st dif	0.0712	0.4747**
LFOSSIL	Level	0.0522	0.0531
	1st dif	0.0346	0.0522
LRESI	Level	0.0969	0.3596*
	1st dif	0.4350***	0.4431*
LHYDRO	Level	0.0739	0.1839
	1st dif	0.1463**	0.1530
LRXM	Level	0.0447	0.4106*
	1st dif	0.0855	0.0855
LRPICE	Level	0.0651	0.3380
	1st dif	0.0522	0.0749
LCM	Level	0.0316	0.0663
	1st dif	0.0600	0.0918

Notes: KPSS stands for Kwiatkowski-Philips-Schmidt-Shin test; CT stands for constant and trend; C stands for constant; ***, ** and * represent significant level for 1%, 5% and 10%, respectively

In the above Table for Estonia, the variable *LIPI* appear to be I(1), while the variables *LHYDRO*, *LRXM* and *LPRICE* appear to be I(0). For the variables *LFOSSIL*, *LRESI* and *LCM*, the tests reveal no consensus about the integration order of the series. Indeed, the variables seems to be I(0)/I(1), depending on constant and trend, constant, or none.

Table 3.4 – ADF and PP unit root tests - Sweden

		ADF			PP		
		CT	C	None	CT	C	None
LIPI	Level	-3.7299**	-2.0855	0.4107	-3.8280**	-2.5414	0.3631
	1st dif	-12.617***	-12.651***	-12.724***	-13.064***	-13.037***	-13.123***
LFOSSIL	Level	-7.1898***	-6.1366***	-1.5692	-3.6642**	-3.4892**	-0.8485
	1st dif	-7.9885***	-7.9337***	-7.7191***	-6.8583***	-6.9028***	-6.9305***
LRESI	Level	-6.9071***	0.5604	2.7137	-3.6850**	-3.2017**	-0.0862
	1st dif	-8.4329***	-8.1480***	-7.5549***	-6.6523***	-6.7004***	-6.7484***
LHYDRO	Level	-3.7652**	-3.7870***	-0.3159	-3.9539**	-3.9779***	-0.3372
	1st dif	-9.4120***	-9.4914***	-9.5619***	-9.4222***	-9.5036***	-9.5751***
LNUC	Level	-4.2121***	-4.2500***	-0.1808	-4.3731***	-4.4100***	-0.2378
	1st dif	-6.2329***	-6.0311***	-6.1046***	-11.189***	-10.278***	-10.401***
LRXM	Level	-4.7556***	-3.6320***	-1.8927*	-4.7954***	-4.1819***	-2.7935***
	1st dif	-8.1744***	-8.1733***	-8.1921***	-9.6804***	-9.6946***	-9.7409***

Notes: ADF stands for Augmented Dickey Fuller test; PP stands for Philips Perron test; CT stands for constant and trend; C stands for constant; ***, ** and * represent significant level for 1%, 5% and 10%, respectively.

Table 3.5 - KPSS unit root tests - Sweden

		KPSS	
		CT	C
LIPI	Level	0.1436*	0.6350**
	1st dif	0.1716**	0.1776
LFOSSIL	Level	0.0341	0.3402
	1st dif	0.0268	0.0296
LRESI	Level	0.0235	0.0250
	1st dif	0.4867**	0.0268
LHYDRO	Level	0.0708	0.0377
	1st dif	0.0705	0.0447
LRXM	Level	0.0822	0.0836
	1st dif	0.0836	0.1081
LRPICE	Level	0.0604	0.7130**
	1st dif	0.0391	0.0857

Notes: KPSS stands for Kwiatkowski-Philips-Schmidt-Shin test; CT stands for constant and trend; C stands for constant; ** and * represent significant level for 5% and 10%, respectively

In the Tables 3.4 and 3.5, the Swedish case was analysed. All variables appear to be borderline I(0)/I(1), except the variable *RXM*, which seems to be stationary in level. Traditional tests ensure that the series for both countries are not I(2), so the use of the ARDL approach seems to be appropriate. In addition to these tests, tests with structural breaks were performed, due the data frequency and the characteristics of the data, in order to ensure that the series are nor definitely I(2) and identity candidates for breakpoints. Zivot-Andrews can be seen in Tables 3.6 and 3.7, for Estonia and Sweden, respectively. Null hypothesis is series has a unit root with structural breaks.

Table 3.6 - Unit root tests with structural breaks Zivot-Andrews - Estonia

Variables		C	Break point	T	Break point	CT	Break point
LIPI	level	-3.2264	2012m3	-4.5351**	2011m2	-3.2264	2012m3
	1st dif	-9.0529***	2011m4	-8.6331***	2011m11	-8.9577***	2011m4
LFOSSIL	level	-4.4971	2012m8	-3.8496	2012m4	-4.5222*	2011m4
	1st dif	-9.4616***	2013m2	-4.8205***	2014m2	-9.9720***	2011m1
LRESI	level	-5.0199**	2012m7	-4.5589**	2012m1	-5.1450**	2012m7
	1st dif	-6.9451***	2012m4	-6.0236***	2013m3	-6.9147***	2012m4
LHYDRO	level	-5.4171***	2013m6	-5.1694***	2012m4	-5.4899**	2013m11
	1st dif	-5.4413***	2013m11	-5.7017***	2013m11	-6.0303***	2013m11
LRXM	level	-6.1304***	2012m1	-5.3528***	2012m5	-6.1678***	2012m1
	1st dif	-8.5788***	2012m4	-8.2265***	2012m2	-8.5494***	2012m4
LPRICE	level	-3.7637	2012m12	-3.1069	2012m01	-3.8295	2012m12
	1st dif	-5.2666**	2012m07	-4.8839***	2013m10	-5.1582**	2013m10
LCM	level	-5.9702***	2012m2	-5.2368***	2012m9	-5.9485***	2012m12
	1st dif	-5.3561**	2013m4	-5.1934***	2014m3	-5.5315***	2011m3

Notes: C stands constant; T stands trend; CT stands constant and trend; ***, ** and * represents significant level for 1%, 5% and 10%, respectively

Table 3.7 - Unit root tests with structural breaks Zivot-Andrews - Sweden

Variables		C	Break point	T	Break point	CT	Break point
LIPI	level	-4.7917*	2012m9	-4.5190**	2014m11	-4.5414	2014m5
	1st dif	-4.8423*	2014m10	-4.7631**	2013m3	-4.9415*	2012m9
LFOSSIL	level	-8.2298***	2011m6	-7.5921***	2012m1	-8.2290***	2011m6
	1st dif	-5.8265***	2011m9	-5.7025***	2014m10	-5.8258***	2011m9
LRESI	level	-6.5955***	2012m5	-6.5895***	2014m8	-6.6320***	2011m6
	1st dif	-6.0699***	2011m4	-5.8700***	2012m8	-6.0344***	2014m8
LHYDRO	level	-4.9133*	2013m4	-4.0126	2012m1	-4.8859*	2013m4
	1st dif	-9.5612***	2013m8	-5.4509***	2013m5	-9.6301	2014m9
LNUC	level	-6.0554***	2012m9	-5.8967***	2013m7	-6.2018***	2012m9
	1st dif	-7.7949***	2011m11	-7.6618***	2012m11	-7.7967***	2011m4
LRXM	level	-4.6463*	2013m5	-4.7829**	2014m11	-5.1187**	2014m6
	1st dif	-8.3965***	2013m11	-5.5443***	2014m8	-5.6657***	2013m11

Notes: C stands constant; T stands trend; CT stands constant and trend; ***, ** and * represents significant level for 1%, 5% and 10%, respectively

The unit root tests with structural breaks are ambiguous about the integration order of the variables. In some series the null hypothesis is rejected, but the tests corroborate that the series are not I(2). This test provides additional support for the use of the ARDL approach in order to study the relationship between the variables.

After observing the stationarity properties of the series, the ARDL model was estimated for both Estonia and Sweden. In the same way the most restricted Schwarz information criterion was used to select the optimal lag length. In both cases the optimal lag order used is one. Due to the data frequency and the characteristics of the data, the presence of structural breaks could be expected. In order to control for this phenomenon, Impulse Dummy variables were used to control outliers and structural breaks. Impulse dummies are obtained following this procedure: (i) Zivot and Andrews unit root test with structural breaks; (ii) individual inspection of possible other periods of shocks; and (iii) test the statistical significance of a few shocks observing irregularities in the residuals. Table 3.8 and 3.9 shows the estimated models for Estonia and Sweden, respectively. Following the parsimonious principle the estimated models only contain the statistically significant variables, in order to preserve the larger number of degrees of freedom. In the case of Estonia, residual tests ensure the quality of the estimations. The ARCH test for heteroscedasticity suggests homoscedasticity. Serial correlation was not detected in the first order. The Normality test confirmed that the error term follows normal distribution. The Ramsey RESET test confirmed the correct model specification.

Table 3.8 - Estimated ARDL – Estonia

	Dependent Variable			
	I - *DLIPI*	II - *DLFOSSIL*	III - *DLRESI*	IV - *DLHYDRO*
DLIPI		2.15024***		
DLIPI(-1)	-0.4213***			
DLFOSSIL	0.0950***			-0.7138*
DLRESI				0.7389***
DLRESI(-1)	0.0218***			
DLHYDRO		-0.0617**	0.1284**	
DLHYDRO(-1)	-0.0382***	0.0845***		
DLPRICE	0.0275*			
DLCM		0.1732***		-0.4358**
LIPI(-1)	-0.1291***	0.3038***	0.7625***	-1.0093***
LFOSSIL(-1)	0.093608***	-0.3541***	-0.5255***	
LRESI(-1)			-0.4750***	0.7316***
LHYDRO(-1)	0.0145***	-0.0749**		-0.5535***
LRXM(-1)	-0.0133**			
LCM(-1)		0.1796**	0.3784***	0.3673**
Time dummies				
A2010M4		-0.3365***		
A2010M6				-0.8282**
A2010M7			-0.8484***	
A2011M7			-0.5477***	
A2012M3	-0.0413**			
A2013M2	-0.0655***			
A2014M4	0.0374**			
A2014M8				-0.7290**
Diagnostic tests				
ARS	0.6889	0.5098	0.6197	0.5552
SER	0.0143	0.0891	0.1844	0.3236
Jarque-Bera	0.7919	0.9048	0.5342	0.3990
LM	(1) [0.8426]	(1) [0.8138]	(1) [0.2110]	(1) [0.9299]
	(2) [0.0223]	(2) [0.8791]	(2) [0.2607]	(2) [0.8424]
	(3) [0.0346]	(3) [0.9585]	(3) [0.3966]	(3) [0.7072]
ARCH	(1) [0.8019]	(1) [0.2748]	(1) [0.3558]	(1) [0.5740]
	(2) [0.2994]	(2) [0.5243]	(2) [0.6191]	(2) [0.2701]
	(3) [0.4549]	(3) [0.6294]	(3) [0.7868]	(3) [0.2190]
RESET	[0.3732]	[0.5605]	[0.2601]	[0.2517]

Notes: the diagnostic test results are based on F-statistics. [ ] represented the p-values of F-statistic and ( ) represented lags for the variables. "A" denotes a dummy variable for Estonia. ARS denoted Adjusted R-squared. SER means standard error of regression. Jarque-Bera is a normality test. LM is Breusch-Godfray serial correlation LM test. ARCH denotes ARCH test for heteroscedasticity. RESET means Ramsey RESET test. ***, ** and * represent significant level for 1%, 5% and 10%, respectively.

Table 3.9 - Estimated ARDL – Sweden

	Dependent Variable				
	V - *DLIPI*	VI - *DLFOSSIL*	VII - *DLRESI*	VIII - *DLHYDRO*	IX - *DLNUC*
constant	1.2034***				
trend		-0.0209***			
DLIPI(-1)	-0.3276***			-1.9503***	
DLFOSSIL	0.0164***		0.1726***		
DLFOSSIL(-1)			0.1595***	0.1687***	
DLRESI	-0.0222	1.2649***			0.4161***
DLHYDRO					-0.3701***
DLHYDRO(-1)		0.4173*			
DLNUC	0.0139		0.2585***	-0.3556***	
DLNUC(-1)					0.2804***
DLRXM		-0.0868*		0.0423*	0.1292***
DLRXM(-1)	0.0077***				
LIPI(-1)	-0.2411***	-1.2141***		0.6468***	0.7269***
LFOSSIL(-1)	0.0098**	-0.6197***			0.0655*
LRESI(-1)	-0.0209**	1.3466***	-0.2342***		0.1099*
LHYDRO(-1)				-0.3439***	
LNUC(-1)			0.2039***		-0.5371***
LRXM(-1)					0.0468*
Time dummies					
B2010M8		-1.1972***			
B2011M6		-0.5357*			
B2012M1	0.0443**				
B2012M5	0.0519***				
Diagnostic tests					
ARS	0.4336	0.6945	0.5175	0.4173	0.6065
SER	0.0176	0.2605	0.1312	0.1209	0.1185
Jarque-Bera	0.5864	0.6337	0.1674	0.7422	0.5102
LM	(1) [0.4175]	(1) [0.2807]	(1) [0.2585]	(1) [0.6278]	(1) [0.7223]
	(2) [0.6146]	(2) [0.1114]	(2) [0.4603]	(2) [0.2369]	(2) [0.8897]
	(3) [0.8068]	(3) [0.2145]	(3) [0.3081]	(3) [0.2842]	(3) [0.7570]
ARCH	(1) [0.8557]	(1) [0.5440]	(1) [0.9576]	(1) [0.8449]	(1) [0.2858]
	(2) [0.8277]	(2) [0.4988]	(2) [0.6700]	(2) [0.9842]	(2) [0.5694]
	(3) [0.5507]	(3) [0.7311]	(3) [0.8513]	(3) [0.4883]	(3) [0.7304]
RESET	[0.8308]	[0.3297]	[0.2601]	[0.1626]	[0.4570]

Notes: the diagnostic test results are based on F-statistics. [ ] represented the p-values of F-statistic and ( ) represented lags for the variables. “B” denotes a dummy variable for Sweden. ARS denoted Adjusted R-squared. SER means standard error of regression. Jarque-Bera is a normality test. LM is Breusch-Godfray serial correlation LM test. ARCH denotes ARCH test for heteroscedasticity. RESET means Ramsey RESET test. ***, ** and * represent significant level for 1%, 5% and 10%, respectively.

In the case of Sweden, the diagnostic tests reveal that the phenomenon of heteroscedasticity was not detected in any model. The Jarque-Bera tests ensured that the errors followed a normal distribution. There was no serial correlation for all models. The Ramsey RESET test supported the correct specification of the model, and the cumulative sum (CUSUM) and CUSUM of squares tests supported the parameter stability for all models (Figure 3.2 and 3.3). The horizontal axis is different due the use of a dummy variables

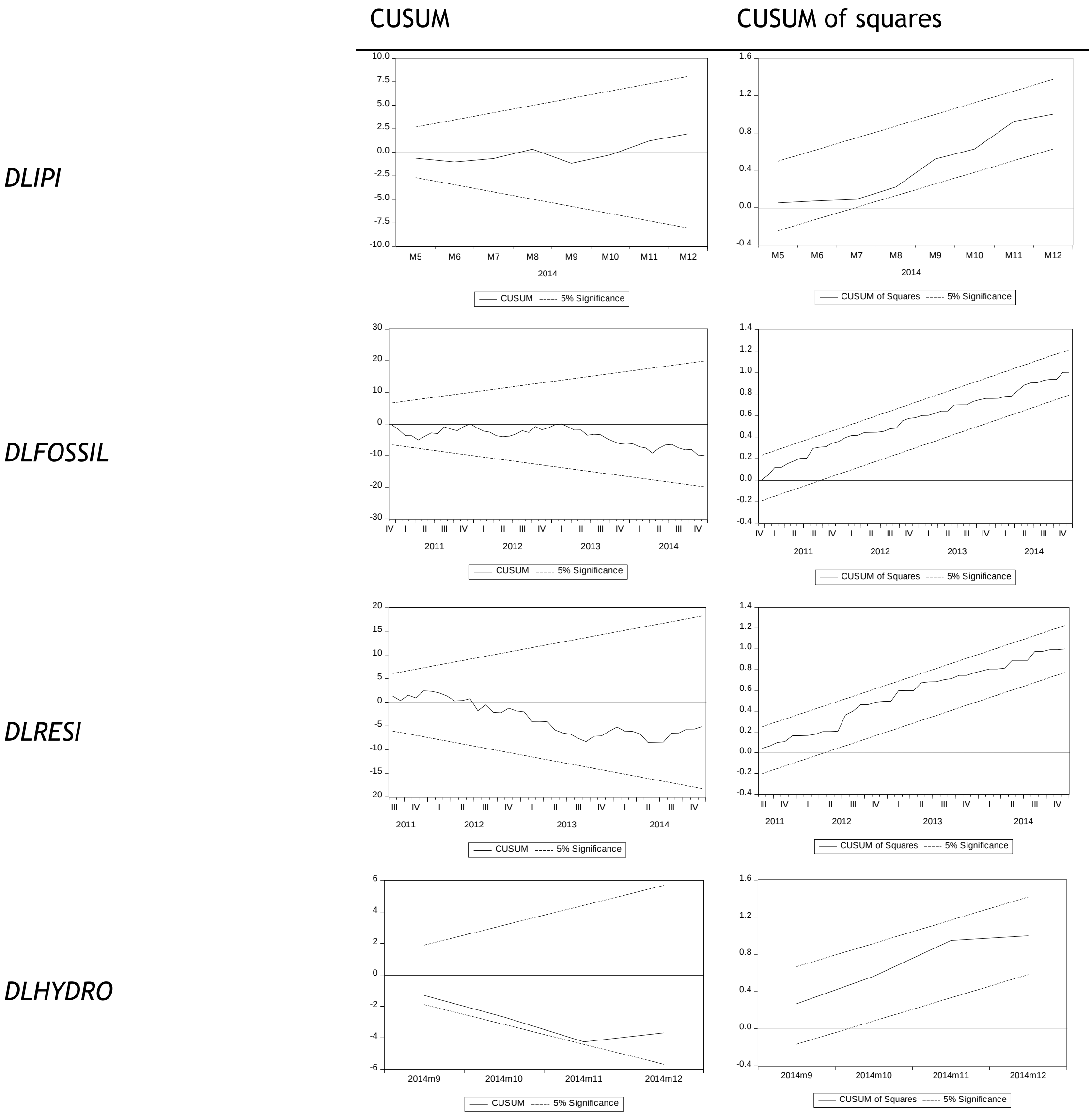


Figure 3.2 - CUSUM and CUSUM of squares tests for Estonia

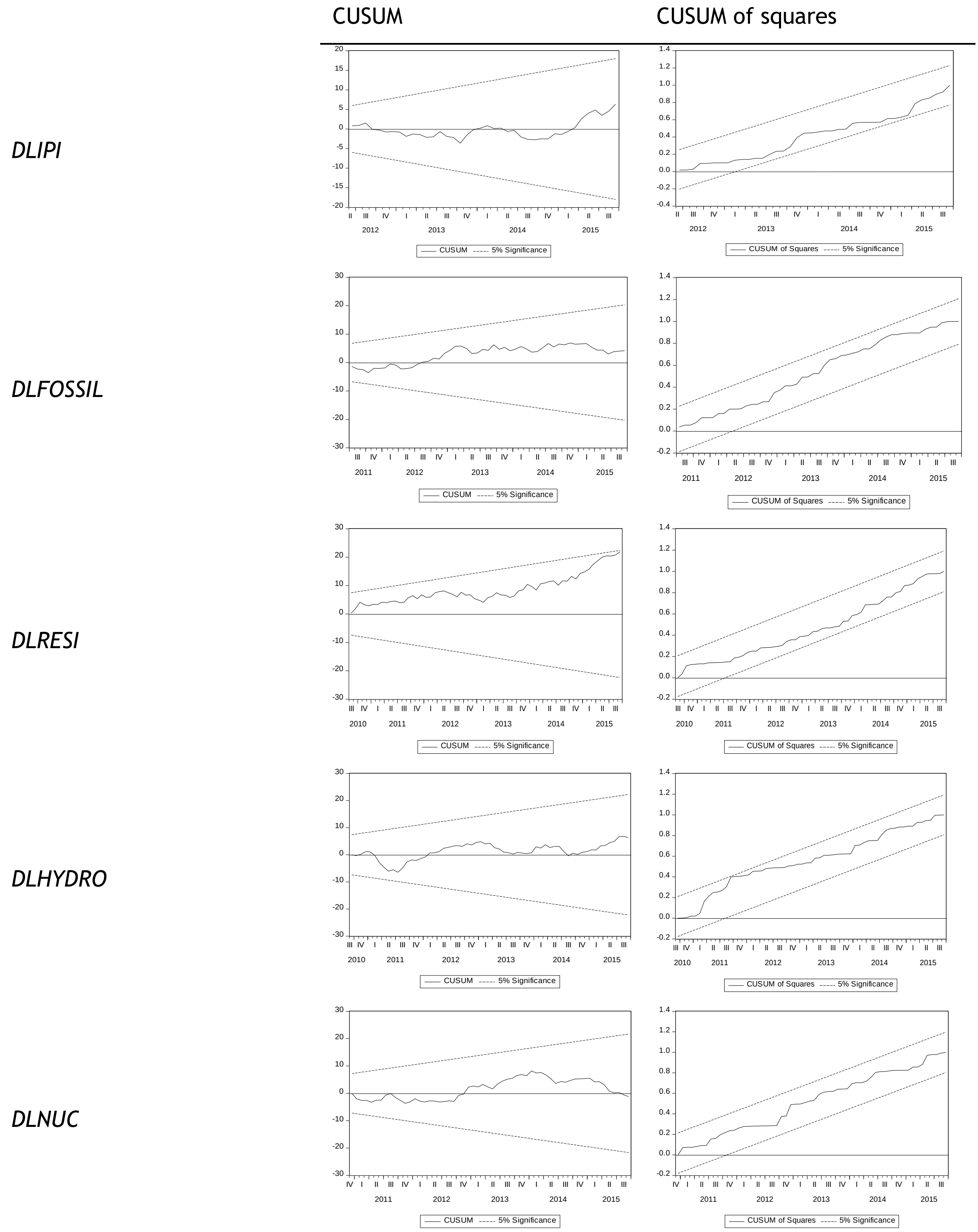


Figure 3.3 - CUSUM and CUSUM of squares tests for Sweden

The ARDL bounds test was performed to appraise the existence of a long-run relationship between variables. Table 3.10 synthesizes these results, for both Estonia and Sweden.

The critical values for all models in the case of Estonia were those taken from options with no intercept and no trend. The null hypothesis of no cointegration was rejected for all models at 1% significance level. Therefore, the variables have a long-run relationship. In other words, a shock in the models does not only affect the short-run. On the contrary, it persists over time, for the time span analysed.

Table 3.10 - Bounds test

Estonia					Sweden				
Model	F-statistic	K	Bottom	Top	Model	F-statistic	K	Bottom	Top
			1 %	1 %				1 %	1 %
I	19.1966***	3	3.41	4.84	V	2.51276*	2	5.15	6.36
II	5.36619***	3	3.41	4.84	VI	18.6010***	2	6.34	7.52
III	12.7334***	3	3.41	4.84	VII	14.7239***	1	4.81	6.02
IV	10.5440***	3	3.41	4.84	VIII	18.5823***	1	4.81	6.02
					IX	6.48186***	4	3.07	4.44

Note: k is a number of dependent variables in equation estimated. ***, ** and * represent significant level for 1%, 5% and 10%, respectively. Critical values Bottom and TOP were obtained from (Pesaran et al., 2001)

Regarding the Swedish case, the option with unrestricted intercept and no trend was applied to Model V. For Model VI, no option is provided (other than trend). Therefore, the critical value was extracted from the single option that can be applied, i.e, the option with unrestricted intercept and unrestricted trend. In Models VII, VIII and IX, the option with no intercept and no trend was applied. The hypothesis of no cointegration can be rejected at 1% significance level, except in Model V, where the hypothesis of no cointegration is not rejected. In Model V there is no long-run relationship, but the ECT is statically significant. In this case, the evidence suggests that series has long memory. The statistically significance of the long-run coefficients (5%) is not enough to produce a long-run relationship, this statement is corroborated by the results of the bunds test and the adjustment speed.

The long-run elasticities were calculated the estimated coefficients. Semi-elasticities and elasticities are shown in Tables 3.11 and 3.12.

Table 3.11 - Semi-elasticities and elasticities – Estonian case

	Dependent Variable			
	I - *DIPI*	II - *DLFOSSIL*	III - *DLRESI*	IV - *DLHYDRO*
Semi-elasticities				
DLIPI		2.15024***		
DLIPI(-1)	-0.4213***			
DLFOSSIL	0.0950***			-0.7138*
DLRESI				0.7389***
DLRESI(-1)	0.0218***			
DLHYDRO		-0.0617**	0.1284**	
DLHYDRO(-1)	-0.0382***	0.0845***		
DLPRICE	0.0275*			
DLCM		0.1732***		-0.4358**
Elasticities				
LIPI(-1)		0.8580***	1.6052***	-1.8235***
LFOSSIL(-1)	0.7251***		-1.1064***	
LRESI(-1)				1.3219***
LHYDRO(-1)	0.1121***	-0.2115**		
LRXM(-1)	-0.1034**			
LCM(-1)		0.5073***	0.7966***	0.6637**
ECT	-0.1291***	-0.3541***	-0.4750***	-0.5535***

Notes: ***, ** and * represent significant level for 1%, 5% and 10%, respectively. ECT stands for Error Correction Term.

In Model I, semi-elasticities reveal that *DLRESI* and *DLFOSSIL* have a positive impact on economic activity. An increase of 1 percentage point (pp) in *DLRESI* and *DLFOSSIL*, has an impact of around 0.0218 and 0.0950 pp, on the *DLIPI*. Estonia is a net electricity exporter, an increase of 1 pp in the electricity market price has an impact of 0.0275 pp on economic activity, but only at 10% significance level. Regarding the long-run, an increase in the *LFOSSIL* causes a higher impact than *LHYDRO* on economic activity. This result is expected due to the low share of the hydro power in the electricity mix. In the model of fossil sources, industrial production has a significant impact on production from this type of source; an increase of 1 pp in *DLIPI* has an impact of 2.15024 pp on the electricity generation by fossil fuels. In the long-run this effect persists, and an increase of 1% causes an impact of 0.8580%. In Model III, economic activity has a positive effect on *RESI* in the long-run, so energy renewables require economic prosperity for investment. In Model IV renewable energy causes a positive impact in both the short- (0.7389 pp) and long-run (1.3219%). Hydro power, essentially run-of-the-river, and wind power are similar to each other, both are renewable, and it is not possible to store their generation on a large scale.

Table 3.12 - Semi-elasticities and elasticities – Swedish case

	Dependent Variable				
	V - *DIPI*	VI - *DLFOSSIL*	VII - *DLRESI*	VIII - *DLHYDRO*	IX - *DLNUC*
Semi-elasticities					
DLIPI(-1)	-0.3276***			-1.9503***	
DLFOSSIL	0.0164***		0.1726***		
DLFOSSIL(-1)			0.1595***	0.1687***	
DLRESI	-0.0222	1.2649***			0.4161***
DLHYDRO					-0.3701***
DLHYDRO(-1)		0.4173*			
DLNUC	0.0139		0.2585***	-0.3556***	
DLNUC(-1)					0.2804***
DLRXM		-0.0868*		0.0423*	0.1292***
DLRXM(-1)	0.0077***				
Elasticities					
LIPI(-1)		-1.9591***		0.8705***	1.3535***
LFOSSIL(-1)	0.040**				0.1220**
LRESI(-1)	-0.0869**	2.1729***			0.2046*
LNUC(-1)			0.2039***		
LRXM(-1)					0.0872*
ECT	-0.2411***	-0.6197***	-0.2342***	-0.3439***	-0.5371***

Notes: ***, ** and * represent significant level for 1%, 5% and 10%, respectively. ECT stands for Error Correction Term.

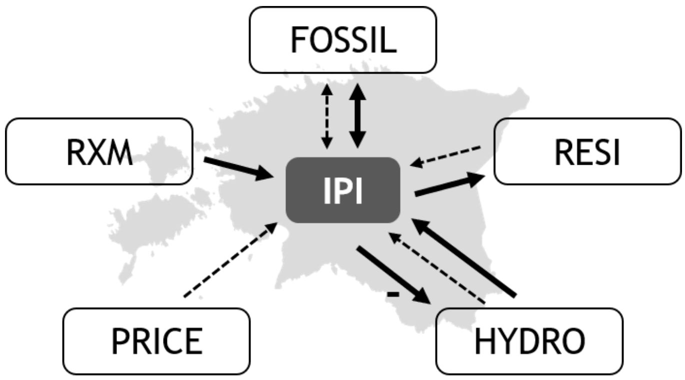
In the case of Sweden, fossil sources have a positive impact in economic activity, 0.0164 pp in the short-run. In Model VI, *RESI* has a positive impact on electricity generation by fossil fuels, more renewables imply more fossil generation due to fossil's backup role for renewables. In Model VII, an increase of 1 pp in *DLFOSSIL* and *DLNUC* causes an increase in *DLRESI* of 0.1726 and 0.2585 pp, respectively. In model VIII, an increase of 1pp in *DLNUC* provokes a reduction of 0.3556ppin *DLHYDRO*, hydroelectricity can replace nuclear plants. In Model IX, renewable energies had a positive impact on the *DLNUC*, in both the short (0.4161 pp) and long-run (0.2046%). This positive impact could be a consequence of the backup to *RESI*, due to the prediction of the intermittent generation such as solar photovoltaic, it is possible to previously adjust the requirements for the nuclear plants. In the long-run, economic activity has a positive impact on electricity generated by nuclear plants; an increase of 1% in *LIPI* has a positive effect of 1.35% on electricity generated by nuclear plants. In the next section the results are discussed and both Estonia's and Sweden's electricity generation systems are compared.

3.7 Discussion

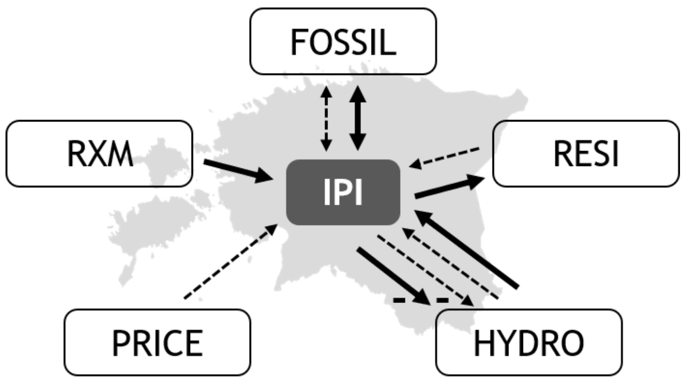
The main purpose of this chapter is to analyse the interaction between electricity generation sources and economic activity in countries with an abundance of certain endogenous natural resources. In Estonia, oil shale predominates, while in Sweden, it is hydro power and nuclear power. The important role of these two types of source in the economic growth of each country is clearly captured by the estimated models.

A first major finding is that there is a bidirectional relationship between electricity generated by fossil fuels and economic growth, which sustains the *feedback hypothesis*, in the case of Estonia. The *conservation hypothesis* was verified in the long-run, for *RESI* in Estonia and for nuclear and hydroelectricity in Sweden. The unidirectional causality running from energy consumption to economic activity, i.e., the *growth hypothesis* was verified for *RESI* in the case of Estonia, and for nuclear and fossil sources in the case of Sweden. These findings deserve the following further discussion, given that they could be helpful in informing the policymakers of both countries. Figure 3.4 shows the verified hypotheses between economic activity and electricity generation sources, for both Estonia and Sweden.

Estonia



Sweden



Long-run ------ Short-run - denotes negative relationship

Figure 3.4 - Diagrams of verified hypotheses

The electricity generated from nuclear plants has a high share in the Swedish energy mix, but due to policy decisions, it has been reduced in favour of renewables. However, the policymakers should be aware that the important role of nuclear plants in the deployment of economic activity in Sweden. A negative relationship between economic growth and fossil generation was found, and because of the abundance of endogenous natural resources, fossil sources are not a priority. The results suggest the existence of an unexpected negative relationship from *RESI* to economic activity. However, this observed negative effect is consistent throughout the models. Although infrequent, this negative effect is not new in the literature (Ocal & Aslan, 2013; Dogan, 2015; Bhattacharya, Paramati, Ozturk, & Bhattacharya, 2016;). This effect could be the consequence of several factors, such as the high level of incentives and programmes to develop renewables supported by the Swedish Government.

Estonia is one of the largest producers of oil shale in the world, and this source of energy represents a high percentage of its energy mix. Estonia is currently faced with a difficult decision. On the one hand, its comparative wealth in this natural resource is a great advantage, and evidence actually shows that oil shale promotes growth, but what about the environment and its international commitments? Like Sweden, Estonia is a member of European Union, and its membership implies commitments to accomplishing renewable quotas. Furthermore, to realize the goal of *RESI* penetration and decrease polluting emissions, it is recommended that renewables be integrated using fossil sources in support. Estonia is in the privileged position of being able to provide this back up inexpensively, due to its abundance of oil shale. This could enable *RESI* to be developed at a more acceptable cost. At the same time, the commitment to *RESI* allows certain kinds of industry with intensive electricity usage to become less dependent on fossil sources, and allows other industries to continue to benefit from the comparative advantages of using abundant fossil sources.

Regarding the interaction between electricity generation sources, in the Estonian system, a substitution effect can be verified between hydropower and fossil fuels. A positive effect can be observed with respect to the interaction between hydropower and *RESI*, and this means that these sources complement each other. However, hydroelectricity is not a priority in Estonia due its geographic characteristics. In contrast, there is no evidence of substitution effect between sources in Sweden, except for hydroelectricity and nuclear plants. This fact is of relevance given that it means that Sweden has not been able to replace fossil sources by *RESI*. A likely reason for this is that, in Sweden, fossil fuels are not the main generation source. Due the abundance of hydro and the high proportion of nuclear plants in the energy mix, the country is not prepared to invest in fossil sources. A negative relationship between electricity generated by hydropower and nuclear plants was found. Hydro power does not produce polluting gases and it can be controlled, so it could replace nuclear power, which has been a controversial issue in public opinion.

The NPS is the biggest and most developed electricity market in Europe. Consequently, the electricity exchanges between its member countries are intensive. The relationship between economic activity and the electricity market was tested by using the export/import ratio, for both Estonia and Sweden. Both countries are net electricity exporting countries. In Sweden, the ratio has a positive impact on economic activity and on electricity generation sources other than fossil. This exception can be explained by the low proportion of fossil sources in the national electricity mix, so that this source is not used for electricity exports. The market price and carbon monoxide emissions were analysed for Estonia, and results are as expected. A positive impact of carbon monoxide emissions in promoting larger amounts of electricity generated by renewables was observed, as *RESI* requires backup from fossil sources.

3.8 Conclusion

In this chapter two member nations of the Nord Pool Spot with distinct energy mixes (Estonia and Sweden) were analysed. As its main generating source, Estonia uses oil shale that produces greenhouse gases. Sweden uses nuclear and hydropower as its main electricity sources, which reduce greenhouse gas emissions. This chapter focuses on analysing the interactions between electricity generation sources and economic growth, using monthly data frequency and the ARDL bounds test approach. This approach allows short- and long-term effects to be observed separately. Consequently, both the semi-elasticities and the elasticities were computed and properly discussed.

The abundance or even the dominance of one kind of electricity source can hamper the diversification of a national energy mix. Estonia has a high share of oil shale in its energy mix while Sweden has substantial hydro power but is still strongly dependent on nuclear plants. The results show the importance of endogenous natural resources in increasing economic activity and reveal the importance of these sources in supporting the penetration of new sources in electricity generation systems.

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Chapter 4

Accommodating renewable energy sources in a small electricity market: an analysis considering the interactions of sources within Portugal and Spain

In this chapter two electricity generation systems in a context of a small are analised. The Iberian market has been isolated and has an increasing proportion of renewable sources. The main objective of this study is to understand how electricity generation sources are interacting with electricity wholesale prices. The VAR approach was used because of its high robustness to cope with the endogeneity detected by Granger block Exogeneity tests. To do this, workweek data recorded since the opening of the Iberian market (July 2, 2007) was used. Despite the geographical proximity of the countries and their access to natural resources, the results provide empirical evidence of different modes of interaction in the market. This outcome could be due to the different sizes of the national systems. The Portuguese electricity generating system does not have an extensive structure to share backup with Spain via conventional sources. Spain's substantial generation structure could be used to provide intermittent backup generation for Portugal. Considering the similar supply and demand patterns of the Iberian generation systems, their openness to the other markets with different consumption and generation patterns could allow a more rational utilization of the renewables already deployed and, consequently, bring greater efficiency to the Iberian electricity market.

4.1 Introduction

The diversification of the electricity generation by the introduction of Renewable Energy Sources (RES) is well underway in domestic electricity mixes worldwide. Diversified mixes incorporating RES, require electricity power systems with internal mechanisms to accommodate these kinds of sources, such as cross-border interconnections, and pumping to create storage. To achieve this, the European Union has set both renewable power generation targets and minimum targets for interconnection between countries (European Commission, 2015).

Different electricity sources, such as intermittent renewables, contribute to the generation mix. Intermittent renewables are characterized by: (i) low marginal costs; (ii) high initial investment costs; and (iii) discontinuous generation. The existence of a large electricity market is important to meet electricity demand during periods when the natural resources of wind and sun are unavailable. Indeed, cross-border interconnections are one of the most flexible instruments in a power system, given that they can be made available instantaneously. Flexible interconnections allow the external market to meet the demand for electricity when domestic generation is scarce, and export surplus electricity when domestic generation is high, and demand is low. The operation of wholesale electricity markets has been adapting to the variability of wind production. However, with the development of solar photovoltaic generation, peak prices may undergo changes, because the most productive period of this source coincides with peak demand.

When the electricity market is small, as in the Iberian market, which consists of Portugal and Spain, the markets of each country are likely to be strongly integrated. Indeed, as the interconnections between the Iberian electricity market (MIBEL) and the rest of Europe are scarce and fairly restricted, the two domestic electricity generation systems are very dependent on each other to satisfy their respective electricity demands and export any surplus.

Electricity market prices could make an important contribution to increasing these interactions between the two power systems, and generation sources could be important in defining the wholesale price of electricity and consequently increasing the exchange of electricity. In the literature, it is generally the impact of intermittent renewable energy on electricity prices that is analysed (Luňáčková, Průša, & Janda, 2017; Quint & Dahlke, 2019). This chapter takes a fresh approach, by analysing the causal inference between electricity prices and generation sources. The objectives of this chapter are: (i) to analyse the role of electricity prices on electricity generation sources; (ii) to assess the effect of electricity generation sources (intermittent and continuous) on the electricity price; and (iii) to compare the behaviour of the two markets that constitutes the MIBEL. Bearing in mind the need to diversify electricity mixes, the electricity market can play an important role in accommodating different generation sources. It could bring economic rationality to the whole system, without requiring major investment in a new generation of backup infrastructure. In practice, this common market could play an important role in sharing back up for intermittent RES.

In this study, daily frequency data was used, more specifically, daily data for working days. The time span starts on the first day of MIBEL operation, on 2 July 2007 and continues up to 30 March 2018. An electricity system is managed in real time, so endogeneity between variables was anticipated. To handle these characteristics, a Vector Autoregressive (VAR) model was used. Generally, the Iberian market is hampered by restrictions, so it is urgent to increase market efficiency to accommodate renewables more easily.

The remainder of this chapter is as follows. In Section 4.2 there is a brief literature review. Section 4.3 describes the data and method used in the study. The results are presented in Section 4.4 and discussed in Section 4.5. Section 4.6 presents the conclusions.

4.2 Literature Review

Many countries have been increasing the share of RES in their energy mix, to reduce both carbon dioxide and meet international agreements. This relationship is well documented in the literature on emissions (Dong et al., 2018; Chen, Wang, & Zhong, 2019). The transition from fossil to renewable sources results from commitments to both national and international programmes, such as the Kyoto Protocol, the directives of the European Union and, most recently, the *2015 United Nations Climate Change Conference*, in Paris.

The European Union Directives (European Commission, 2001, 2003, 2009) and incentive programmes established targets to deploy RES. Feed-in tariffs and renewable portfolio standards are some examples of these RES incentives, revealing the importance the European Union has given to the new renewables (namely wind and photovoltaic). Feed-in tariffs and renewable portfolio standards are really effective in encouraging the deployment of RES (Alizada, 2018). However, the penetration of renewable sources through this type of incentive programs increases the cost of electricity to final consumers (e.g. Gallego-Castillo & Victoria, 2015). Moreover, the well-known characteristic of RES intermittency can lead to excess installed capacity (Flora, Marques, & Fuinhas, 2014). Indeed, some literature warns that greater use of RES could constrain economic activity (Bhattacharya, Paramati, Ozturk, & Bhattacharya, 2016). Other authors (Brouwer, Van Den Broek, Seebregts, & Faaij, 2014) note that the use of the new renewables requires a flexible system. A flexible system is characterized by high capacity generation by fossil fuels and renewable energies, a high interconnection capacity and electricity storage. This flexibility is encountering barriers that can slow hamper the change (Hu, Harmsen, Crijns-graus, Worrell, & Broek, 2018). Thus, cross-border interconnections and market integration issues worldwide, have deserved particular attention in the literature (Cepeda, 2018; Van den Bergh, Bruninx, & Delarue, 2018; Loureiro, Claro, & Fischbeck, 2019).

The high penetration of RES in the energy mix of countries has received particular attention in the literature, due to the effect that these intermittent sources can have on electricity prices. The low marginal cost of wind and solar photovoltaic power can decrease the wholesale market price, this phenomenon is known as merit order effect (Sensfuß, Ragwitz, & Genoese, 2008). With respect to wind generation, the effect seems to be consensual: wind power generation reduces the wholesale electricity market price (Cludius, Hermann, Chr, & Graichen, 2016).

The literature has found that the impact of intermittent renewable generation is more prevalent in European Countries due to their earlier deployment of renewables. In Italy, higher generation through intermittent renewables has decreased the wholesale price, but led to higher volatility (Clò, Cataldi, & Zoppoli, 2015). In Slovakia, evidence of the merit order effect was found with respect to photovoltaic energy (Janda, 2018), although its effect was small, because of the high share of nuclear power plants in Slovakia. In the preceding study the cost of supporting schemes was found to be greater than the savings obtained through solar generation. Other studies such as Luňáčková et al. (2017) found that photovoltaic generation does not reduce electricity prices but, due to subsidies, could actually increase wholesale electricity prices and the cost for consumers.

The merit order effect was also found in the largest electricity market in the world. The Midcontinent Independent System Operator (United States and Canada), where the negative effects of wind power on electricity price were also found (Quint & Dahlke, 2019). However, the merit order effect is not a feature of small electricity markets. In Australia, wind and solar photovoltaic generation decrease wholesale electricity prices, when studied using intraday and daily data (the results are similar in both frequencies) (Csereklyei, Qu, & Ancev, 2019). The merit order effect for Portugal and Spain has already been analysed in the literature (Figueiredo & Silva, 2019). The author found evidence for the merit order in both intermittent generation sources: wind power and solar photovoltaic.

The previously mentioned studies have quantified the decrease in electricity prices due to intermittent generation with low marginal costs, but the inverse relationship has not been analysed. This study aims to fill this gap, by discovering whether there is a bidirectional effect between electricity wholesale prices and electricity generation sources.

4.3 Data and Method

In order to achieve the objectives previously defined and, in particular, to assess the interaction between electricity sources and the impact of these interactions on the price of electricity, the variables used, for each country, were: (i) electricity generation by source; (ii) the market price for each country; and (iii) net exports of electricity. As the chapter intends to compare the characteristics of the two countries comprising the MIBEL, the Spanish and Portuguese electricity systems were analysed separately.

Management of the electricity system, in particular, the composition of the mix, operates in real time. As such, in order to accurately assess those dynamics, a daily[6] frequency was used, for the period covering 2 July 2007 (when the Iberian market started operating) to 30 March 2018 (according to the data available at April 2018). The analysis focused on the workweek, i.e. from Monday to Friday, and comprised of 2805 observations. The database came from the Transmission System Operators (TSO) of each country, namely REN (Redes Energéticas Nacionais), and REE (Red Eléctrica de España), for Portugal and Spain, respectively. The sources of electricity generation considered were hydropower, coal, wind power, solar photovoltaic and nuclear plants (only for Spain). All of these variables are in MWh.

As this study is focused on the interaction between electricity generation sources and the electricity market, we used information about: (i) intermittent renewable energy sources (*RES-I*) that includes solar photovoltaic and wind power; (ii) electricity generated by conventional sources (*CONV*), i.e. coal and pumped[7] storage (run of the river was not included), in the Spanish case, electricity generated by nuclear plants was also considered; (iii) net exports of electricity, i.e. electricity exports minus electricity imports (*SXM*); and (iv) daily price (*LPRICE*), which is the natural logarithm of the arithmetical average price for each country. It should be noted that the price variable was extracted directly from the database of MIBELs' electricity market operator (OMIE), and the units are EUR/MWh. The market price for both electricity systems overlapped most of the time. This means that capacity was available via the interconnections most of the time, and the price only differed when the interconnections were fully occupied. This was the market-splitting phenomenon. The *SXM* components, in MWh, were extracted from the OMIE's Market Results section.

Electricity generated by *CONV* can play a double role in the management of the system, by backing-up renewables (large hydro) and providing a base load (coal). Hydropower allows the storage of water to generate electricity at a future time. Unlike fossil sources, it does not increase greenhouse gas emissions. Nuclear plants are the least flexible energy source, due to their inability to quickly increase the electricity they generate. As such, they have an absolute base-load role within the electricity system, are always in continuous generation,

[6]It is worthwhile to note that the smallest available frequency is 10 minutes in Spain and 15 minutes in Portugal. In order to obtain unbiased result, because of excessive white noise, the data were converted to a daily frequency.

[7] In the Spanish case, data on the electricity generated by water reservoirs and pumping consumption is only available separately on a monthly frequency. At a higher frequency, only the balance between electricity generated and pumping consumption is available. Using a linear interpolation, the pumping consumption was estimated to subsequently calculate the absolute value of the electricity generated by hydro as daily data.

and have dispatch priority. When the market price is low, one of the national electricity systems can import surplus electricity from the other, preventing a network bottleneck. Thus, the energy traded in the Iberian market depends primarily on the capacity of interconnections (availability), but also on the market price and electricity demand in real time.

There are several ways to deal with seasonality in the electricity data, namely the insertion of seasonal dummy variables and the use of a seasonality functions, such as sinusoidal functions. Another way to obtain de-seasonalized series consists of decomposing the time series into seasonal and trend components. A time series analysis of seasonal trend decomposition using the Loess (STL) method was developed by Robert B Cleveland, William S. Cleveland, Jean E. McRae, & Irma Terpenning (1990). In contrast to the well-known Census X11 and X-13 ARIMA-SEATS, STL decomposition can be applied to any data. STL decomposition consists of decomposing the time series into seasonal, trend and remainder components. The adjusted series was obtained by subtracting the seasonal component from the original series. The results for the STL decomposition are shown in Figure 4.1 for the Spanish case and in Figure 4.2 for the Portuguese case. This adjusted series was used in the next steps.

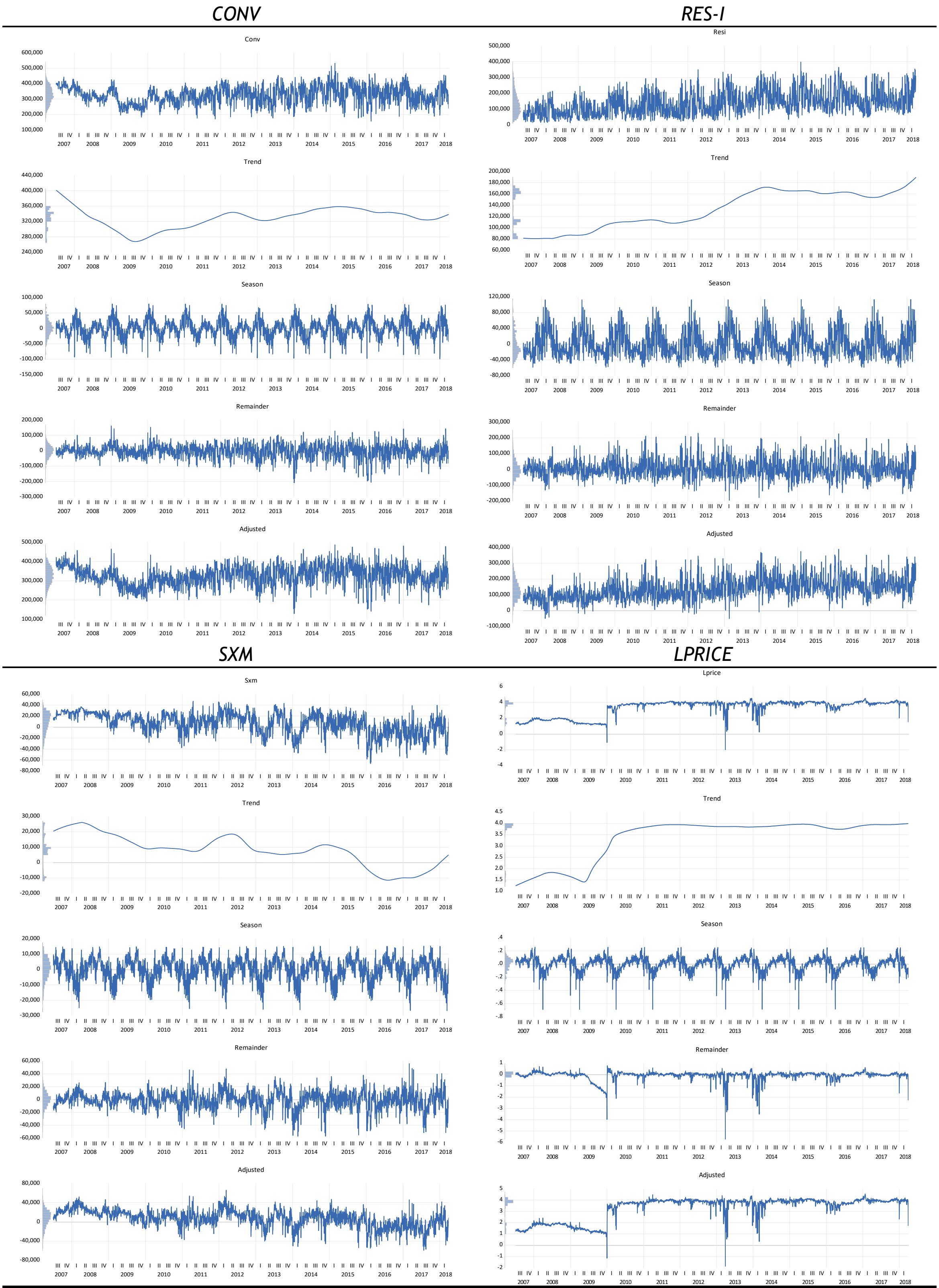

Figure 4.1 - STL Decomposition for Spain

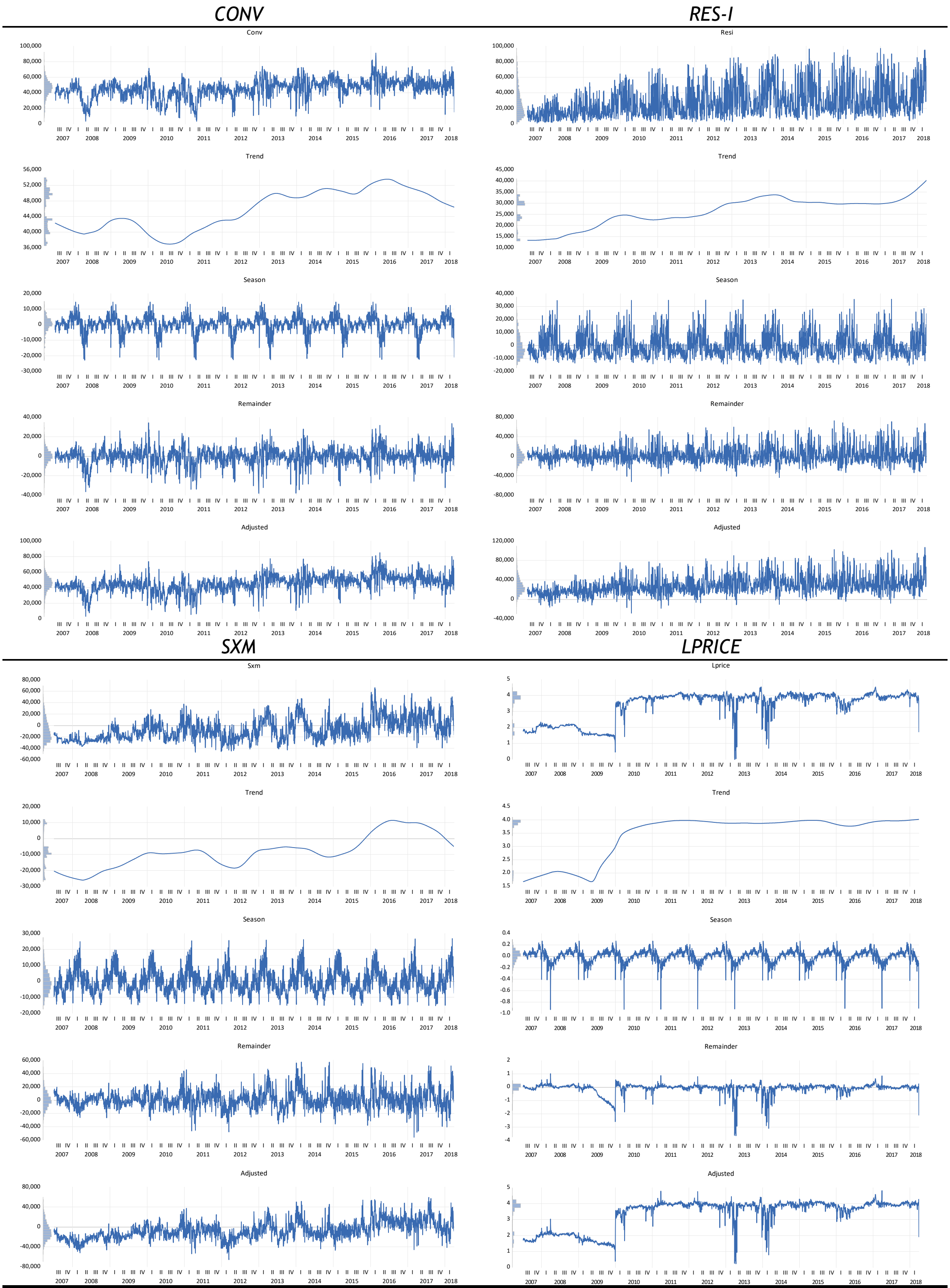

Figure 4.2 - STL Decomposition for Portugal

In order to avoid biased results due to the presence of potential outliers, these were controlled by observing the Interquartile Range (IQR) in the boxplot. In Figure 4.3, the boxplots are presented, and data outside the range of the power and upper limit was trunked.

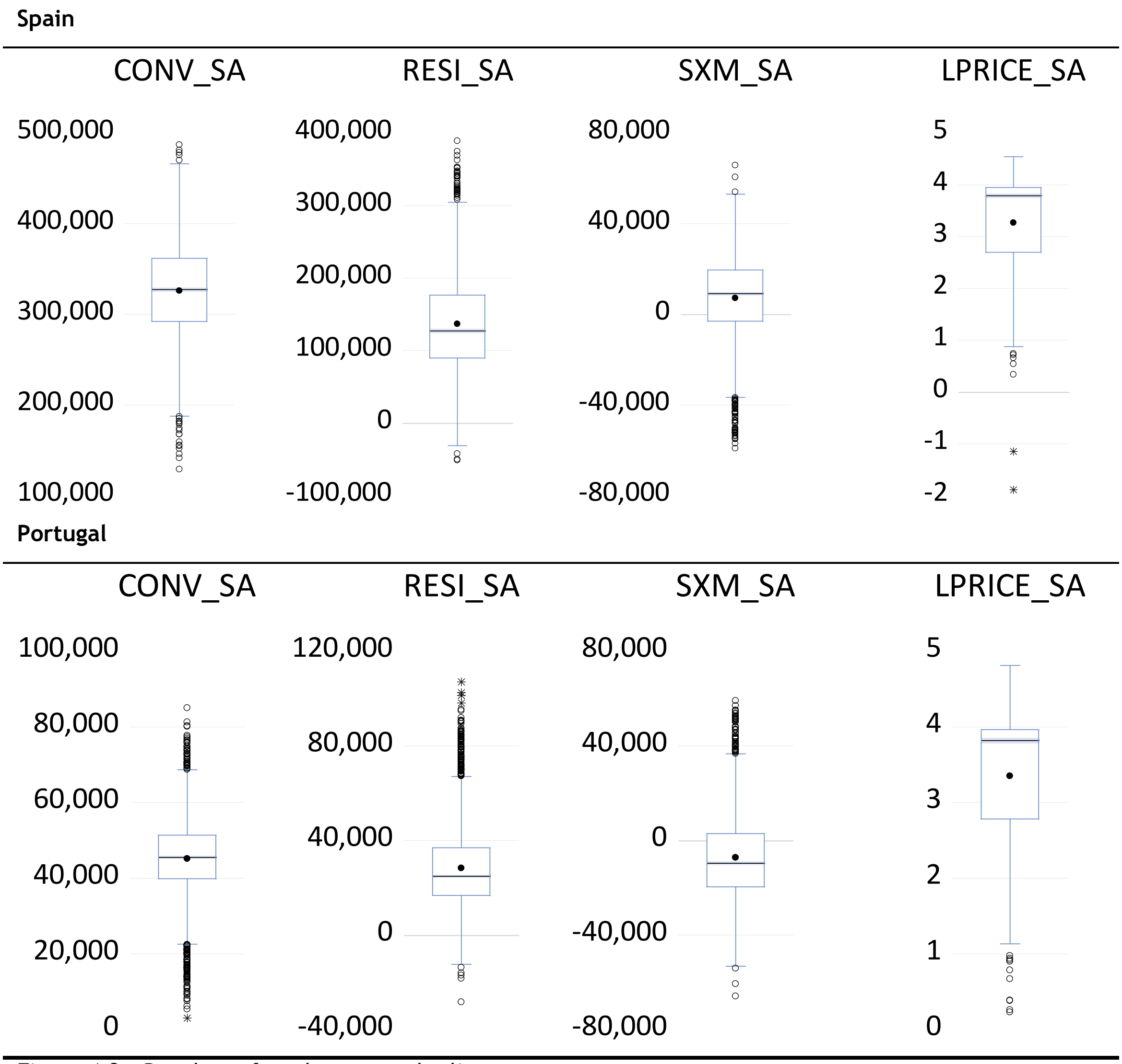

Figure 4.3 - Boxplots after the seasonal adjustment

The descriptive statistics of the variables, after seasonal adjustment and outlier correction can be seen in Table 4.1. The normality test was also displayed. The null hypothesis of the Jarque-Bera test is the normal distribution of the variables. The null hypothesis was rejected for all variables in all countries. The kurtosis values are high, that is, the series are leptocurtic.

Table 4.1 - Descriptive statistics

	Spain			
	CONV	*RESI*	*SXM*	*LPRICE*
Mean	326153.00	136385.60	7361.34	3.27
Median	327846.70	127878.60	9391.68	3.80
Maximum	466623.10	306649.80	53406.72	4.55
Minimum	187658.00	-40077.56	-36762.06	0.83
Std. Dev.	50630.09	64596.61	17395.03	1.02
Skewness	-0.18	0.46	-0.43	-1.13
Kurtosis	2.84	2.99	2.96	2.55
Jarque-Bera	18.99	100.48	87.18	617.77
Probability	0.000075	0.00	0.00	0.00
	Portugal			
	CONV	*RESI*	*SXM*	*LPRICE*
Mean	45322.49	27883.09	-7361.34	3.35
Median	45689.33	25070.07	-9391.68	3.83
Maximum	68725.62	67131.62	36762.06	4.81
Minimum	22650.21	-13413.86	-53406.72	1.02
Std. Dev.	9708.59	16245.13	17395.03	0.92
Skewness	-0.18	0.57	0.43	-1.11
Kurtosis	3.17	3.06	2.96	2.55
Jarque-Bera	19.28	153.90	87.18	595.44
Probability	0.00	0.00	0.00	0.00

Continuing with the data analysis, subsection 4.3.1 describes how the stationary properties of the variables were analysed in order to find the most suitable models for accomplishing the objective of this study. In subsection 4.3.2, the assumptions of the vector autoregressive model are shown, as well as the specification model.

4.3.1 Unit root tests

There are two different points of view regarding the data frequency for integration tests. The frequency can be important to evaluate the stationarity of the series (Otero & Smith, 2000), and frequency data can affect the integration order (Zhou, 2001). Following the most recent literature (Csereklyei et al., 2019; Figueiredo & Silva, 2019), unit root tests based on autoregressions were applied.

To check the stationary properties of the series, traditional unit root tests were performed, namely the ADF (Augmented Dickey Fuller) test, as well as the PP (Philips Perron) test. Results can be seen in Table 4.2. The null hypothesis for both the ADF and PP tests on the series had a unit root, thus the variable was non-stationary. The two tests pointed in the same direction. The null hypothesis was rejected at a statistically significant level of 1% for practically all variables. The exception was rejected at a statistically significant level of 5% (see Table 4.2). The results thus supported the stationarity of the variables in levels, in both tests, so all series were I(0).

Table 4.2 - Unit root tests

	ADF		PP	
Variables	CT	C	CT	C
Spain				
CONV	-4.781588***	-4.604016***	-29.74209***	-29.57797***
RES-I	-21.79461***	-12.13546***	-30.68999***	-33.37377***
SXM	-9.910417***	-7.741062***	-33.79116***	-28.03276***
LPRICE	-3.416046***	-2.910281**	-6.821407***	-4.430039***
Portugal				
CONV	-12.79930***	-9.470920***	-36.62791***	-34.07476***
RES-I	-31.69533**	-13.54086***	-33.33834***	-37.11663***
SXM	-9.910417***	-7.741062***	-33.79116***	-28.03276***
LPRICE	-4.111598***	-3.299129**	-7.137697***	-4.470606***

Notes: CT stands for constant and trend; C stands for constant; *** and ** represents a statistical significance level of 1% and 5%, respectively.

4.3.2 VAR model

Having verified that the variables were I(0), the VAR (Vector Autoregressive) model was estimated with the variables in levels. The adjustment speed of the variables within the electricity system was expected to be fast. VAR/VECM models are widely used in empirical energy economics studies (Bloch, Rafiq, & Salim, 2015; Kim & Thompson, 2014; Shahbaz, Zeshan, & Afza, 2012). This method is particularly suitable when the variables are simultaneously explained and explanatory. This model can be specified as follows:

$$X_t = \sum_{1=1}^{k} \Gamma_i X_t - i + CD_t + \varepsilon_t \tag{4.1}$$

where k is the number of lags Γ_i and C are the coefficient matrices of endogenous variables; ε_t denotes the residuals, X_t = [endogenous variables] and D_t = [constant].

The path of the empirical study was as follows. The first step was to analyse the optimal lag length. After this, the residual diagnostics tests were computed. In the third step, the Granger causality/Block Exogeneity Wald test was performed to examine the endogeneity of the variables. The forecast error variance decomposition revealed how a variable responds to shocks in specific variables. In turn, the Impulse Response Functions (IRF) allowed the behaviour of the variables to be observed, assuming the existence of an impulse in one variable. Overall, this path is the guideline for the next section.

4.4 Results

The lag order selection procedures for both the Spanish and the Portuguese electricity systems were performed. For Portugal, the Schwartz information criterion (SIC), and the Hannan-Quinn information criterion (HQ) suggested the number of lags being 5, and the Akaike Information Criterion (AIC) suggested an optimal lag of 7. Following good econometric practice, 5 and 7 were tested, and the results remained identical. Therefore, five lags were chosen according to the most restricted criterion. For Spain, the SIC, HQ, pointed to 6 lags and AIC pointed to 7. As the data is daily, and considers the workweek (Monday-Friday), i.e. 5 days per week, the optimal lag length was chosen for both models, and was 5 lags. Whichever criterion was used, the results for the diagnostics tests remained unchanged.

Two VAR models were estimated, one for Spain and one for Portugal. Then, estimation, residual diagnostic tests were made for both models. The autocorrelation Lagrange Multiplier test had the null hypothesis of no serial correlation. The null hypothesis for the White test (no cross terms) was homoscedasticity. The Jarque-Bera normality test had the null hypothesis of error terms following a normal distribution. For all these tests the null was rejected at a statistically significant level of 1%, which means that the residuals of the estimated models had autocorrelation, heteroscedasticity and did not follow a normal distribution. The residuals diagnostic results were in line with other studies (Menezes & Houllier, 2015). Considering the high frequency of data (daily), this outcome does not pose a significant problem (e.g. Lumley, Diehr, Emerson, & Chen, 2002). Indeed, the series did not follow a normal distribution due to the high value of kurtosis, i.e. the distribution is leptokurtic. Taking into account these preliminary results, the Granger causality was performed, and the results can be seen in Table 4.3.

The Granger Causality/Block Exogeneity results suggested that the variables must be considered as endogenous variables, which reinforce the appropriateness of using VAR modelling to understand the relationships between generation sources and the Iberian electricity market.

Regarding Spain, Table 4.3 reveals the high endogeneity between variables. In short, the causalities are: *CONV↔RES*-I; *CONV↔SXM; CONV←LPRICE; RES-I↔SXM; SXM←LPRICE;* and

LPRICE→RES-I. Focusing on Portugal, the causalities found are: *CONV↔RES-I; CONV↔LPRICE; CONV←SXM; RES-I↔LPRICE;* and *RES-I↔SXM*.

Table 4.3 - Granger causality test/Block Exogeneity Wald Tests – Spain and Portugal

Spain				
	Dependent Variable			
	CONV	*RES-I*	*SXM*	*LPRICE*
CONV does not cause		13.31968***	14.61526**	6.537358
RES-I does not cause	227.0548***		15.84230***	6.487275
SXM does not cause	37.62211***	47.56584***		5.121093
LPRICE does not cause	45.78069***	42.05374***	10.17345*	
All	289.3082***	128.3547***	34.64295***	21.90866*
Portugal				
	Dependent Variable			
	CONV	*RES-I*	*SXM*	*LPRICE*
CONV does not cause		14.46798**	5.789855	16.91381***
RES-I does not cause	68.69278***		10.56912*	13.30634**
SXM does not cause	18.68197***	152.5584***		2.664926
LPRICE does not cause	29.38388***	38.56805***	5.735190	
All	155.8649***	271.4654***	28.31397**	50.52439***

Notes: the results are based on Chi squared statistics. ***, ** and * represents statistically significant level for 1%, 5% and 10%, respectively.

In Spain, conventional sources had no effect on market prices. Intermittent generation was also unable to affect market prices, even with the low associated marginal costs. In Portugal, net exports only affected electricity generated by wind power and solar photovoltaic at a 10% statistically significant level. The availability of these resources cannot be controlled. Inversely, renewables could affect market prices, but only at a 5% statistically significant level. The major difference between the two countries is their differing capacity to induce exports through electricity generation and market prices, which occurred in Spain, but not in Portugal.

The variance decomposition and the Impulse Response Functions (IRFs) were performed taking into account the usual Cholesky order, i.e. placing the variables in decreasing order of exogeneity. Nonetheless, whichever order was chosen, the overall results remained unchanged. The variance decomposition for Spain and Portugal is shown in Table 4.4 and Table 4.5, respectively.

Table 4.4 - Variance decomposition for Spain

Variance Decomposition of *CONV*:					
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	32974.55	54.4493	45.2564	0.2921	0.0022
5	38795.66	53.2052	44.4104	0.6884	1.6960
10	42971.71	60.0846	36.3472	1.9012	1.6671
30	48140.22	65.8843	29.5196	3.1391	1.4571
Variance Decomposition of *RES-I*:					
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	49432.55	0	99.7950	0.16210	0.0429
5	62218.80	0.1639	96.3345	1.80556	1.6961
10	64588.66	0.5627	93.1608	4.58670	1.6898
30	67582.41	2.0371	86.3531	9.1723	2.4374
Variance Decomposition of *SXM*:					
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	10260.93	0.0000	0.0000	99.9245	0.0755
5	12585.96	0.3270	0.0915	99.3480	0.2335
10	14465.93	0.4256	0.3337	99.0259	0.2147
30	16551.78	0.4318	0.6778	98.2926	0.5978
Variance Decomposition of *LPRICE*:					
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	0.229219	0.0000	0.0000	0.0000	100.0000
5	0.324253	0.0701	0.0285	0.0739	99.8275
10	0.405048	0.0696	0.2675	0.2688	99.3941
30	0.590744	0.1571	0.8470	2.0166	96.9793

Note: Cholesky Ordering: *LPRICE SXM RES-I CONV*.

Regarding the variance decomposition of *CONV*, after 30 periods, it explained around 66 % of the forecast error variance by itself, with 29.52 % being due to *RES-I*. This occurred because, in Spain, *CONV* includes electricity generated by hydroelectricity and nuclear plants, i.e. uninterruptable generation. Electricity generated by water has a backup role in the system, and a baseload role in periods of abundant precipitation. Like gas turbines, hydropower is a flexible source. Intermittency is not a problem, as there is no shortage of water in the reservoirs so, even with *RES-I*, the system can maintain the renewable share, by using large amounts of hydropower.

With regard to *RES-I*, after one period, the forecast error variance is explained 99% by itself. After 30 periods, around 9% of the forecast error variance is explained by the *SXM*, due to the interaction with the Portuguese electricity generation system, and only around 2% is explained by *CONV*. Conventional sources have a backup role due to hydroelectricity, but the backup for intermittent generation seems to be achieved by the market.

After 30 periods, shocks in *CONV* explain around 0.43% of the forecast error variance of the *SXM*. Meanwhile, *RES-I* explain about 0.67%. Spain usually exports by using electricity generated by *RES-I* and nuclear plants. Excess electricity generated by nuclear plants can provoke electricity exports. The nuclear power plants are the least flexible generation source and also have dispatch priority. Because their generation is continuous, production is independent of other sources, but the other sources must take nuclear generation into account. Net exports are stimulated by intermittent generation due to low marginal costs and the availability of resources (sun and wind).

100% of the forecast of the error variance of *LPRICE*, is explained by itself after 1 period, in contrast to the result of the variance decomposition of *CONV*. The cost of *CONV* depends on the price of fossil raw materials and not on the market price of electricity. Only after 30 periods is 3.14% of the forecast error variance explained by *SXM*. Generation sources are incapable of influencing market prices.

In the estimated model for the Portuguese electricity system, *CONV* only includes electricity generated from coal and hydropower for obvious reasons, i.e. the absence of nuclear power in Portugal. The forecast error variance for Portugal is presented in Table 4.5. After one period, 68% of the forecast error variance for *CONV* is explained by itself, almost 17% by *RES-I*, and around 14% by the market price. After 10 periods, i.e. two workweeks, this result is divided, around 12% by *RES-I* and *LPRICE*. Only after 30 periods does *SXM* explain 12% of the *CONV*. The substitution effect between *CONV* and *RES-I* is noticeable after 1 period, although the effect is less representative than in the Spanish case. It should be noted that *CONV* has two different roles: providing a backup via hydroelectricity, and a base load through coal power stations. Because of its backup role, this outcome was expected.

Focusing on *RES-I*, after only one period, around 87% of the forecast error variance is explained by itself, and around 13% by *LPRICE*. As to net exports of electricity, even after 30 periods around 99% is explained by itself. Wind power and solar photovoltaic have a small impact on net exports of electricity. Compared with the Spanish electricity system, this result is VERY similar. After 30 periods, 99.9% of the forecast error variance of *LPRICE* is explained by itself.

Table 4.5 - Variance decomposition for Portugal

Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
Variance Decomposition of *CONV*:					
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	6490.02	68.1210	16.9542	0.0790	14.8458
5	7827.18	71.1835	12.9028	2.1575	13.7562
10	8521.54	72.1181	11.1199	4.7870	11.9750
30	9403.60	68.2167	9.6804	12.0124	10.0905
Variance Decomposition of *RES-I*:					
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	12779.99	0.0000	86.7797	0.3867	12.8337
5	14818.88	0.0211	79.1798	8.6415	12.1576
10	15099.06	0.6344	77.1495	10.3733	11.8428
30	15544.84	1.2365	73.0383	13.2373	12.4879
Variance Decomposition of *SXM*:					
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	10272.49	0.0000	0.0000	100.0000	0.0000
5	12523.41	0.1010	0.1521	99.6571	0.0898
10	14382.02	0.1392	0.2444	99.5367	0.0796
30	16486.67	0.5570	0.4043	98.6403	0.3984
Variance Decomposition of *LPRICE*:					
Day	S.E.	*CONV*	*RES-I*	*SXM*	*LPRICE*
1	0.209178	0.0000	0.0000	0.1257	99.8743
5	0.290652	0.0697	0.2352	0.1458	99.5493
10	0.355183	0.2491	1.0541	0.3017	98.3951
30	0.510967	0.9947	2.0178	1.5310	95.4564

Cholesky ordering for Portugal: *SXM LPRICE RES-I CONV.*

Figure. 4 represents the IRFs of the endogenous variables for both Spain and Portugal. Looking at Spain, in general, all variables converge to the equilibrium within one month and, as such, there is no long memory and the adjustment is fast. From the Figure, one can observe that *RES-I* has a positive response to shocks in *CONV*. *SXM* also has a positive impact, but of less intensity. The response of *LPRICE* to shocks in *CONV, RES-I* and *SXM* is very low. This result is in line with the variance decomposition outcomes. A one standard deviation shock in *LPRICE* decreases *RES-I*, but not *CONV*.

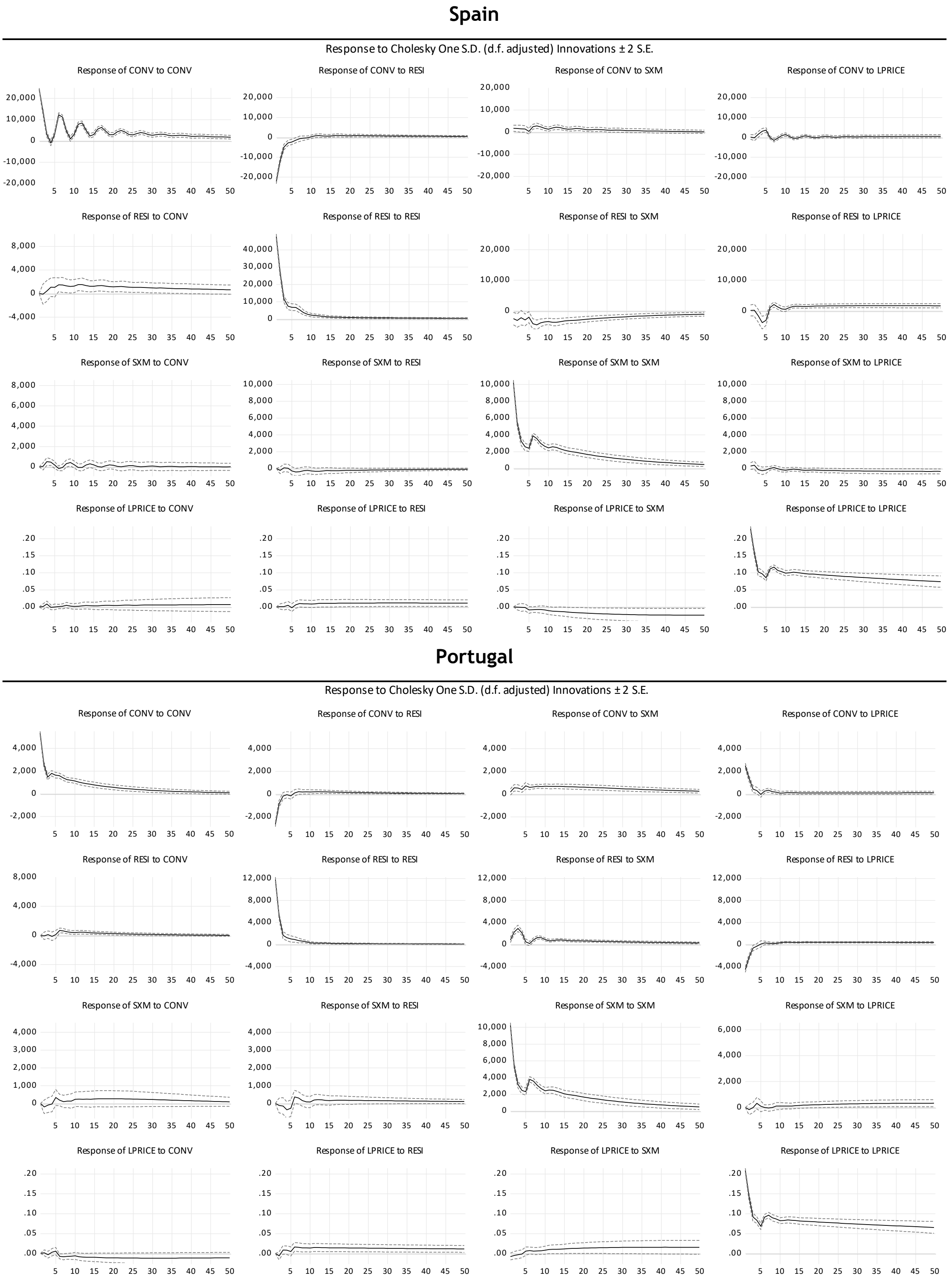

Figure 4.4 - Impulse responses functions

Note: The vertical axes of some graphs were rescaled in order to enhance observations of the results.

The response of *CONV* seemed to have a kind of sinusoidal effect in Spain. In order to assess the potential cause of this phenomenon, the models were re-estimated without considering the large nuclear baseload source. As suspected, this type of pattern was then removed but, more importantly, the results remain the same. All of this suggests that there is a weekend effect, that can be explained by the low flexibility of nuclear power plants, which are unable to quickly increase or decrease the amount of electricity generated. The response of *RES-I* to shocks in *SXM* is negative and similar to shocks on *CONV*. Electricity generated by *RES-I* is not constant, and depends on the availability of natural resources.

Looking at Portugal, in the second half of Figure 4.4, the IRFs of the VAR model of the Portuguese system are presented. In general, all variables converge to equilibrium within 50 periods at most, although with different adjustment speeds. A one standard deviation shock to *CONV* causes a positive response in *RES-I*, even with low intensity. *RES-I* has a negative response when a deviation shock is introduced in *LPRICE*. When *SXM* suffers a shock, intermittent sources have a positive response, similar to *CONV*, but with greater intensity. Electricity exports occur when there is surplus electricity generation by renewable sources. The impulse response of *CONV* to *RES-I* shows that a one standard deviation shock to *RES-I* tends to increase *CONV*. A substitution effect between *CONV* and *RES-I* can be observed, despite being weak. *RES-I* has dispatch priority, but intermittent generation, while *CONV* is always available.

4.5 Discussion

This chapter is focused on the analysis of the interactions between electricity generation sources, in two separate domestic electricity generation systems which must cooperate with each other. Both the Spanish and the Portuguese electricity systems were analysed and compared. The systems are managed in real time and, accordingly, high frequency data was used to ensure robustness in the estimations. The five weekdays (Monday to Friday) were chosen for two reasons: (i) most people consume electricity in their homes at the weekend, while industries operate during the week, so the consumption patterns are different in these two periods; and (ii) the need to reduce white noise from the series. Indeed, the procedure of only studying data from workdays, rather than the entire week, thus reducing it from 7 to 5 days per week, allowed the entire period to be examined, capturing economic cycles, while using a lower number of observations.

In general, the results for both Spain and Portugal are similar in terms of the interaction between electricity generation sources. Nonetheless, the difference between Spain and Portugal, in terms of system size is noticeable. Regarding the results of the interaction between electricity generation sources and the market (electricity exports and price), the findings appear to be dissimilar for the two generation systems. This result is in line with the findings of Ciarreta, Nasirov, & Silva (2016). Total electricity consumption in Spain is almost 6 times larger than in Portugal, and the size of the generation structure is quite different. The

Spanish system is able to share backup with the Portuguese system, while the inverse is less likely. The Portuguese power system faces a problem, of scale. To address this, the results of this study suggest that one possibility for the Iberian market would be auctions of shared backup, using flexible fossil generation sources, such as gas turbines and cogeneration. The Iberian market has the potential for greater adjustment, due to the difference between installed capacity in Portugal and Spain. This could be crucial not only to accommodate the renewables already installed, but also to enlarge the use of these generation sources.

When focusing on the markets, a comparison with the largest European electricity market (Nord Pool) is inevitable. The differences between the Iberian Market and Nord Pool Spot (NPS) are understandable. The Iberian Market is composed by two countries with similar electricity standards, while NPS is composed of more countries with different characteristics regarding electricity supply and demand, and a higher share of electricity consumption is transacted. The NPS consists of a larger number of countries than the Iberian Market. The NPS has access to other electricity markets, e.g. Netherlands and Germany. The members of NPS have distinct electricity mixes. For instance, Estonia’s main electricity generation source is oil shale, Denmark has a high share of off-shore wind farms, while Sweden intensively uses hydroelectricity and nuclear plants.

Ideally, countries forming an electricity market should have different supply and demand patterns to allow flexibility in the management of both a scarcity and surplus of electricity. Pricing policy measures can also shape electricity demand to introduce flexibility into the market. These incentives should lead consumers to increase or even reduce their electricity consumption according to the availability of RES. In the case of the Iberian market, the interconnections to other electricity markets are limited and restricted to the region. Access to other electricity markets could bring greater efficiency to the market through increased heterogeneity in the net load (total electricity demand minus the supply from renewables). With a more balanced electricity market, it would be possible to fully satisfy demand without increasing the installed capacity of generation sources, and surplus electricity could be exported.

4.6 Conclusion

This chapter examines the interaction of two power systems of different sizes, interacting in a small electricity market. The interactions between electricity generation sources and electricity wholesale price within the Portuguese and Spanish electricity generation systems were analysed separately to allow comparison, for a time span from 2 July 2007 to 30 March 2018. Daily frequency data was used, and the VAR approach was chosen, as it is highly robust in the presence of endogeneity among variables. Two VAR models were estimated, one each for the Portuguese and Spanish electricity systems in the Iberian Market. After this, variance decomposition and impulse response functions were carried out.

Despite the results being similar for the two systems with respect to the interaction between electricity sources, the interaction within the Iberian market as a whole was found to be quite different. The scale of the national electricity systems of the two countries is quite dissimilar. The two systems should play different roles in the Iberian market. The Spanish system is more able to accommodate shared backup capacity, due to its large generation structure. This measure could bring additional economic efficiency to the whole market.

The accommodation of renewables is more challenging and economically inefficient in small markets, such as the Iberian market. Ignoring their difference in scale, there are evident similarities between Portugal and Spain, such as geographical proximity, meteorological conditions and the availability of resources to generate electricity, excluding the nuclear plants in Spain. Consequently, the patterns of consumption are similar in these two countries. However, this study confirms that electricity markets benefit when the characteristics of their members are heterogeneous. Pricing policy measures could shape demand patterns to take greater advantage of the installed capacity of renewable energy. These differing patterns of supply and demand could then allow the electricity systems to better accommodate different kinds of generation sources. This implies that the Iberian market needs to be more open to interact with different countries. This openness could also be extremely useful for dealing with the new challenges facing power systems, such the accommodation of small-scale generation for self-consumption.

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Chapter 5

Determinants of the energy transition: Empirical evidence for OECD countries

An energy transition is currently occurring globally as a response to accomplishing the objectives laid out by international agreements. Since the Kyoto Protocol, countries have increased their share of renewable energy by replacing fossil fuel sources with alternatives. The role of nuclear energy in any energy transition should also be deliberated. Considering different types of energy transition, this chapter analyses the determinants of Low Carbon Energy transition and Clean Energy transition. The sample comprises two panels composed of OECD countries, for the time span from 1971 to 2016. After applying a battery of tests, the most suitable estimators are the PCSE and FGLS. There is still a long way to go regarding energy transition, namely in the concept of transition. A genuine transition will only begin by decreasing the use of fossil fuels. The development of renewable energies has been used to satisfy the increased demand for energy. Energy efficiency measures are necessary to accelerate a Low Carbon Energy transition. It is vital to discipline energy demand. The results prove that openness can drive an energy transition; countries must share technologies to accelerate the transition process, in both Low Carbon and Clean Energy transitions.

5.1 Introduction

Throughout history, the energy mix has experienced some changes. One of the first energy transition phenomena in history was the transition from wood to coal. More recently, with the electrification of various sectors, together with environmental concerns, a transition from fossil sources to renewables can be observed in several countries around the world. The transition concept is widely used to explain the requirement to change from an existing state to a healthier scenario. Lately, countries have started to consider broader environmental concerns when defining economic policies to achieve sustainable development. In this context, different terminologies of energy transition can be found in the literature, examples such as sustainable energy transition (Lange, O'Hagan, Devoy, Le Tissier, & Cummins, 2018), low carbon energy transition (Geels, Berkhout, & Van Vuuren, 2016) and green energy transition (Nilsson & Nykvistt, 2016). Often the concept of transition is confused (unintentionally) with the concept of addition (York & Bell, 2019). Thus, the increase in the installed capacity of renewables does not necessarily mean a transition. An energy transition is only verified when contemplating the substitution of generation sources in the energy mix.

In this framework, two concepts of energy transition were analysed: Clean Energy transition and Low Carbon transition. The first type is associated with the necessity of replacing conventional sources with renewable energy ones, while Low Carbon Energy transition is associated with the transition from conventional to clean energies (renewables and nuclear power). This study is composed of 25 Organisation for Economic Co-operation and Development (OECD) countries covering 46 years. These countries were chosen to cover the largest number of countries for the longest possible time span. Energy transition is a fundamental requirement to accomplish the objectives of international agreements, or even to meet ambitious national environmental targets. The determinants of the deployment of renewable energies are already well documented in the literature, contrary to that available for energy transition drivers. This chapter seeks to fill this gap in the literature. The research question of this chapter is: what can drive energy transition? Energy transition may not require the same efforts for all countries; it depends on the level of renewables share when the transition was started. The share of renewables in the energy mix could be determined by favourable geographical characteristics or by international impositions.

It is vital to take into consideration the role of nuclear plants in an energy transition. Since this type of investment is made in a long-term perspective, and to accommodate this issue, the sample was separated into nuclear producers and non-nuclear producers. In the first sample, the determinants of a Low Carbon energy transition were analysed, while in the second one, a Clean Energy transition is the focus. In fact, some countries have plans to shut down their nuclear plants, while other countries already have this strategy in progress (Gralla, Abson, Møller, Lang, & von Wehrden, 2017). In fact, countries with nuclear plants are faced with two types of different concepts of their energy transition. The question that arises for these countries is: decarbonisation or clean energy?

Panel stationary techniques were used to examine the determinants of energy transition. PCSE and FGLS estimators were applied to deal with heteroskedasticity and cross-section dependence. The results show that energy efficiency and trade openness are the main drivers in both Clean and Low Carbon Energy transitions. Energy security is constraining Low Carbon Energy transition.

The rest of this chapter is planned as follows. In Section 5.2, a brief literature review is presented; in Section 5.3, the econometrics process is exposed; in Section 5.4, the data collected is described; in Section 5.5, the results of the cointegration analysis and specification tests are shown; in Section 5.6, the results of the estimators are presented; in

Section 5.7 a discussion of the results is given; and finally, Section 5.8, presents the conclusion of this study.

5.2 Literature Review

The analysis of the determinants of renewable energy is already present in the recent literature (Papież, Śmiech, & Frodyma, 2018; Silva, Cerqueira, & Ogbe, 2018; Damette & Marques, 2019). The authors use various measures to quantify the share of renewable energies in the energy mix. Some of the most commonly used measures are the growth rate of the share of renewables in the electricity mix (Silva et al., 2018); the share of renewables in total energy production (Damette & Marques, 2019); and per capita supply of renewable energy (Gan & Smith, 2011). Authors have found that different factors can affect the deployment of renewable energies, such as political, economic, energy security and environmental factors. The results depend on the characteristics of the sample examined and the methods used.

Economic factors, such GDP, contribute positively to the deployment of renewable energies (Damette & Marques, 2019), but the opposite has also been found; the negative impact of GDP on the increase of renewables (Romano, Scandurra, Carfora, & Fodor, 2017). This negative impact could be justified by the fact that countries are not guiding wealth in favour of renewables but in favour of other economic activities. Carbon dioxide emissions seem to be a supporter of the deployment of renewables (Aguirre & Ibikunle, 2014; Romano et al., 2017). The effect of energy import dependency also seems to be common to most studies (Aguirre & Ibikunle, 2014; Romano et al., 2017); this factor constrains the growth of renewables.

Usually, an energy transition is measured by the renewable share in the energy mix. Other measures of energy transitions are presented in Singh, Bocca, Gomez, Dahlke, & Bazilian, (2019), and even the World Economic Forum has developed its own indicator that takes into account the various dimensions of energy transition. These complex indicators could not be applied for a large sample of countries and time span, due to their complexity and, in addition, data availability.

The energy transition phenomenon has been studied by proposing different scenarios in the future (Child, Koskinen, Linnanen, & Breyer, 2018; Vaillancourt, Bahn, & Levasseur, 2019) and from a socio-technical approach (Bolwig et al., 2019). In these studies, the authors sought to provide the implications of an energy transition in the future and what objectives can be achieved. These analyses are made for case studies with a high level of detail, and sometimes it is difficult to extrapolate the findings to other cases.

Considering the various types of energy transition, it is essential to clarify the role of nuclear energy in a transition. In terms of nuclear strategy (Gralla et al., 2017), it is possible to group countries into nuclear producers, non-nuclear producers, phase-out countries and countries that have plans to produce. In fact, countries are faced with a trade-off, and there are some factors that influence the decision to produce or not, namely energy independence and long-term investment. Contrary to wind power and solar photovoltaic, nuclear energy can bring stability to the electricity system, due to its generation predictability and low carbon emissions. Consequently, some countries have concentrated efforts in the development of nuclear technologies (Bointner, 2014). Nuclear plants can bring security issues, and nuclear waste has a long life cycle. Some country´s governments have already implemented nuclear phase-out programs due to the public perception of this energy source (Chung & Kim, 2018). These decisions are important in an energy transition definition.

A Clean Energy transition to 100% renewable generation brings some challenges in terms of system flexibility (Child, Kemfert, Bogdanov, & Breyer, 2019). To achieve this ambitious goal, it is necessary to go through several states of transition (Connolly & Mathiesen, 2014). Any energy transition depends on several factors that will be investigated in the next sections of this study. A change in the energy sector is required, but the issue is related to how renewable energies can replace fossil fuels, without compromising the energy supply, and considering some investments already made.

5.3 Method - panel stationary techniques

The estimation process that accomplishes the goal of this study, and evaluates the effects of each energy transition driver, employs a set of models and tests. The first model is the linear panel data model, with a common constant for all countries (pooled regression). Pooled regression is represented in Equation (5.1).

$$Y_{it} = \alpha + \sum_{K=1}^{j} \beta_k X_{it} + \varepsilon_{it} \tag{5.1}$$

Where Y represents the dependent variable, X represents a set of independent variables, α is the constant, j is the number of independent variables (energy transition drivers), ε is the error term, t is the time period and i is the section. The model was applied separately in each energy transition approach. Following with the econometric procedure, the random effect model was estimated and is represented in the following Equation (5.2):

$$Y_{it} = (\alpha + v_i) + \sum_{K=1}^{j} \beta_k X_{it} + \varepsilon_{it} \tag{5.2}$$

where v is the random parameter. This random component brings variability in the constant for each section, as that the constant is $\alpha + v_i$. The Hausman test was performed to assess the most suitable estimator between the random effects model and the fixed effects model, under the null hypothesis that the difference in coefficients is not systematic, i.e., the suitability of the random effects estimator.

Considering that the panels comprised OECD countries, common shocks are expected, such as financial crises, geographic proximity, and common policies. The CD-test developed by Pesaran (2004) was applied to investigate the presence of cross-section dependence in each variable.

Verifying the presence of cross section dependence, the first-generation panel unit root test is no longer robust enough to evaluate the stationary properties of the variables. So, a second-generation unit root test was applied. The CIPS (Cross section Im-Pesaran-Shin) test proposed by Pesaran (2007), and the Breitung test (2005) were computed to verify the integration order of the variables. The CIPS test is based on a Dickey-Fuller regression (2003) with a single unobserved common factor under the null hypothesis of non-stationarity. The Breitung test considers that each panel has a specific autoregressive parameter and the t-statistic is robust to cross-sectional correlation. The null hypothesis is that all panel have a unit root, while the alternative hypothesis points to the stationarity of the series.

Seeing the results of the second-generation unit root test, and the time span of 46 years, the existence of a long-run relationship between the explained variable and the explanatory variables is observed. The Westerlund (2007) cointegration test provided statistics for the absence of cointegration in the presence of cross-section dependence. With this test, the alternative hypothesis could be specified in two ways; cointegration in some panels, and cointegration in all panels. Considering the existence of common unobserved factors, the Westerlund & Edgeron (2007) cointegration test with bootstrap that obtains robust p-values is used.

Continuing with the estimation process to choose the most appropriate estimator, the specification test was performed. The Lagrange-Multiplier test for serial correlation was applied to test the presence of the first-order autocorrelation in the panels, with the null of no serial correlation. The homoscedasticity is tested using a modified Wald test; this test could be applied in a fixed-effects model and generalised least squares (GLS) model. Due to the sample characteristics with a large T (years) and a small N (countries), the cross-sectional correlation in the residuals could be problematic in the results of the estimated models. To explore this phenomenon, two tests were computed based on the residuals. The CD-test allows the application in the residuals of the fixed and random effects regression, and the Breusch-Pagan LM test allows the application in the residuals of the fixed effect and GLS estimations.

Considering the specification test, two estimators might be applied: Panel-Corrected Standard Errors (PCSE), and Feasible Generalized Least Squares (FGLS) due to the small n (cross-section) and large T (time periods). Both estimators are robust in the presence of heteroskedasticity and cross-section dependence, or even in the presence of serial correlation in all panels or within panels. Alternative estimators were used to ensure the robustness of the estimations.

5.4 Sample and description of the energy transition drivers

The sample includes OECD countries. This group of counties was considered since they share economic policies, including energy policy measures. To obtain a balanced panel, only 25 OECD countries from 1971 to 2016 were considered due to the lack of data. To accomplish the objective of this chapter in analysing the determinants of a Low Carbon Energy transition and a Clean Energy transition, two panels were built. Despite the separation of the sample, there are enough observations to estimate the econometric models due to the long-time span.

The first panel is composed of 13 nuclear producer countries. The countries are Belgium, Canada, Finland, France, Germany, Italy, Japan, Mexico, The Netherlands, Spain, Sweden, The United Kingdom and The United States. Italy shut down all nuclear generation in the 1990s. Germany and Belgium have phase-out plans in progress. The second panel comprises 12 non-nuclear producer OECD countries: Australia, Austria, Chile, Denmark, Greece, Ireland, Israel, Luxembourg, New Zealand, Norway, Portugal, and Turkey. Currently, none of these countries have plans to start production from nuclear power.

To understand what drives Low Carbon and Clean Energy transitions, two ratios were computed. The ratios cover only sources of electricity due to the expansion of electrification in the economic sectors, such as the transportation sectors. On the one hand, to measure a Low Carbon Energy transition, a ratio between electricity generation by renewable energy sources combined with nuclear power, divided by fossil sources, was calculated and used as a dependent variable in the estimated models. On the other hand, a ratio between renewable energy sources and fossil sources was computed to assess the Clean Energy transition determinants.

A set of ratios was calculated to test what drives an energy transition. To compute the ratios, a dataset was collected from official databases: WDI, EDGAR and IEA. The variables, the definitions, units, and the sources are presented in Table 5.1. Gross domestic product and gross fixed capital formation are in millions to avoid scale problems with the estimated coefficients.

Table 5.1 - Definition of collected data and source

Variables	Definition	Units	Source
RES	Renewable energy sources include electricity generated by hydro, geothermal, solar, wind, waves, biofuels, and renewable waste	GWh	IEA
FOSSIL	Fossil fuels include electricity generated by coal, peat, oil shale, oil, and natural gas	GWh	IEA
NUC	Nuclear includes electricity generated by nuclear power plants	GWh	IEA
EM	Energy imports include imports of coal, oil, natural gas, and electricity	ktoe	IEA
TPES	Total primary energy supply according to the source is calculated as follows: production + imports – exports – international marine bunkers – international aviation bunkers +/- stock changes	ktoe	IEA
CO_2	Carbon dioxide emissions of all sectors during a year	units	EDGAR
GDP	Gross Domestic Product (in millions)	constant 2010 US$	WDI
EC	Energy consumption is the sum of the consumption in the end-use sectors.	ktoe	IEA
TRADE	Trade openness is the sum of exports and imports as a share of GDP.	%GDP	WDI
GFCF	Gross Fixed Capital Formation (in millions)	constant 2010 US$	WDI
POP	Total population	Number of people	WDI

Note: IEA stands for International Energy Agency; EDGAR stands for Emission Database for Global Atmospheric Research; and WDI stands for World Development Indicators. All variables are in logarithms and were differentiated once.

The included variables are chosen by analysing the existent literature about renewable energy and energy transition. The calculation is as follows:

CET - Clean Energy transition: a ratio between electricity generated by renewable energies and electricity generated by fossil fuels;

LCET - Low Carbon Energy transition: the sum of electricity generated by renewables and nuclear plants was divided by the electricity generated by fossil fuels;

ES - Energy Security: is the ratio between energy imports and the total primary energy supply. Higher values of the ratio mean more dependence on energy imports;

CO2GDP – carbon intensity of the economy is given by the ration between dioxide carbon emission and GDP. More carbon intensity means that the country is moving in the opposite direction of the environmental objectives;

CO2INT - Carbon intensity of energy consumption is the ratio between CO_2 emissions and total final consumption. This gives a global picture of the energy mix in all sectors;

EEF - Energy Efficiency of the economy: the ratio between Gross Domestic Product and Total Final Consumption. Higher values mean fewer energy units to generate wellness;

TRADE - Trade Openness: is the sum of the imports and exports related to Gross Domestics Product. This variable is used as a proxy of globalization and the technology transfers;

GFCFPC - Gross Fixed Capital Formation per capita: is the Gross fixed capital formation divided by the total population.

The determinants of the Clean Energy transition are shown in the Equation (5.3).

$$CET = f\ (ES, CO2GDP, CO2INT, EEF, TRADE, GFCFPC) \quad (5.3)$$

The drivers of the Low Carbon Energy transition will be given as a function of the LCET variable, as can be seen in the Equation (5.4).

$$LCET = f\ (ES, CO2GDP, CO2INT, EEF, TRADE, GFCFPC) \quad (5.4)$$

All variables are in natural logarithms to avoid scale problems with the coefficients and to make the relationships linear between variables.

5.5. Cointegration and specification tests

In this section, variables tests are presented as well as model specification tests. The Variance Inflation Factors (VIF) test is computed in both Equation (5.3) and Equation (5.4) to ensure that there are no exact linear relationships between independent variables. The results prove the absence of multicollinearity in both Clean and Low Carbon Energy transition, the mean VIF is 3.31 and 3.96, respectively.

To investigate the presence of cross section dependence, the phenomenon CD-test (see Table 5.2) was carried out on all variables of both samples.

Table 5.2 - Pesaran CD-test

	Clean Energy transition				Low Carbon Energy transition			
Variable	CD-test	p value	corr	abs(corr)	CD-test	p-value	corr	abs(corr)
CET	7.25	0	0.132	0.373				
LCET					13.30	0	0.222	0.471
ES	8.05	0	0.154	0.421	20.87	0	0.348	0.458
CO2GDP	19.15	0	0.348	0.554	51.06	0	0.852	0.852
CO2INT	5.40	0	0.098	0.496	23.19	0	0.387	0.554
EEF	21.96	0	0.399	0.638	48.93	0	0.817	0.817
TRADE	26.13	0	0.474	0.610	47.06	0	0.786	0.786
GFCFPC	40.01	0	0.726	0.726	47.40	0	0.791	0.791

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

Analysing the output of the CD-test, the null hypothesis of cross-section independence is rejected at 1% of statistical significance level. The result of cross-sectional correlation was expected, both panels are macro panels (T>N), and all countries are OECD-members and are grouped in nuclear and non-nuclear countries. This phenomenon needs to be considered in the unit root test and estimated models.

Proceeding with the inspection of the variable's characteristics, panel unit root tests that take into account the presence of unobserved effect are presented in Table 5.3 and Table 5.4. In Table 5.3, the second generation CIPS unit root test with constant and trend is presented for Clean and Low Carbon transition.

Table 5.3 - CIPS unit root test with cross section dependence

	Variables	Clean Energy transition		Low Carbon Energy transition	
		Constant	Trend	Constant	Trend
		Zt-bar	Zt-bar	Zt-bar	Zt-bar
At level	*CET*	1.6920	2.8950		
	LCET			-2.7260*	-1.5610
	ES	0.4930	1.2290	0.5040	-0.9280
	CO2GDP	1.3400	3.8850	-0.6500	0.1260
	CO2INT	0.6590	0.6350	0.0010	2.3440
	EEF	1.3930	1.1700	-0.8930	1.1390
	TRADE	-2.1610	-0.5860	-2.1160*	-0.9650
	GFCFPC	-0.7860	0.8410	-0.8500	1.4470
1st differences	*CET*	-9.2410***	-9.6330***		
	LCET			-12.0630***	-11.3590***
	ES	-10.3930***	-9.7050***	-10.3600***	-9.0470***
	CO2GDP	-9.6940***	-10.8910***	-10.3720***	-9.8670***
	CO2INT	-11.7040***	-11.7360***	-10.6360***	-9.8630***
	EEF	-9.4920***	-9.2460***	-10.4350***	-9.7660***
	TRADE	-10.2760***	-9.2940***	-10.3260***	-8.7050***
	GFCFPC	-6.9410***	-5.3530***	-7.6650***	-5.9080***

Note: *** and * stands for 1% and 10% of significant level, respectively. CIPS test assumes cross-section dependence in the form of a single unobserved common factor, and the null hypothesis is the series are I(1).

The Breitung test was also calculated with constant and trend, and the results are compatible with the conclusions of the previous unit root test. All variables have a unit root in level and are stationary in first difference with 1% statistically significant level. The exception is *TRADE* with trend in the Low Carbon transition approach. In this case, the null hypothesis is rejected only at 10% of statistic significant level.

After confirming that all variables are integrated of order 1, the presence of a long-run relationship between independent variables and the dependent variable must be tested. The Westerlund cointegration test can be seen in Table 5.5.

Table 5.4 - Breitung unit root test with cross section dependence

	Variables	Clean Energy transition		Low Carbon Energy transition	
		Constant	Trend	Constant	Trend
		Zt-bar	Zt-bar	Zt-bar	Zt-bar
At level	*CET*	-1.8132*	-0.5038		
	LCET			0.4613	-0.9138
	ES	-0.2495	0.3099	1.4772	1.9065
	CO2GDP	2.9550	1.7586	4.3526	0.1013
	CO2INT	0.9621	0.9638	3.4169	-0.1396
	EEF	4.3293	1.5968	4.1916	-0.7552
	TRADE	0.9181	-0.4657	1.0395	-1.4541*
	GFCFPC	2.9330	4.9354	1.3583	-0.1197
1st differences	*CET*	-5.5329***	-6.0926***		
	LCET			0.4613***	-6.3190***
	ES	-9.9254***	-8.1178***	1.4772***	-8.1644***
	CO2GDP	-6.9147***	-10.1297***	4.3526***	-7.6277***
	CO2INT	-10.3456***	-12.7407***	3.4169***	-10.1529***
	EEF	-8.9293***	-9.9447***	4.1916***	-5.4642***
	TRADE	-9.5587***	-9.3659***	1.0395***	-7.5492***
	GFCFPC	-7.2645***	-2.1442***	1.3583***	-2.4418***

Note: *** and * stands for 1% and 10% of significant level, respectively.

The Breitung test was also calculated with constant and trend, and the results are compatible with the conclusions of the previous unit root test. All variables have a unit root in level and are stationary in first difference with 1% statistically significant level. The exception is *TRADE* with trend in Low Carbon transition approach. In this case, the null hypothesis is rejected only at 10% of statistic significant level.

After confirming that all variables are integrated of order 1, the presence of long-run relationship between independent variables and dependent variable must be tested. The Westerlund cointegration test can be seen in Table 5.5.

Table 5.5 - Westerlund cointegration test and Westerlund cointegration test with bootstrap

	Clean Energy transition				Low Carbon Energy transition			
Statistic	Value	Z value	P-value	Robust P-value	Value	Z value	P-value	Robust P-value
Gt	-2.7150	0.9810	0.1630	0.0230	-2.7560	1.1660	0.1220	0.0802
Ga	-8.4700	2.2370	0.9870	0.2030	-6.3470	3.2460	0.9990	0.6360
Pt	-9.2280	1.5630	0.0590	0.1550	-5.8300	1.5370	0.9380	0.6150
Pa	-5.8950	1.6270	0.9480	0.5250	-1.4440	3.5260	1.0000	0.9000

Notes: The null hypothesis of Westerlund's cointegration test is no cointegration; the bootstrapping regression with 800 reps was performed to obtain robust p-values.

The null hypothesis of cointegration absence is not rejected for any statistic of country individually (Gt and Ga) or pooled panel (Pt and Pa), according with the standard p-value. Regarding the p-value obtained from bootstrapping critical values that takes into account the correlations between cross sections, the results are quite similar. The null is not rejected for Ga, Pt and Pa. Regarding the Gt statistic, the null is rejected only at 5% and 10% of statistical significance level, for the Clean transition sample and the Low Carbon transition sample, respectively. Nonetheless, the global results point to the absence of cointegration. Due to this result, all variables were differentiated once to use panel stationary techniques. The absence of long run relationships is expected, since throughout the time span, the electricity mix has experienced some changes, namely the phase-out of oil sources and the appearance of intermittent renewable sources.

The Hausman testes were computed to find the most suitable estimator between fixed and random. The x^2 statistic was 2.85 and 5.14 for Clean and Low Carbon samples, respectively. The null hypothesis was not rejected, so, the random effects model was the most suitable. Specification tests were calculated considering the former result. The results for specification tests are presented in Table 5.6.

Table 5.6 - Specification tests

	Clean Energy transition	Low Carbon Energy transition
Wooldridge test	2.887	0.967
Modified Wald test	1590000***	13091.69***
Pesaran CD-test	2.080***	5.397***
LM test	67.320***	101.363**

Notes: *** and ** denotes statistical significance at 1 and 5 %, respectively. The results of the Modified Wald test, Wooldridge test and Pesaran test, are based on Chi-squared distribution, F distribution and standard normal distribution, respectively.

The Modified Wald test for heteroskedasticity and LM test for cross section independence were calculated by considering the random effects GLS regression once random effects were detected through the Hausman test. The null of the Wooldridge test is not rejected for any statistical significance level, so there is no serial correlation. The outcome is the same for both Clean Energy and Low Carbon Energy transition. The results for the modified Wald test show the rejection of the null of homoscedasticity in the errors. In both the Pesaran CD-test and the LM test for cross section dependence in the residuals, the null of cross-section independence is rejected.

After confirming the presence of heteroskedasticity, the robust Hausman specification test was also computed in both sub-samples and the results corroborated with the standard Hausman test; the random effect model is the most suitable estimator.

5.6 Models estimation results

This section is divided into three subsections to simplify the analysis of each type of energy transition. The first subsection presents the determinates for Clean Energy transition, while in the second one, Low Carbon Energy transition determinants are presented. In the third section, two alternative estimators were computed to evaluate the results´ robustness.

All variables are integrated in order 1 and there is no cointegration in the panels. Considering this, all variables are used in first differences to make them stationary. The phenomenon of cross section dependence and heteroskedasticity were verified. Therefore, the Specification test determines that the most suitable estimators are PCSE (Panel-Corrected Standard Errors) and FGLS (Feasible Generalized Least Squares).

5.6.1 Determinants of the Clean Energy Transition

Two structures of the PCSE estimator were specified. The PCSE estimator with cross-section dependence, heteroskedasticity, and no serial correlation structures was estimated. The PCSE estimator with cross-section dependence, heteroskedasticity and first-order autocorrelation in each country was also estimated to ensure that the presence of panel specific autocorrelation is not a problem. The same structures were performed with the FGLS estimator. The Pooled OLS estimator was also estimated to guarantee that there are no sign changes of the significant coefficients. The results are presented in Table 5.7.

Table 5.7 - Determinants of the Clean Energy transition

Variable	OLS	PCSE (i)	PCSE (ii)	FGLS (i)	FGLS (ii)
ES	-0.1556	-0.1556	-0.1218	-0.0900	-0.1218
CO2GDP	2.0316	2.0316	1.7579	1.9282***	1.7579
CO2INT	-3.0671***	-3.0671***	-3.1168***	-2.1721***	-3.1168***
EEF	1.1372**	1.1372**	1.0667**	0.8829***	1.0667**
TRADE	0.2546**	0.2546***	0.2625***	0.1531***	0.2625**
GFCFPC	-9.9080	-9.9080	-7.1269	-8.2164	-7.1269
constant	-0.01763**	-0.01763**	-0.0172**	-0.0070*	-0.0172**
Observations	540	540	540	540	540
F-statistic	16.02635***				
chi2-statistic		111.0816***	115.7077***	214.5220***	103.9390***

Note: (i) stands for heteroskedastic and contemporaneously correlated error structure with independent autocorrelation structure. (ii) stands for stands for panel-specific autocorrelation of order 1. ***, ** and * stands for 1%, 5% and 10% of statistic significant level, respectively.

The estimated models do not follow a parsimonious principle to demonstrate what does not affect a Clean Energy transition. The results are quite similar in all estimators, the exception is the *CO2GDP* in the FGLS (i) estimator.

The *ES* ratio is not statistically significant in any of the estimators; therefore, it has no effect on a Clean Energy transition. The same results could be observed for *CO2GDP*. The carbon intensity of the energy use is inhibiting the energy transition. The necessity to satisfy energy demand could constrain the switching to renewables; these sources are characterized by their intermittency (expect hydroelectricity). Therefore, countries are obliged to use fossil sources to meet demand with standards of high levels of energy intensity.

The *EEF* drives Clean Energy transition, so, it is not necessary to increase total final consumption to generate more wealth for countries; this means that the same amount of renewable energy can replace the same amount of fossil energy in the electricity mix.

Openness also drives energy transition, due to the sharing of technology and knowledge to deploy renewables, as well as the inflows of foreign direct investment. Globalization reveals to be important in the energy transition process.

5.6.2 Determinants of the Low Carbon Energy Transition

In this approach, the estimations are like the previous one, in terms of the estimator's structure, once that the specification tests point to the same estimators. The results of all estimations, including the Pooled regression model, are presented in Table 5.8.

Table 5.8 - Determinants of the Low Carbon Energy transition

Variable	OLS	PCSE (i)	PCSE (ii)	FGLS (i)	FGLS (ii)
ES	-0.7428***	-0.7428***	-0.7982***	-0.4230***	-0.7982***
CO2GDP	5.7144***	5.7144***	6.3664***	2.0349***	6.3664***
CO2INT	-4.8855***	-4.8855***	-5.1374***	-2.8572***	-5.1374***
EEF	2.7941***	2.7941***	3.0079***	1.3848***	3.0079***
TRADE	0.1185**	0.1185**	0.1249**	0.0986**	0.1249**
GFCFPC	-7.9389	-7.9389	-7.2742	-8.5982	-7.2742
constant	-0.0187***	-0.0187***	-0.0195***	-0.0126***	-0.0195***
Observations	585	585	585	585	585
F-statistic	65.74946***				
chi2-statistic		290.6475***	321.672***	434.827***	449.0601***

Note: (i) stands for heteroskedastic and contemporaneously correlated error structure with independent autocorrelation structure. (ii) stands for stands for panel-specific autocorrelation of order 1. ***, ** and * stands for 1%, 5% and 10% of statistic significant level, respectively.

Analysing the results presented in Table 5.8, the results are similar in all estimators applied in terms of statistical significance level and the coefficient sign. Energy security and the carbon intensity of energy consumption has a negative impact on Low Carbon Energy transition. Only gross fixed capital formation per capita does not have any impact on energy transition. These results are coherent in all models.

The results show that energy security inhibits the transition to decarbonisation. To reduce energy dependence, it is necessary to increase energy production, which requires the use of the installed capacity of fossil sources, as low carbon sources are not sufficient to ensure energy dependence.

The carbon intensity of an economy produces a positive impact on Low Carbon transition, due to the environmental concerns of the countries. At the same time, the carbon intensity of energy consumption hampers the transition due to the use of fossil sources rather than low carbon energies.

As verified in the Clean Energy transition approach, energy efficiency also promotes the transition from fossil sources to low carbon sources. The result of the *GDPPC* is not as expected , there is no impact on Low Carbon transition. Investment capacity could be directed into the transition, but appears to have no effect. Globalization promotes Low Carbon transition; the share of know-how and green technologies can increase the speed of the transition.

5.6.3 Robustness check

Alternative estimators are tests to check the results´ robustness in the previous sections. Table 5.9 shows the results for both Clean and Low Carbon transitions. The alternative estimators computed are the Random Effects (RE) model, RE robust, Driscoll-Kraay (DK) and Driscoll-Kraay with Random Effects (DK-RE).

Table 5.9 - Results of alternative estimators

	Clean Energy transition					Low Carbon Energy transition				
Variable	Coef.	RE	RE robust	DK	DK-RE	Coef.	RE	RE robust	DK	DK-RE
ES	-0.1556	-	-	-	-	-0.7428	- ***	-**	- **	- **
CO2GDP	2.0316	+	+	+	+	5.7144	+ ***	+	+ ***	+ ***
COINT	-3.0671	- ***	- ***	- ***	- ***	-4.8855	- ***	-**	- ***	- ***
EEF	1.1372	+ **	+ *	+ **	+ **	2.7941	+ ***	+ ***	+ ***	+ ***
TRADE	0.2546	+ **	+ *	+ ***	+ ***	0.1185	+ **	+ ***	+ **	+ **
GFCFPC	-9.9080	-	-	-	-	-7.9389	-	-	-	-
constant	-0.0176	- **	- **	- *	- *	-0.0187	- * **	- ***	- ***	- ***

Note: ***, ** and * stands for 1%, 5% and 10% of statistic significant level, respectively.

The coefficients are the same for all estimators. The difference between estimators is the standard error used in the calculation of the p-values of the coefficients. The RE model is based on a GLS regression. RE robust uses a sandwich estimator to produce standard error robust in the presence of heteroskedasticity. In the regression with DK standard errors, the residual structure is heteroscedastic, with serial correlation and contemporaneously correlated between countries.

The results corroborate with the results of the previous subsections. Regarding the results of Clean Energy transition, *ES*, *CO2GDP*, and *GFCFPC* are not significant. As in PCSE and FGLS, the carbon intensity of the energy use has a negative sign and statistical significance. *EEF* and *TRADE* have a positive impact and statistical significance. Looking at the results of the alternative estimators for Low Carbon Energy transition, the results are almost identical to those in Table 5.8, except the statistical significance of the *CO2GDP* in the RE robust estimator. Therefore, the coefficient of *CO2GDP* has no statistical significance for any level.

In the next section, the results will be discussed and policy recommendations to increase the speed of an energy transition will be provided.

5.7. Discussion

Two types of energy transition were analysed here: Clean Energy transition and Low Carbon Energy transition. In the first approach, only countries with no nuclear generation in the electricity mix were analysed, while in the second, only nuclear producer countries were examined. The results in both approaches are similar; only energy dependence and carbon intensity ratios have a different role in the transition. The data characteristics, tests and estimators performed are the same, allowing comparability between the two transitions.

The energy transition measure used in this study is the ratio between renewables or renewables and nuclear power, by fossil sources. Usually, in the literature, energy transition is measured by the share of the renewables. Despite these differences, the transition determinants are remarkably similar in both measures.

Different results can be observed when analysing the role of energy security in the two types of transition studied. Clean Energy transition is not driven by energy security. Typically, energy security constrains energy transition due to the need of some countries to import energy when they do not have endogenous resources available to meet the energy demand. The negative effect of energy independence was founded in the Low Carbon Energy transition approach. Nuclear producer countries should be able to ensure energy security, but the results point to the opposite. The low cost of energy imports could be the explanation; it is cheaper to import than invest in more installed capacity.

The carbon intensity of an economy does not boost Clean Energy transition, while the reverse is seen with Low Carbon transition. The inefficiency between GDP and CO_2 emissions leads countries to change from fossil sources to low carbon ones. The carbon intensity of energy consumption obstructs both transition approaches. The dominance of polluting sources in the energy mix makes it more challenging to change energy sources, mainly because investments already made in these sources need to be recovered.

Energy efficiency proves to be a driver for both Clean and Low Carbon Energy transition in countries with high levels of energy efficiency. Not all countries begin their energy transition at the same level, it depends on the natural resources available, whether they are fossil resources or renewable natural resources. In countries in a higher level of energy transition, energy efficiency is vital to ensure there is no reversion in the transition due to increased energy demand. While in countries with a low level of renewable sources, efficiency can accelerate the transition to renewable sources.

Trade openness is also a determinant for both energy transition approaches. Through market opening, countries can specialize, and thereby create efficiency in technological progress. With an increase in trade openness, countries can place any surplus electricity generated by renewables in the electricity market, if it is physically possible.

Finally, we need to consider other energy transition policies and the electrification of other economic sectors, namely, the transport sector. This can bring additional challenges in increasing energy demand, but it is also known that electrifying vehicles can increase the flexibility of an energy system by storing electricity. The end consumer can play a key role in the transition. Consumers can contribute by investing in electricity generation for self-consumption, reducing the demand for electricity in the market. Consumers can also adjust their consumption patterns to match the availability of renewable electricity.

5.8 Conclusion

This chapter analyses the determinants of energy transition. The research comprises a sample of 25 OECD countries for the time span 1971-2016. The sample was divided into two sub samples to examine two types of transition: Clean Energy transition and Low Carbon Energy transition. The PCSE and FGLS estimators were applied to avoid any potential problem in the estimated models. The results are robust for all estimators computed. There is no long-run relationship between variables in any of the approaches. The OECD countries reveal concerns about sustainability; most of the countries are replacing fossil fuels with clean and low carbon energies. Energy efficiency and trade openness are drivers of energy transition. The concern to bring efficiency to energy consumption is crucial; thus, it is necessary to discipline the energy demand to accelerate the energy transition process.

For future research, it could be important to analyse countries separately, that is to understand each one’s specificities. To do so, other factors should also be considered that are not available for a panel data model. The roles of research and development and the electricity market could be analysed with more detail in time-series.

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Chapter 6

Conclusions

This thesis aims to contribute to a better understanding of the critical issue of energy transition. It analyses the effect of an energy transition on economic growth, taking into account barriers to the diversification of sources, and the determinants of the energy transition. It focuses on the analysis of two barriers: the dominance of generation sources in the electricity mix (Chapter 2), and the size of the electricity market (Chapters 3 and 4). Two categories of electricity markets with different sizes were analysed here. Firstly, countries that belong to a large electricity market were analysed, i.e., markets composed of several participants and with a diversified electricity mix among the members (Chapter 3). Secondly, countries belonging to a small electricity market were analysed, i.e. an electricity market with few participants and with a similar electricity mix among its members (Chapter 4). Beyond the barriers analysed, this thesis also focuses on the determinants of the energy transition (Chapter 5). Barriers to the diversification of generation sources are a relevant factor that must be considered when formulating renewable energy policies to reduce carbon dioxide emissions without compromising economic growth.

Numerous econometric methods that deal with different data structures, time series and panel data, and data frequency (daily, monthly, and annual) were applied. This diversity of models was used to ensure robust results and to answer the research questions with reinforced confidence. In order to accomplish the proposed objectives, the focus was to ensure that the best econometric practices were followed to thoroughly test all the outcomes and achieve results on which little doubt can be cast.

1.1 Concluding remarks

The analysis of the dominance of electricity sources in the electricity mix was carried out considering a single criterion for choosing the sample countries, that is, countries that belong to the top ten largest producers of a specific electricity generation source. The dominance of one source type in the electricity mix can be a consequence of the abundance of endogenous natural resources (e.g. coal, gas, oil, hydro) or a strategic option (e.g., nuclear). This is where Chapter 2 focuses. The analysis was carried out for the time span from 1995 to 2013. Taking into account the sample's characteristics, the heterogeneity of the variables was tested, but the latter was not confirmed. Hereupon, an autoregressive distributed lag approach with a DK estimator was carried out, which corrects the standard deviations of the coefficients of the presence of the phenomenon of cross section dependence, autocorrelation, and heteroscedasticity. For the time span considered, there is empirical evidence for a negative relation of renewable energies to economic growth. Conversely, fossil sources cause a positive impact on economic growth in the short run. Considering the nature of this finding, namely regarding the effect of renewables, a dedicated discussion was provided.

It is shown that countries with a dominant source, whether from the abundance of natural resources, or the strategic choice of a generation source, have an absolute advantage in producing from that source. The wide use of these dominant sources makes it possible to take advantage of economies of scale in spreading the high fixed costs of technology implementation. Consequently, these countries are faced with a trade-off between continuing to produce using the current generation sources, and encouraging economic growth, or developing alternative generation sources, low-carbon energy sources, something that could compromise economic growth. In sum, this finding is consistent with the idea that renewable support schemes require an additional effort from countries, and these costs are transferred on to the economy. Indeed, one of the most common tools for meeting environmental requirements is setting minimum renewables quotas. This may be the reason for the added cost to the economy. One way to overcome this issue may be to set maximum quotas for fossil fuel sources. This can bring additional motivation to countries in enhancing energy efficiency.

Intermittent generation, a typical feature of renewable sources, may cause idle capacity or electricity surplus. The implementation of demand response programs is recommended so that progressively, electricity demand instantaneously meets the electricity supply generated by renewables. In addition to these demand response programs of approximating demand and supply, electricity markets can also be a critical tool in accommodating renewables into the electricity mix. Considering the intermittent characteristics of renewables, electricity markets make it possible to allocate the surplus, and compensate for low generation, efficiently. Understanding the role of the markets and their characteristics in the diversification of the mix was the main motivation for the next two essays.

In Chapter 3, another barrier to the diversification of the electricity mix was examined, namely the market size. Two member countries of the Nord Pool Spot, Estonia, and Sweden were analysed. Apart from the electricity market size, these two countries also have dominant sources, namely shale oil in Estonia, and nuclear and hydroelectricity in Sweden. Monthly data was used to study the relationship between electricity generation sources and economic activity in these countries. The ARDL model was applied to capture both short- and long-run effects, as well as the presence of cointegration between variables. Results show that endogenous natural resources support economic growth in Estonia. This result corroborates the precedent findings from Chapter 2, even though the contexts are different.

Taking into account that renewable sources are not geographically concentrated, and even complementary to some extent, the development of this type of generation source (sun, wind, and hydro mainly) is associated with technology costs and the need for flexibility of balancing instruments. For that, cross-border interconnections in the electricity markets, water storage based on pumping to alter generation time, or demand side management measures, are all critical points. Indeed, in the absence of electricity stock, the market proves to be important in controlling the surplus, and in backing up the intermittent characteristic of renewables.

The electricity market allows countries to specialize in one type of electricity source. A country such as Estonia (in Chapter 3) can generate electricity from fossil sources and yet consume renewable electricity by recurring to the market. Sweden may use the electricity market to allocate nuclear production due to the low flexibility of this source. Following the analysis of the importance of the wholesale electricity market in the energy transition, in Chapter 4, in contrast to the previous chapter, a small electricity market is analysed, the Iberian market. This market is made up of only two members with geographical proximity. High frequency data was used to assess the interaction of electricity generation sources with the wholesale electricity market price.

The results found so far, in Chapters 3 and 4, lead us to think that a debate is needed on ways and strategies such as deepening/developing an integrated electricity market, which is effectively a key element in the sustainability of diversification. One of these strategies may be the establishment of a specialization profile in the production of the market member countries, as well as the diversification of consumption periods.

In Chapter 4, the autoregressive vector model was estimated with daily data, from July 2007 to April 2018. Decomposition of time series into seasonal, trend and remainder components were used to avoid seasonality problem. The countries under consideration, have a similar electricity mix, except for nuclear power plants in Spain. In fact, the results show that the operation of electrical systems is similar, however, the systems interact with the electricity market differently. This may be related to the scale of each one, although, in terms of consumption and production patterns, the countries are similar.

After analysing the barriers to the diversification of the electricity mix, the determinants of the energy transition were analysed. Diversification of the electricity mix can be used to reduce energy dependency and promote energy transition. Two energy transition concepts were discussed in Chapter 5, namely, clean energy transition and low carbon energy transition. On the one hand, in a clean energy transition, renewable energy is considered as part of the transition. On the other hand, in a low carbon energy transition, both renewable energy and nuclear power were considered as part of the transition. Two indicators were computed and proposed to measure both transitions. Some potential determinants were analysed for a time period from 1971 to 2016, for which two estimators were applied. The sample was divided into two subsamples, nuclear and non-nuclear producers. Panel corrected standard error and feasible generalised least squares estimators were applied in both clean and low carbon approaches.

The main results showed that energy efficiency and trade openness are the main determinants of the energy transition. Countries do not all start at the same starting point for the energy transition. Some countries have even regressed in terms of energy transition, due to increased demand for electricity, and countries have increased the production of fossils to meet demand. Energy efficiency measures are needed so that the transition is effectively a replacement of the electricity generation sources and not an addition to existing generation sources. Energy transition can benefit from trade, and this finding corroborates those from Chapters 3 and 4 which could be seen as a signal of great internal consistency in this thesis.

In short, this thesis adds knowledge in this area of energy transition, namely by showing the importance of overcoming constraints to the transition path, particularly by exploring the role of domestic barriers, such as the dominance of sources in the electricity mix, and external barriers, such as the market size. In fact, the thesis being constituted by empirical evaluation constitutes support for the formulation of quality policies for the energy transition without compromising economic growth.

1.2 Further research

In the course of this thesis, some questions have arisen. Indeed, as answers to the research questions initially proposed were found, this thesis also arouses new ideas and curiosities for research. While they do not fit the scope of this thesis, they deserve a brief note to describe future research paths. This thesis focuses on the barriers and determinants of large-scale electricity production. Small-scale electricity generation by individual prosumer, firms, and communities can also contribute to promoting the energy transition. As with large-scale generation, micro-generation is also faced with structural, strategic, and even legal barriers, more specifically in the absence of regulation. The role of microgeneration in economic activity can also be analysed to understand the effect its generation incentives have on economic activity.

While renewable energies are a first option, being clean and taking advantage of natural resources, nonetheless, their non-disposable intermittence remains a fully unsolved issue. This intermittency is close to being mitigated by major developments in energy storage, such as electric vehicles. There are still other sources of energy that may still contribute to the diversification of the electricity mix. Nuclear power has not yet exhausted its full capacity to support the energy transition, notably in accomplishing environmental emission reduction targets. There is still opportunity for improvement in the development of nuclear energy, such as thermonuclear experimental reactors. This is a subject surely worthy of future research.

As countries attempt to develop renewable sources without inhibiting economic activity, diversification of the electricity mix may not have the desired effect. Economic growth has been used as a guiding measure for policy makers. Considering a trade-off between environmental concern and economic growth, other measures could be considered. Gross domestic product has some limitations in measuring the welfare and sustainability of natural resources. It does not consider negative externalities or any social components such as domestic work or inequality. There are some indicators already developed that consider environmental and welfare components. The Index of Sustainable and Economic Welfares (ISEW) and the Genuine Progress Indicator (GPI) are two of the indicators that consider the elements, social, economic and sustainability. The construction of these indicators still requires standardisation to allow comparability. Potential research questions may be able to assess the effect of the energy transition on ISEW or GPI and may provide information on how renewables have been implemented, as their full contribution to society might not be mirrored in GDP.