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# The Impact of Renewable Energy Sources on Economic Growth and $CO_2$ Emissions: Evidence from Iberian Peninsula

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# ABSTRACT

During the last years, due to a constant increase of the concern about environmental questions and an accompanying development of related policies, there has been an increase in energy production from renewable sources. In this line of thought, the aim of this dissertation is to examine the relationship between renewable energy production, economic growth and $CO_2$ emissions in the Iberian Peninsula, using a Structural Vector Autoregressive model. The innovative contribution of this dissertation is the incorporation of oil prices, as an exogenous variable, since the increase in the price of this raw material in the international market have had very negative impacts on the economies of both countries. This study covers the sample period from 1960 to 2009 and it approaches two distinct analyses: one for aggregate energy production (TRES), considering the total of renewable energy sources; another for disaggregated energy sources, considering hydroelectricity separately from the other renewable sources, due to the high weight of the first in energy production. For the two cases, both the structural factorization results and the impulse-response functions show that, contrary to what was expected, a shock on energy does not have a significant impact on GDP. Total RES and hydro only affect negatively $CO_2$ emissions during the first year. This situation led to conclude that hydroelectric is the main source that contributes to the total RES. Another important result is the positive impact of $CO_2$ emissions to a shock on GDP that occurs at least most during six years. The variance decomposition shows, for both countries, a large amount of uncertainty in the forecast of the growth rate of $CO_2$ emissions, mainly due to a shock on TRES (30% in Portugal and 20% in Spain) for aggregate analysis and due to a shock on hydro (28% in Portugal and 20% in Spain) for disaggregate analysis and almost no uncertainty in predicting the growth rate of TRES and GDP.

**Key words:** Renewable energy sources, economic growth, $CO_2$ emissions, SVAR model.

**JEL Classification**: O44 - Environment and Growth
Q42 - Alternative Energy Sources

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# LIST OF ABBREVIATIONS/ACRONYMS

ADF - Augmented Dickey-Fuller test

AIC – Akaike criteria

ARDL - Autoregressive distributed lag

DEA - Data envelopment analyses

DSP - Difference stationarity process

ERSE – Entidade reguladora dos serviços energéticos

EU - European Union

EWEA - European wind energy association

GDP – Gross domestic product

IEA - International energy agency

IES - Independent electricity system

IRF - Impulse-response function

KPSS - Kwiatkowski–Phillips–Schmidt–Shin test

MIBEL - Single Iberian Electricity Market

NRES - Non-renewable energy sources

NREAP – National renewable energy action plan

PES - Public electricity system

PP - Phillips-Perron test

PT - Portugal

PTR - Panel threshold regression

RES - Renewable energy sources

SIC – Schwarz criteria

SP – Spain

SRP - Special Regime Production

SVAR - Structural vector autoregressive

TSP – Trend stationarity process

VAR - Vector autoregressive

VECM - Vector error correction model

WTI – West texas intermediate

# 1. Introduction

The dependence on fossil fuels in energy production has led to discussions about the sustainability of current energy consumption in many countries. One subject that has been heavily discussed is the use of alternative energy sources, as a way to mitigate the environmental impact of $CO_2$ emissions, improving the sustainability of energy consumption in countries with strong energy dependence and hence the contribution of these sources to economic growth.

In the last years, in the Iberian Peninsula, we have been observing a decrease of the dependence on non-renewable energy sources (NRES), mainly fossil fuels, and an increase in electricity production from several renewable energy sources (RES). This change is due not only to internal measures, like awareness of environmental concerns and the associated policy changes, but also external measures, linked with international commitments related to the environment, like the Kyoto Protocol, created in 1997 but which entered into force in 2005 that set a limit to the greenhouse gas emissions, namely carbon dioxide, for industrialized countries.

As will be presented in the literature review, in recent years the studies about the relationship between renewable energy consumption and economic growth, measured in terms of gross domestic product (GDP) have been increasing, among them studies by (Chien and Hu, 2007, 2008; Sadorsky, 2009a, 2009b; Apergis and Payne, 2010).

In addition to the relationship between the two variables cited in the preceding paragraph, $CO_2$ emissions have also been extensively explored in the literature. Studies that relate GDP and $CO_2$ emissions have the main goal of analyzing the existence of an Environmental Kuznets Curve, that is, an inverse U-shaped relationship between pollution and income, so that economic growth could be viewed as one of the solutions to environmental problems (Soytas and Sari, 2009).

Apparently, only (Silva et al., 2011) studied the impact of RES, measured in terms of electricity generation, on economic growth and $CO_2$ emissions, using a Structural Vector Autoregressive (SVAR) model, in four different countries, among them Portugal and Spain. There isn't any other study addressing the case of Iberian Peninsula, using a SVAR model and which became the main motivation for this research.

Thus, the main goal of this dissertation is to perceive the evolution of electricity production from renewable energy sources, during the period 1960-2009, in the Iberian Peninsula and analyze to what extent this development affected economic growth and $CO_2$ emissions. For this purpose a SVAR model is used, which unlike the unrestricted VAR model takes into account the interactions of all variables in the model, based on insights from economic theory.

So, the restrictions used in the estimation of the model are based on empirical evidence and, for the aggregate analysis, we assume that TRES and GDP affect $CO_2$ emissions, although $CO_2$ does not affect directly any of the other variables. For the disaggregate analysis we assume as restrictions that RES, hydro and GDP do not receive any impact of the others variables and only $CO_2$ emissions receive a negative impact of the hydro and a positive impact of GDP. Comparing with the constraints used by (Silva et al., 2011), where RES affects GDP and $CO_2$ emissions, GDP affects $CO_2$ emissions and $CO_2$ emissions does not affect any variable, we can conclude that the first one is different.

With this research I also intend to study the dynamic responses of the different variables to a shock in RES, which in other words means to evaluate to which extend and how long it takes until the long-run equilibrium is reached, if it is reached at all, and to analyze which shocks are the main cause for the variability of the endogenous variables of the system. Finally, there will be a comparison of results for each country.

This study also aims to answer the following question: What are the consequences for the economic and environmental development in the Iberian Peninsula from the increase in electricity production from renewable energy sources and how do individual countries respond?

This research contributes to the field of energy economics in three important ways. First, we employ a relatively new time-series approach capable of uncovering relationships that might otherwise be missed using more conventional methods, as the use of data referred to the electricity production from renewable energy sources, rather than the consumption, which includes energy imports, which was used in the study by (Silva et al., 2011). This type of variable hasn't been widely used in the existing literature. Second, two distinct analyses are presented, one considering aggregate energy production, including total RES, and another one with disaggregated energy production, divided into hydroelectric sources and other renewable sources, thus providing a more comprehensive analysis. Third, the innovative contribution of this dissertation is the incorporation of oil prices in the analysis, since the increase in the price of this raw material in the international market have had very negative impacts on the economies of both countries. This situation led to an increase in demand for alternative sources, cheaper and cleaner and also with a more positive effect on the balance of trade.

## 2. Energy sector in the Iberian Peninsula

In this section a brief description of the Iberian Peninsula is presented, namely the characterization of the energy sector in Portugal (PT) and Spain (SP).

### 2.1 Overview

The Iberian Peninsula – Portugal and Spain - located in Southern Europe, is the extension of the European Continent, from the Pyrenees Mountains to the Atlantic Ocean and Mediterranean Sea. These two countries have been members of the European Union (EU) since 1986 and from that time their economies grew steadily, increasing standards of living, international competitiveness and economic growth in the Iberian Peninsula. Nevertheless, Portugal and Spain continue to face economic challenges, as well as most European countries, due to the economic crisis that is affecting the world and especially Europe. In both countries unemployment rates remain stubbornly high and they have repeatedly exceeded the EU's limits on budget deficits.

In the years following the entry into the EU, the economic growth of these countries led to corresponding increases in energy consumption; for example, Spain's per capita energy demand has increased over 100 percent since the mid-1970s, as shown in Figure 1. This situation is mainly due to the development of a diversified service-based economy, with sectors such as telecommunications, finance, transportation and energy placing significant pressure on electricity consumption (Shahbaz et al., 2011).

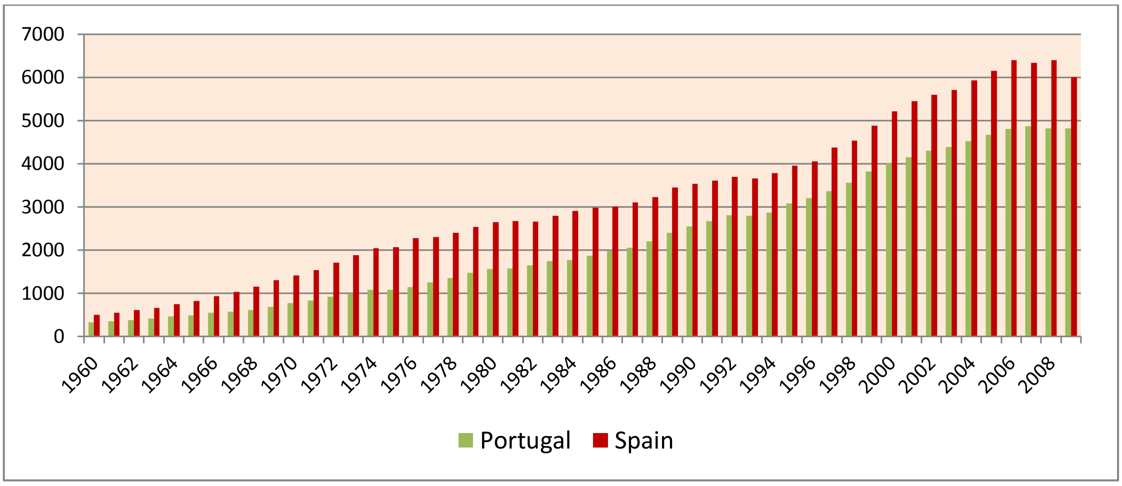


**Figure 1 - Electric power consumption (kWh per capita)**
**Source: World dataBank**

The Iberian Peninsula has limited energy resources, so both Portugal and Spain must depend upon imports for the bulk of their energy needs, as shown in Figure 2.

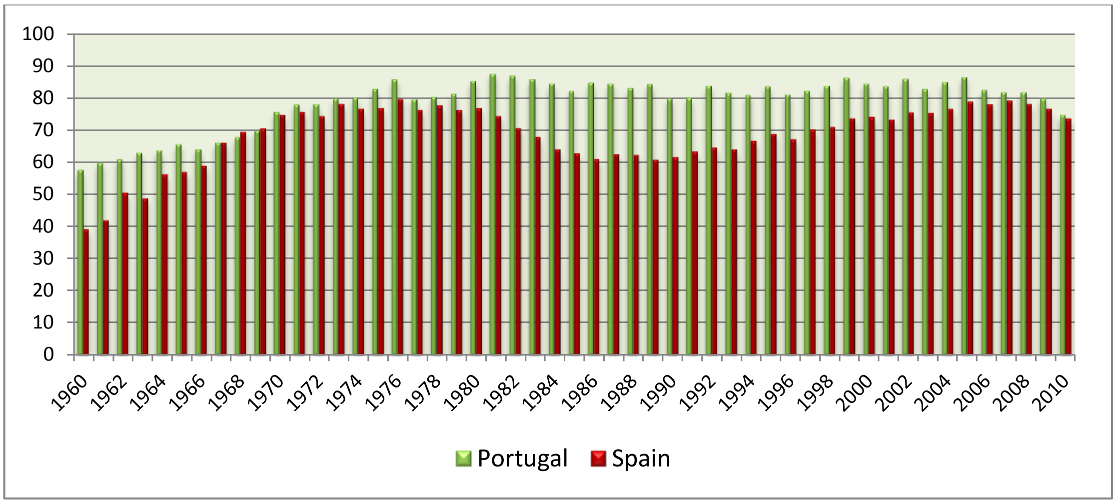


**Figure 2 - Energy imports, net (% of energy use)**
**Source: World dataBank**

Electricity in Portugal and Spain is generated by a combination of fossil fuels such as coal, oil and gas, and renewable energies, such as hydroelectricity, wind and biomass, although until the 1990s, only hydro contributed to the energy production from RES. Spain also has some nuclear power plants.

After the oil shocks in the 1970s, and especially since the negotiation of the Kyoto Protocol, in 1997, which establishes a limit for greenhouse emissions for industrialized countries, there have been attempts to develop domestic energy sources, focusing on hydropower and renewables, as shown in Figure 3 and Figure 4.

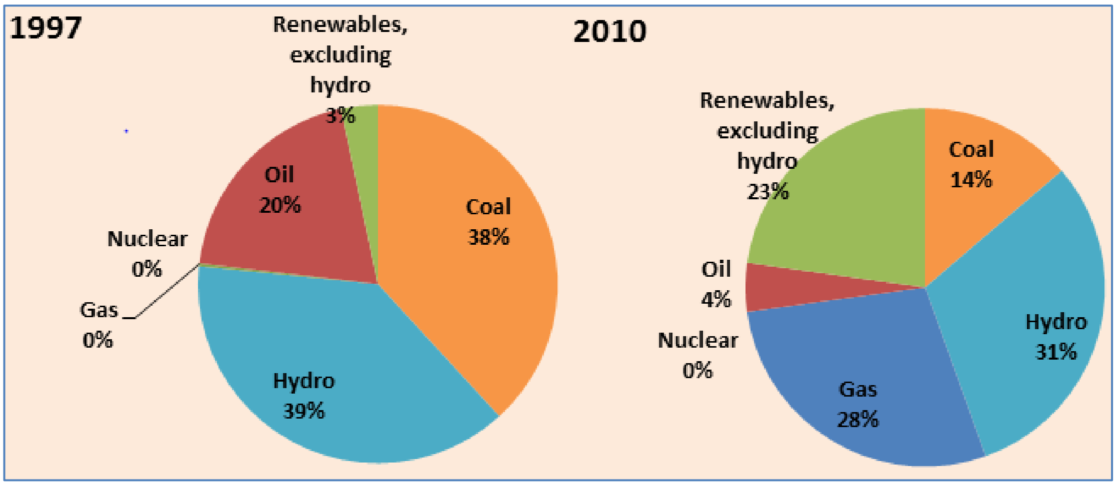


**Figure 3 - Electricity production by source in Portugal (% of total)**
**Source: World databank**

In Portugal, since 1997 we can verify a substantial increase in the share of electricity production using renewable sources, from 42% in 1997, which includes 39% from hydroelectricity and 3% from other renewables sources to 54% in 2010, which includes 31% from hydroelectricity and 23% from other renewables sources. This situation led to a decrease in the importance of electricity production from fossil fuels, especially coal and oil, which have recorded much smaller values in the total of production from 58% in 1997 to 18% in 2010. Hydroelectricity continues to record the highest values in the total of electricity production, mainly due to the increase in the number of dams built in Portugal, but other renewables have shown a very significant increase from 3% to 23% of total electricity production.

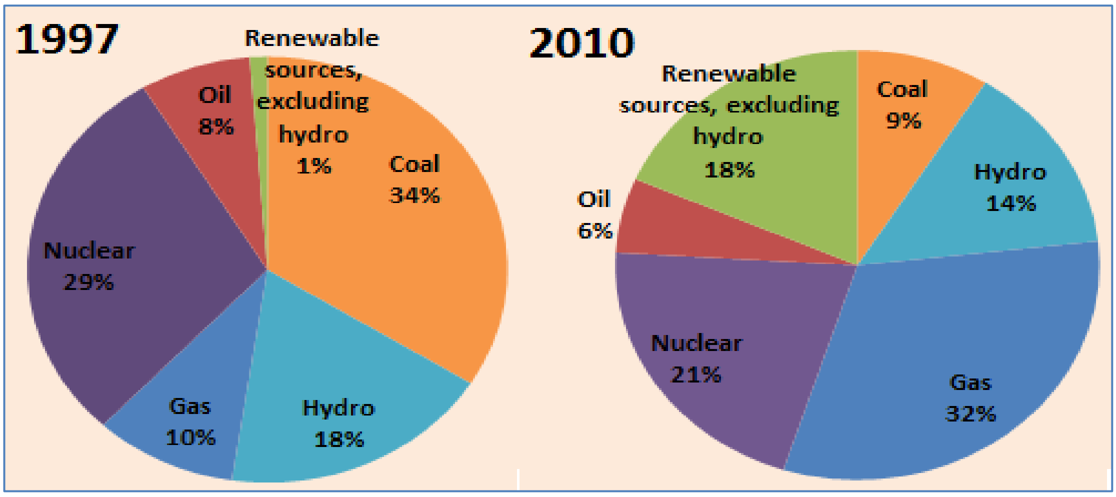


**Figure 4 - Electricity production by source in Spain (% of total)**
**Source: World dataBank**

In Spain, since 1997, renewable sources excluding hydro have increased from 1% to 18% in 2010, which led this country to become one of the most important in terms of clean energy. The importance of electricity production from oil has, however, remained practically the same from 8% in 1997 to 6% in 2010, while that of coal decreased substantially, to the point where it was in 2010 the second least significant energy source in electricity production.

In addition, both countries have sought greater integration of the Iberian energy sector through policy coordination and infrastructure projects, among them the Iberian Electricity Market (MIBEL) which after several delays, entered into force in July 2007 and it constitutes a joint initiative from the Governments of Portugal and Spain, with a view to the construction of a regional electricity market, where it is possible for any consumer in the Iberian zone to acquire electrical energy under a free competition regime, from any producer or retailer that acts in Portugal or Spain.

## 2.2 Electricity Sector Organization

Before market integration, the market structure was different in each country, with a near monopoly in Portugal and a strong duopoly in Spain.

In 2007, Endesa was the largest power generating and distributing company in Spain, which controls about half of the regulated electricity market and one-third of the liberalized market. The second largest power utility in Spain was Iberdrola, though the company controls the largest share of the deregulated portion of the market.

In Portugal there are two electricity markets, the Public Electricity System (PES) and the Independent Electricity System (IES). PES is the regulated market with power supplied at fixed rates under long-term contracts. The IES consists of smaller producers and consumers that allow unrestricted access by generators and distributors. Formerly state-owned Electricidade de Portugal (EDP) maintains a dominant position in both markets. EDP controls almost all of the generating capacity in the PES and holds significant stakes in generating capacity in the IES. EDP's wholly-owned subsidiary, EDP Distribuição, controls distribution in the PES. Electricity transmission in these markets is controlled by national grid operators Rede Eléctrica Nacional (REN) and Red Elétrica de España. (“Encyclopedia of Earth,” 2007)

## 2.3 Renewable Energy Sources

Nowadays energy resources have a key role in the production process in general. There has been strong technological progress based on an increasingly intensive use of energy resources, instead of other resources. However, such use has a negative consequence on the environment, namely in terms of the quantity of greenhouse gases that it generates.

According to the World Energy Outlook 2011 report by the International Energy Agency (IEA), electricity production is responsible for about 40% of global $CO_2$ emissions. So, it is clearly important to take measures to reduce the environmental impact of energy production, taking into account that the main resources for energy production are scarce, so the dynamics of the market will migrate to optimize the use of these resources.

The implicit scarcity of nonrenewable resources such as fossil fuels, should drive market dynamics to find alternative resources. Renewable energy sources have the strengths of environmental and long-term economic sustainability, although there is still a gap until renewable sources become efficient enough to fully meet energy needs.

In Portugal and Spain, the weight of special regime production (SRP) in consumption is approximately the same. In 2011, more than one third of the energy consumed was assured by SRP and the evolution in time is substantially the same (more pronounced in the Portuguese case).

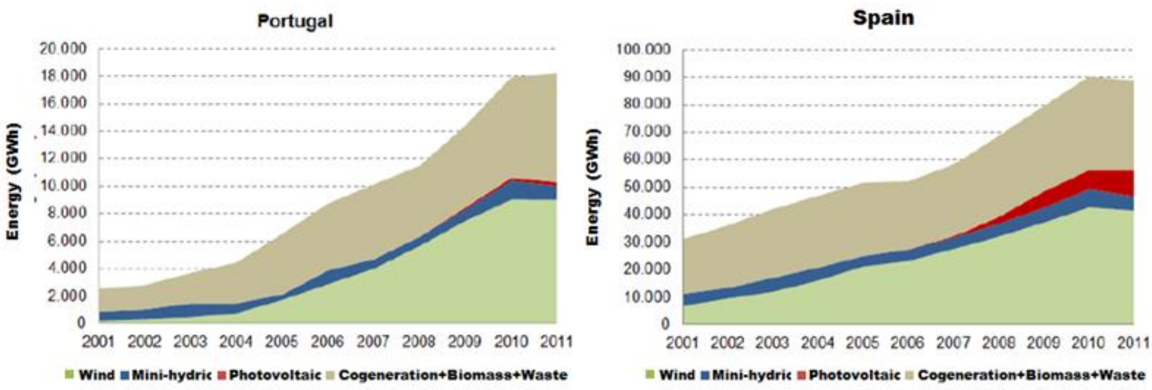


**Figure 5 - Energy consumption by source (GWh)**
**Source: Entidade Reguladora dos Serviços Energéticos (ERSE)**

The aggregate composition of SRP is very close between Portugal and Spain, as shown in Figure 5. In 2011, wind accounted for about 19% of consumption in Portugal and 16% in Spain and the SRP photovoltaic represented about 16% of consumption in Portugal and 12% in Spain.

## 2.4 Energy Policies

After the approval of the Kyoto Protocol, the EU developed a renewable energy policy, which comprises the Directive 2003/87/EC and the Directive 2009/28/EC, with the goals of reducing greenhouse gas emissions, ensuring security of supply and improving EU competitiveness.

EU policies set ambitious targets in order to promote energy from renewable sources. Due to this situation, European companies are world leaders in wind power technology and have a leading share of the world market. As a result, Europe today gets approximately 20% of its electricity from renewable energy sources, including 5.3% from wind energy.

In the graph below it is possible to observe the share of consumption from renewable sources expected for 2020 for each European country. Portugal and Spain are in the top 10 of the countries, with a high percentage of wind energy, which is expected to be the source that will contribute most to the consumption from RES in these countries in 2020.

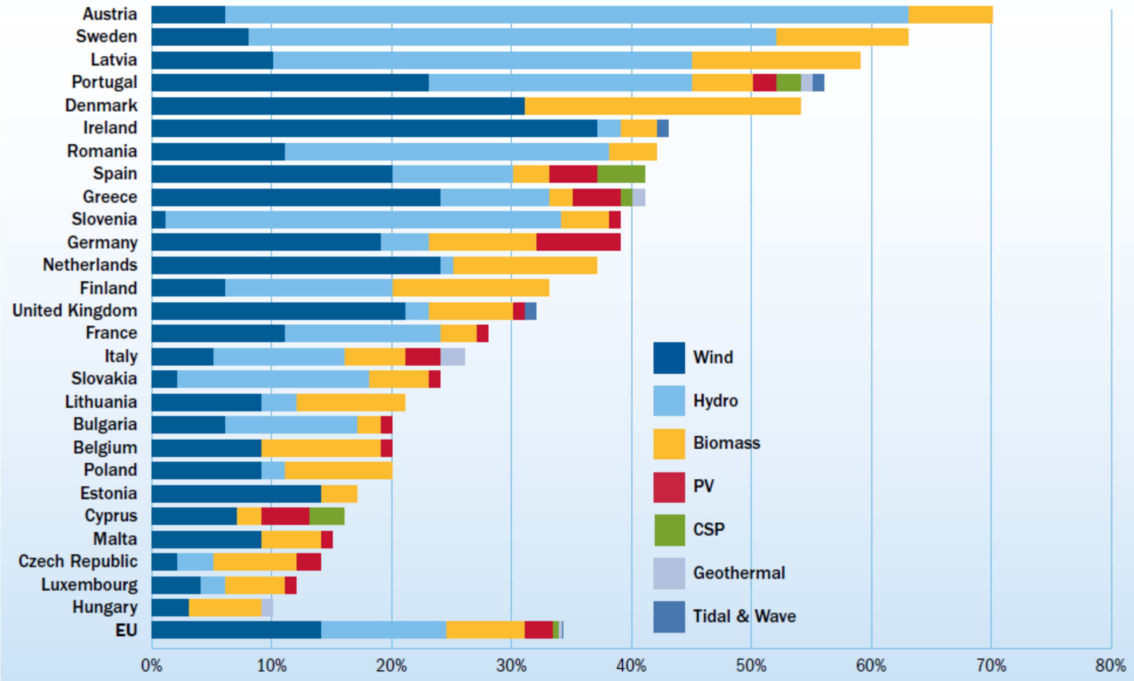


**Figure 6 - Renewable electricity share of consumption per member state in 2020 (%)**
**Source: European Wind Energy Association (EWEA)**

In the following sections, a brief review of the policies and the targets expected for 2020 in Portugal and Spain is presented.

### 2.4.1 Portugal

As referred above, Portugal is still highly dependent on energy imports, namely fossil fuels (oil and gas) which are scarce. So, due to the scarcity of these resources and in order to correspond to the original EU directive on renewable energy (2001/77/EC), the Portuguese government launched, in 2001, the E4 programme (i.e. Energy Efficiency and Endogenous Energies), which focused on the expansion of renewable energy, principally via guaranteed feed-in tariffs for renewable electricity (Appendix 1), direct subsidy payments (PRIME-Programme) and tax incentives.

Subsidy payments and tax incentives have been largely used for smaller-scale renewable energy applications, while feed-in tariffs and tendering schemes were used principally for larger-scale renewable applications. Feed-in tariffs are what energy producers get paid for each unit of electricity fed into the grid and power companies are generally mandated to purchase all electricity from eligible producers in their service area over a long period of time, usually 15 to 20 years. (Global Energy Network Institute (GENI)).

In Portugal the tariff prices were decided in the Decree-law 33-A/2005 of 16th February. The formula for calculation of the feed-in tariffs takes into account the technology, the environmental aspects and the inflation rate through the consumer-price index. There are also some minimum and maximum tariffs, according to the variations of load on the grid. The Decree-law 225/2007 introduced new tariffs for emerging technologies, such as wave energy and Concentrated Solar Power providing the legal basis for government use of public maritime areas for producing electricity from sea-wave power.

The Portuguese energy policy intends to be a factor of economic growth, promoting competition in energy markets, value creation and skilled employment in sectors with high technological incorporation.

The goals of (*National Renewable Energy Action Plan Portugal*, 2009) are: reducing energy dependency to 74% in 2020; reaching the target of 31% of final energy from renewable sources, meeting the objectives of the EU; increase to 60% electricity production from renewable sources, 30.6% heating and cooling from RES and 10% RES in transport; create more 121,000 jobs and providing exports equivalent to 400 million euros and further reduce 20 million tons of $CO_2$ emissions over a time horizon until 2020.

According to the plan, at that date wind power should be the country's leading RES technology, with an annual production of 14.6 TWh, covering almost 23% of electricity consumption with a cumulative installed capacity of 6,800 MW onshore and 75 MW offshore.

Renewable energy production is mostly based on the combination of hydropower and wind power. Even so, the national vision for this sector is the diversification of the portfolio of renewable energy, investing in mature technologies and which could give an immediate contribution to the power generation system, but also in research and development of newer technologies and projects under test with potential for value creation in the national economy.

The investment in renewable energy, in addition to energy production, generates a set of positive externalities related to the environment. It also creates wealth and employment and contributes to the trade balance.

| 2020 RES target in Directive 28/2009/EC | 2020 RES target in NREAP | 2020 RES-E target in NREAP | Wind capacity installed at end 2010 | 2020 wind capacity in NREAP | 2020 wind production in NREAP | 2020 wind share of electricity consumption in NREAP |
|---|---|---|---|---|---|---|
| 31% | 31% | 55,3% | 3.898 MW | 6.875 MW | 14,6 TWh | 22,6% |

**Table 1 - Energy Targets to 2020 in Portugal**

### 2.4.2 Spain

Spain is a world leader in renewable energies due to the high implementation of wind and solar power. In 2010, Spain was able to meet 32% of its electricity demand using renewable energies, with the largest contributions coming from wind, hydropower and solar. Despite this and the tremendous progress, the majority of the country's electricity is still derived from fossil fuels.

The (*National Renewable Energy Action Plan Spain*, 2010) aims to exceed the country's binding 20% target by almost three percentage points. The authorities clearly intend to use the excess in co-operation mechanisms with other Member States.

The document emphasizes the role of the power sector in reaching the overall target and forecasts that 41% of all electricity consumption will be met by RES in 2020, with wind power alone expected to meet half this amount.

Surprisingly, however, the action plan has reduced wind power capacity ambitions to 35 GW onshore, with build-out rates below what the Spanish market has delivered in recent years.

| 2020 RES target in Directive 28/2009/EC | 2020 RES target in NREAP | 2020 RES-E target in NREAP | Wind capacity installed at end 2010 | 2020 wind capacity in NREAP | 2020 wind production in NREAP | 2020 wind share of electricity consumption in NREAP |
|---|---|---|---|---|---|---|
| 20% | 22,7% | 40% | 20.676 MW | 38.000 MW | 70,5 TWh | 20,8 % |

**Table 2 - Energy Targets to 2020 in Spain**

Like Portugal, Spain also uses feed-in tariffs (Appendix 2) in order to promote renewable energy sources. Two types of tariffs are available, guaranteed and variable tariffs. Guaranteed tariffs are the minimum tariff that the country gives out. Variable tariffs based on factors such as the season. Biomass and hydroelectric producers are able to choose a variable tariff over a guaranteed tariff. If electricity is generated from renewable energy sources that are above 50 MW and are not a photovoltaic system, then the producer can choose between a guaranteed tariff and a bonus "on top of the price achieved in the free market".

In Spain the tariff prices were decided in the Royal Decree 661/2007. The tariffs for photovoltaic were updated in Royal Decree 1578/2008.

## 3. Literature review

In the energy economics literature there are several studies about the relationship between energy consumption, economic growth, measured in terms of gross domestic product (GDP), and other parameters, like $CO_2$ emissions, in both developed and developing countries, since the earliest publication by (Kraft and Kraft, 1978), who examined the relationship between these variables in the USA.

Recent surveys can be found in (Ozturk, 2010; Payne, 2010), where it is made clear that empirical findings on the direction of causality between energy consumption and economic growth are controversial.

The existing studies focus on different countries, time periods, variables and econometric methodologies. The empirical evidence shows that the causal relationship between energy consumption and economic growth differs from one economy to another and over time, which leads the authors to conclude that, currently, there isn't a consensus in relation to this theme.

The relationship between energy consumption and economic growth can be categorized into four types of hypothesis.

The first is known as growth hypothesis according to which energy consumption serves a vital role in economic growth. In economies with a strong energy dependency, this hypothesis suggests that an increase in energy consumption causes an increase in real GDP and hence a decrease in energy consumption restrains economic growth.

The second is the conservation hypothesis, which claims that economic growth determines energy consumption and not the inverse; this means that an increase in real GDP causes an increase in energy consumption. On the other hand, this hypothesis is related to energy conservation policies, which are designed to reduce energy consumption and waste and accordingly may have no adverse impact on real GDP. If so, these policies could be implemented with little or no adverse effects on economic growth. In this context, a unidirectional causal relationship from economic growth to energy consumption implies that a country is not entirely dependent on energy for its economic growth.

The third is the feedback hypothesis, in which energy consumption and real GDP are interdependent, with bidirectional causality between them. This hypothesis also suggests that an energy policy oriented towards improvements in energy consumption efficiency may not have an adverse effect on economic growth.

And, finally, the fourth is the neutrality hypothesis, which does not assert a causal relationship between the variables. In other words, energy consumption is not correlated with GDP, which would mean that energy conservation or expansion policies do not have any impact on economic growth, nor does the latter have an impact on energy consumption (Ozturk, 2010; Payne, 2010).

Table 3 presents an overview of empirical studies for the four types of hypothesis on the causality between energy consumption and economic growth, for some countries that are most analyzed in the literature.

| Country | Conservation hypothesis | Growth hypothesis | Feedback hypothesis | Neutrality hypothesis |
|---|---|---|---|---|
| | **GDP → EC** | **EC → GDP** | **EC ↔ GDP** | **EC --- GDP** |
| **France** | (Lee, 2006) | (Ang, 2007), (Soytas and Sari, 2003), (Soytas and Sari, 2006) | (Lee and Chang, 2007a) | ( Erol and Yu, 1987) |
| **India** | (Cheng, 1999), (Ghosh, 2002) | (Masih and Masih, 1996), (Asafu-Adjaye, 2000), (Fatai et al., 2004) | (Paul and Bhattacharya, 2004) | (Soytas and Sari, 2003) |
| **Japan** | (Cheng, 1998), (Lee, 2006) | (Soytas and Sari, 2003) | ( Erol and Yu, 1987) (Soytas and Sari, 2006) | |
| **Korea** | (Yu and Choi, 1985), (Soytas and Sari, 2003) | (Masih and Masih, 1997), (Oh and Lee, 2004) | (Glasure, 2002) | |
| **Malaysia** | (Ang, 2008) | (Chiou-Wei et al., 2008) | | (Masih and Masih, 1996) |
| **Taiwan** | (Cheng and Lai, 1997a) | (Lee and Chang, 2005), (Lee and Chang, 2007b), (Chiou-Wei et al., 2008) | (Hwang and Gum, 1991), (Masih and Masih, 1997), (Yang, 2000) | |
| **Turkey** | (Lise and Van Montfort, 2007), (Karanfil, 2008) | (Soytas and Sari, 2003), (Jobert and Karanfil, 2007) | (Erdal et al., 2008) | (Altinay and Karagol, 2004), (Karanfil, 2008), (Soytas and Sari, 2009), (Halicioglu, 2009) |
| **USA** | (Kraft and Kraft, 1978), (Abosedra and Baghestani, 1989) | (Stern, 1993), (Stern, 2000), (Soytas and Sari, 2006), (Bowden and Payne, 2009) | (Lee, 2006) | (Akarca and Long, 1980), (Yu and Hwang, 1984), (Yu and Choi, 1985), (Erol and Yu, 1987b), (Yu and Jin, 1992), ( Cheng, 1995), (Soytas and Sari, 2003), (Chiou-Wei et al., 2008), (Payne, 2009) |

**Table 3 - Overview of selected studies on the EC-Growth causality relationship**

**Note:** EC → GDP - causality runs from energy consumption to growth.
GDP → EC - causality runs from growth to energy consumption.
EC ↔ GDP - bi-directional causality exists between energy consumption and growth.
EC---GDP - no causality exists between energy consumption and growth.

Most literature about the impact of energy consumption on economic growth, according to (Yang, 2000), uses aggregate energy data, which does not allow an analysis of the extent to which countries rely on different energetic resources, such as renewable energy sources (RES). Thus, a new branch in the literature emerged, which analyses the causal relationship between disaggregated energy sources, testing for example the link between renewable energy consumption and GDP as an economic growth indicator. However, this branch is not as developed as the previous one.

Below a literature review of the most important studies in this area is presented. The studies that have analyzed the relationship between renewable energy consumption and economic growth can be classified into three groups.

The first group is related to the empirical causality context, which analyses the direction of the causal relationship between variables, using several causality tests such as standard Engle-Granger causality, Toda-Yamamoto causality, ADRL bound testing approach, VAR causality and Vector Error Correction causality tests. In this way, the relationship between RES and economic growth can be explained by the four types of hypothesis presented above.

(Sari and Soytas, 2004) undertake a generalized forecast error variance decomposition model to analyze the variation in the growth of domestic product that could be explained by the growth of different sources of energy consumption (coal, oil, hydraulic power, asphaltite, lignite, waste and wood) and of employment, in Turkey, between 1969-1999. They find, in terms of RES, that waste consumption has a major initial impact, as it explains 17,3% of the forecast error variation in real GDP, followed by oil. However, for a 3-year horizon lignite, waste, oil and hydraulic power have the four highest amounts of variation between GDP and energy sources with about 25%, 17%, 15% and 10% respectively.

(Wolde-Rufael, 2004) analyze the causal relationship between several types of industrial energy consumption and GDP, in Shanghai, for the period 1952-1999, using a Toda-Yamamoto causality test. In this study, the authors conclude that there is unidirectional Granger causality from coal, coke, electricity and total energy consumption to real GDP and no causality, in any direction, between oil and real GDP.

(Awerbuch and Sauter, 2006) conclude that renewable energy sources have a positive effect on economic growth, decreasing the negative impact of oil price volatility and providing security for power supply.

Using the same approach as (Sari and Soytas, 2004), (Ewing et al., 2007) investigates the relative impacts of disaggregate energy consumption (coal, oil, natural gas, hydro power, wind, solar, waste and wood) and employment on industrial output in the USA over the monthly data period 2001:1-2005:6. Their results suggest that unexpected shocks to coal, natural gas and fossil fuel energy sources have the highest impacts on the variation of industrial output, while several renewable sources exhibit considerable explanatory power as well; hydroelectric power explains roughly 1,9% of the forecast error variance for industrial production; solar 3,8%; waste 10,6%; wood 6%; wind 5,8%; and total renewable energy consumption 2,4%. They also found that employment explains more of the forecast error variance of industrial output than any energy sources.

In a follow-up study to (Ewing et al., 2007), (Sari et al., 2008) estimate an autoregressive distributed lag (ARDL) model, for the period 2001:1-2005:6, to analyze the relationship between disaggregate energy consumption (coal, fossil fuels, conventional hydroelectric power, solar energy, wind energy, natural gas, wood and waste), industrial production, as well as employment, in the USA. They find that in the long run industrial production has a positive impact and employment a negative impact respectively on hydroelectric, waste, and wind energy consumption. In contrast, industrial production has a negative impact and employment a positive impact on solar energy consumption, while neither industrial production nor employment have a statistically significant long run impact on natural gas and wood energy consumption.

(Payne, 2009) focusing attention on the USA for the period 1949-2006, employs the Toda-Yamamoto causality test in a multivariate framework, with the inclusion of capital and labor, to compare the causal relationship between RES and non-RES energy consumption and real output. The author finds that the Toda-Yamamoto test reveals the absence of Granger causality between renewable or non-renewable energy consumption and real output, thus supporting the neutrality hypothesis.

(Bowden and Payne, 2009) compute the Toda-Yamamoto test to examine the causal relationship between renewable and nonrenewable energy consumption by sector and real GDP in the USA for the period 1949-2006. The test reveals the absence of Granger causality with respect to commercial and industrial renewable energy consumption and real GDP. However, it also reveals bidirectional Granger causality between commercial and residential non-renewable energy consumption and real GDP. Finally, the results find unidirectional causality from residential renewable energy consumption and industrial non-renewable energy consumption, to real GDP.

In the same year, (Sadorsky, 2009b) used an empirical model to estimate the impact of RES, which include wind, solar, geothermal, biomass, wave and tidal, in economic growth and $CO_2$ emissions for the G7 countries. The author found, through the panel cointegration he estimated, that in the long term increases in real GDP per capita and $CO_2$ emissions per capita are found to be major drivers behind renewable energy consumption per capita. The oil price increases had a smaller although negative impact on renewable energy consumption.

The second group of studies relied mostly on cross-section panels, which generalizes the causal relationship between energy consumption and economic growth across few years and very countries. The question of using cross-sectional method is that gathering into groups economies that are at different stages of economic development. This method fails to address the country-specific effects of energy consumption on economic growth.

(Chien and Hu, 2007) analyze the effects of renewable energy on technical efficiency in 45 economies, during the period 2001-2002. They use a data envelopment analysis (DEA) model, which includes as inputs labor, capital stock and energy consumption and as output real GDP, and conclude that the increase of the use of renewable energy, among total energy supply, has a significantly positive impact on technical efficiency that is measured in each economy by how far apart they are from their efficiency frontier in that year. On the other hand, the increase of the use of traditional energies (non-renewables) decreases technical efficiency. OECD economies, comparatively to non-OECD economies, have higher technical efficiency and a higher share of geothermal, solar, tide and wind fuels in renewable energy sources. However, non-OECD economies have a higher share of renewable energy in their total energy supply than OECD economies.

(Chang et al., 2009) use a panel threshold regression (PTR) model for OECD countries in the period 1997-2006 to investigate the influence of energy prices in the development of renewable energy sources. The authors claim that there isn't a simple and direct relationship between GDP and the contribution of renewables to energy supply. They still conclude that the level of economic growth of a country influences the use of renewable energy, because RES are a way to respond to shocks in the oil prices. Countries with high economic growth use RES to minimize the effects of adverse shocks in prices, while countries with low income tend to be unresponsive to energy price changes in the renewable energy use. In other words the contribution of renewable energy is price inelastic in low-growth countries.

(Sadorsky, 2009a) investigates the relationship between renewable energy consumption per capita (wind, solar, geothermal, wood and waste) and income per capita, in 18 emerging economies, within a bivariate panel error correction model, for the period 1994-2003. His results present evidence of bidirectional causality between renewable energy consumption and economic growth. They show that increases in real per capita income have a positive and statistically significant effect on per capita renewable energy consumption. In the long run, a 1% increase in real income per capita increases the renewable energy consumption per capita by approximately 3,5% in emerging economies and the renewable energy per capita consumption price elasticity estimates are approximately equal to -0,70.

Recently (Apergis and Payne, 2010) studied the relationship between renewable energy consumption and economic growth in 20 OECD countries, during the period 1985-2005, in a multivariate framework, through panel cointegration and error correction model, including labor force and capital formation in their analyses. The authors find a long-run equilibrium relationship between real GDP, renewable energy consumption, capital formation and labor force as well as bidirectional causality between renewable energy consumption and economic growth in both short and long run in Eurasian countries. They also find that a 1% increase in renewable energy consumption increases real GDP by 0.76%, a 1% increase in real gross fixed capital formation increases real GDP by 0.70% and a 1% increase in the labor force increases real GDP by 0.24%.

With respect to the particular case of the Iberian Peninsula, it appears that these countries have rarely been considered in the research agenda. However, there are some published papers that discuss the relationship between energy or electricity consumption and economic growth in Portugal and/or Spain, which will be presented below.

(Paresh Narayan and Prasad, 2008) use a bootstrapped causality testing approach in 30 OECD economies, for the period 1960-2002, and conclude that there was a causality relationship from electricity consumption to GDP in Portugal.

(Shahbaz et al., 2011) use a cointegration approach (unrestricted error correction model) and Granger causality (vector error correction model) to evaluate the relationship between electricity consumption, economic growth and employment in Portugal, during the period 1971-2009. The authors conclude that electricity consumption, economic growth and employment in Portugal are cointegrated and that there is a bidirectional Granger causality between the three variables, in the long run. With the exception of a Granger causality between electricity consumption and economic growth, the rest of the variables also have a bidirectional Granger causality, in the short run. They also conclude that there is a unidirectional Granger causality of economic growth to electricity consumption, although the inverse does not apply.

(Ciarreta and Zárraga, 2007) used the methodology of Toda-Yamamoto and Dolado and Lütkepohl and also apply the standard Granger causality tests in a VAR for the series in first differences to achieve stationarity, for the period of 1971-2005, to analyze the linear and nonlinear causality between electricity consumption and economic growth in Spain. They found unidirectional linear causality from real GDP to electricity consumption and by contrast they found no evidence of nonlinear Granger causality between the series in either direction.

The last group of studies is based on the SVAR model, which is yet underexplored in the energy economics literature and there are few studies based on this model.

A very recent study prepared by (Silva et al., 2011), of Faculdade de Economia do Porto, used a SVAR approach that had been applied to India by (Tiwari, 2011), in order to assess to what extent the increase in electricity production from RES affects GDP and $CO_2$ emissions in four distinct economies, among which the two of the Iberian Peninsula, for the period 1960-2004. In the estimation of SVAR they used as constraints that RES affects GDP and $CO_2$, GDP affects $CO_2$ and $CO_2$ does not affect any other variable. Through the impulse-response functions, estimated by their SVAR, they conclude that for all countries of the model, except for the U.S., the increase of RES has economic costs in terms of GDP per capita and leads to a reduction in $CO_2$ emissions. Through the variance decomposition they conclude further that a significant part of the forecast error variance of GDP per capita and a relatively minor part of the error variance of $CO_2$ emissions is due by the RES.

## 4. Econometric model

Despite the large number of studies in the literature of energy economics using a reduced form vector autoregressive (VAR) model to examine the relationship between the variables of interest, there are only a few references using a structural vector autoregressive (SVAR) model to the same purpose.

The VAR model of (Sims, 1980) is considered a popular econometric tool used in many empirical studies, mainly in the field of macroeconomics and finance. This model is a reduced-form system of a list of time series describing the economy that is estimated by ordinary least squares, treating all variables symmetrically and where the econometrician "does not rely on any incredible identification restrictions"[1].

In VAR analysis, the impulse response functions and the variance decomposition show the dynamic characteristics in empirical modeling. These quantities are obtained in such a way that some authors believe unrelated to economic theory, which takes this model to be often described as atheoretical.

So, a main disadvantage of this approach is related to economic theory, which plays a limited role and it only serves to determine the order in which the innovation shocks are imposed or, in other words, it corresponds to the order in which the variables in $y_t$ are arranged.

This criticism led to the development of a "structural" VAR approach by (Bernanke, 1986), (Blanchard and Watson, 1987) and (Sims, 1986), which allows to use economic theory to transform the reduced-form VAR model into a system of structural equations, where the parameters are estimated by imposing structural restrictions. The main difference between unrestricted and structural VARs is that the latter provide impulse responses and variance decompositions that can be given structural interpretations.

(Shapiro and Watson, 1989) and (Blanchard and Quah, 1990) developed a specific structural VAR model, which uses long-run restrictions to identify the economic structure from the reduced form. These models have long-run characteristics that are consistent with the theoretical restrictions used to identify parameters. Moreover, they often exhibit sensible short-run properties as well.

Although unrestricted VAR and SVAR models are different in some important aspects, the later model may be considered one of the best econometric tools to estimate the structural relationship between the variables of interest like, energy production, economic growth and $CO_2$ emissions. SVAR model makes it also possible to analyze

[1] (Sims, 1980)

the net effect of an unexpected change in one variable (like oil price shock) on the other variables in the system.

In this dissertation, it is used a SVAR approach to estimate the impact of renewable energy sources on economic growth and $CO_2$ emissions and the model specifications are described next.

Structural VAR($p$) model is related to the non-structural VAR($p$) model

$$y_t = c + \Psi X_t + \Phi_1 y_{t-1} + \cdots + \Phi_p y_{t-p} + v_t \quad (1)$$

with $t = 1, \dots, T$

where

- $y_t$=*[TRES, GDP, $CO_2$Emiss]* or $y_t$=*[RES, Hydro, GDP, $CO_2$Emiss]* is an nx1 vector of endogenous variables, with n=3 or n=4;
- $c$ is a n-vector of intercept parameters;
- $\Psi$ is a matrix 3xk (analysis with 3 variables) or 4xk (analysis with 4 variables), where k represents the exogenous variables;
- $X_t$ is a kx1 vector that includes the dummies variables and the oil prices;
- $p$ denotes the order of the VAR model;
- $\Phi_j$ are nxn parameter matrices;
- $v_t \sim w.n._k$ with $E(v_t) = 0_{kx1}, E(v_t v'_t) = \Omega_{kxk}$ is an nx1 vector of reduced form errors.

by

$$y_t = A_0^{-1}\mu + A_0^{-1}\Pi X_t + A_0^{-1}A_1 y_{t-1} + \cdots + A_0^{-1}A_p y_{t-p} + A_0^{-1}u_t \quad (2)$$

Hence

- $c = A_0^{-1}\mu$;
- $\Psi = A_0^{-1}\Pi$
- $\Phi_p = A_0^{-1}A_p$ for $p$ = 1,..,$p$;
- $v_t = A_0^{-1}u_t \sim w.n.$ with $\Omega = E(v_t v'_t) = E(A_0^{-1}u_t u'_t A'^{-1}_0) = A_0^{-1}\Sigma_u A'^{-1}_0$;

And, so, the latter parameter can be transformed into

$$u_t = A_0 v_t \quad (3)$$

with $\Sigma_u = A_0 \Omega A'_0$.

As we can observe from above, effectively the matrix $A_0$ of structural parameters links the non-structural innovations $v_t$ to the structural innovations $u_t$.

In this model there exists unpredictable or structural shocks ($\varepsilon_t$) like preferences, oil shocks, among others, that are related to $v_t$ and determine the dynamics of $y_t$. Due to unpredictability, assume that $\varepsilon_t$ are mutually uncorrelated (thus orthogonal), $\varepsilon_t \sim w.n.(0, I_k)$, and, for simplicity, assume that the structural errors $u_t$ depend of $\varepsilon_t$ by a linear relation,

$$u_t = B\varepsilon_t \quad (4)$$

with $\Sigma_u = BB'$

So, a SVAR model can be written as

$$A_0 y_t = \mu + \Pi X_t + A_1 y_{t-1} + \cdots + A_p y_{t-p} + B\varepsilon_t \quad (5)$$

where the matrix $A_0$ is used to model the instantaneous relationships; the matrix $B$ contains structural form parameters of the model; $y_t$=*[TRES, GDP, $CO_2$Emiss]* or $y_t$=*[RES, Hydro, GDP, $CO_2$Emiss]* and the non-structural VAR errors are

$$v_t = A_0^{-1} B\varepsilon_t \quad (6)$$

with $\Omega = A_0^{-1} BB' A'^{-1}_0$.

Now, in order to identify the structural form parameters $A_0$ and $B$, we need to place restrictions on these nxn matrices.

At the unrestricted VAR model, there are $k\ (k + 1)/2$ non-redundant available terms at the variance-covariance matrix $\Omega$ and, at most, we can only identify these number of parameters at the structural form, $A_0$ and $B$, out of a total of $2k^2$ coefficients. So, in this case we need to impose at least

$$2k^2 - \frac{k(k+1)}{2} = k^2 + \frac{k(k-1)}{2} \quad (7)$$

restrictions at $A_0$ and $B$ to identify the full model.

Even if we assume $A_0$ or $B$ equal to the identity matrix we would still need extra $\left(k^2 + \frac{k(k-1)}{2}\right) - k^2 = \frac{k(k-1)}{2}$ restrictions.

There are 4 types of SVAR models according to identification/restriction schemes and for this study it is chosen to be estimated the *AB* model proposed by (Amisano and Giannini, 1997): $A_0 v_t = B\varepsilon_t$ with $\left(k^2 + \frac{k(k-1)}{2}\right)$ restrictions out of $vec(A_0) = R_{A_0}\gamma_{A_0} + r_{A_0}$ and $vec(B) = R_{B}\gamma_{B} + r_B$ and so, we need to identify $k\ (k\ +1)/2$ parameters. It is chosen the *AB* model because, by construction, the structural restrictions are placed at both $A_0$ and *B*.

For more about this model, please read (Hamilton, 1994) or (Enders, 2003).

The SVAR model presented above is applied for Portugal and Spain, firstly with 3 variables and after that with 4 variables. All variables are expressed in variations (renewables and hydroelectric in absolute variations and GDP, $CO_2$ emissions and oil prices in relative variations), because of the unit root tests results.

In the SVAR model presented below, variables in the left side of the system are the residuals ($v_t$'s) obtained from the reduced form VAR equations, representing unexpected disturbances and variables in the right side of the system represent the structural disturbances/innovations (ε's), associated to the different variables.

For Portugal and Spain, in a SVAR context, the tri-variable system of equations can be written as follows:

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ a_{31} & a_{32} & 1 \end{bmatrix} \begin{bmatrix} v_t^{\Delta TRES} \\ v_t^{\Delta GDP} \\ v_t^{\Delta \mathrm{CO2}Emiss} \end{bmatrix} = \begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{\Delta TRES} \\ \varepsilon_t^{\Delta GDP} \\ \varepsilon_t^{\Delta \mathrm{CO2}Emiss} \end{bmatrix} \quad (8)$$

In the constraints above, all variables are in grow rates, and so, Δ*TRES* represents the energy production from total renewable energy sources, Δ*GDP* represents the gross domestic product and $\Delta CO_2 Emiss$ represents the $CO_2$ emissions.

The first equation represents an external shock emanating from ΔTRES. The second equation represents an external shock emanating from ΔGDP. Both first and second equations despict no contemporaneous relationship between ΔTRES, ΔGDP and $\Delta CO_2$ emissions. The third equation implies that the $\Delta CO_2$ emissions are contemporaneously affected by both the ΔTRES and the ΔGDP.

The last constraint can be explained in terms of economic theory by the fact that $\Delta CO_2$ emissions are highly dependent of the behavior of these two variables, according as $CO_2$ emissions tend to vary directly with GDP and inversely with TRES.

With 4 variables, the SVAR model can be expressed as follows:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix} \begin{bmatrix} v_t^{\Delta RES} \\ v_t^{\Delta \mathrm{Hydro}} \\ v_t^{\Delta GDP} \\ v_t^{\Delta \mathrm{CO2}Emiss} \end{bmatrix} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{\Delta RES} \\ \varepsilon_t^{\Delta \mathrm{Hydro}} \\ \varepsilon_t^{\Delta GDP} \\ \varepsilon_t^{\Delta \mathrm{CO2}Emiss} \end{bmatrix} \quad (9)$$

In this case, the constraints above include ΔR*ES*, which represents the energy production from renewable energy sources, excluding hydroelectric, Δ*Hydro* represents the energy production from hydroelectric sources and Δ*GDP* and $\Delta CO_2 Emiss$ represent the same as in the first case.

The first equation despicts an external shock emanating from ΔRES. The second equation represents an external shock emanating from ΔHydro. The third equation represents an external shock emanating from ΔGDP. These three equations despict no contemporaneous relationship between ΔRES, ΔHydro, ΔGDP and $\Delta CO_2$ emissions. The fourth equation represents the $\Delta CO_2$ emissions to be contemporaneously affected by ΔRES, Δhydro and the ΔGDP.

# 5. Empirical results and discussion

After defining the theoretical framework it is now presented the data source and methodology used as well as the empirical results, for Portugal and Spain, during the period from 1960 to 2009, which includes results obtained using E-views software in terms of unit root tests, cointegration tests and the SVAR model estimated as well as the impulse-response functions and variance decomposition.

## 5.1 Data source and methodology

This section describes the data set used in this study as well as the sources where it was collected and the methodology followed in this dissertation.

This study uses annual data for real gross domestic product (GDP) (Appendix 3), $CO_2$ emissions (Appendix 4), renewable energy production (Appendix 5), hydroelectric energy production (Appendix 6) and oil prices (Appendix 8), from 1960 to 2009, that is, a 50-year period, for the Iberian Peninsula countries (Portugal and Spain).

Since this sample period contains some important events for each country, some structural breaks are considered throughout the empirical analysis, more specifically in the VAR specification and estimation.

Annual data for renewable energy production, hydroelectric production and $CO_2$ emissions per capita were obtained from the World Bank online database (http://databank.worldbank.org/ddp/home.do). Data for GDP per capita was taken from the European Comission online database (http://ec.europa.eu/economy_finance/ameco/user/serie/SelectSerie.cfm). Data for Oil Prices were sourced from Inflation Data (http://inflationdata.com/inflation/inflation_rate/historical_oil_prices_table.asp).

Renewable energy production is measured by a percentage of total electricity production from renewable sources, which includes, for Portugal, wind, solar photovoltaic, geothermal, biogas, primary solid biofuels and waste, and the same for Spain but with solar thermal instead of geothermal, and excluding hydroelectric in both countries; hydroelectric production is measured by a percentage of total electricity production from hydroelectric sources; GDP per capita, in euros, in 2005 market prices is used as a proxy of economic growth; $CO_2$ emissions in metric tons per capita including carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring; finally, oil prices are measured as an annual average on West Texas Intermediate (WTI) crude oil at constant prices (Index 2005). It is also important to highlight that there are two types of oil prices: the WTI crude oil, mostly used in the

USA and the Brent oil, mostly used in Europe, but as the two types move closely and as I didn't get the series of Brent for a long time period, I chose to include the WTI prices as exogenous variable, instead of Brent in this dissertation.

This dissertation presents two approaches: firstly, analysis is based on total renewable energy sources, measured as the sum of renewable energy sources (RES) plus hydroelectricity; secondly an analysis is performed for RES disaggregated, in other words considering hydro separately from other RES. The decision to include these two analyses is due to the presence of a high percentage of hydroelectric sources in both countries, so it would be important to understand if considering these separately from other renewables has a significant impact on the results obtained.

Both analyses begin with the examination of the stationarity properties of the variables by employing a battery of unit root tests, like Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests. For the first two unit root tests the null hypothesis is a unit root process, which means that the series is non-stationarity, while the alternative hypothesis is stationarity. For the KPSS test the null hypothesis is stationarity and the alternative hypothesis is non-stationarity.

Then, to determine whether the variables are cointegrated or not the Johansen method is employed (Johansen, 1988).

For more details on this topic, please read (Enders, 2003) and (Hamilton, 1994).

In the next step, after transforming all variables into natural logarithms, in order to minimize the fluctuations of the series, the VAR lag-length is determined by employing the VAR Order Selection Criteria and the Lag Exclusion Wald Tests.

After this, a SVAR model is estimated assuming as restrictions, for the aggregate analysis, that TRES and GDP affect $CO_2$ emissions, although $CO_2$ does not affect directly any of the other variables and for the disaggregate analysis assuming that RES, hydro and GDP do not receive any impact of the others variables and only $CO_2$ emissions receive a negative impact of the hydro and a positive impact of GDP.

Afterwards, the impulse-response functions (IRFs) are plotted, in order to evaluate how a variable reacts if in a given time a shock occurs in a unit of another variable.

And finally, the forecasts error variance decomposition of the SVAR model are presented to determine which shocks are the main cause of uncertainty of forecasting the endogenous variables in the system.

## 5.2 Unit root analysis

We start by applying the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) unit root tests to each individual series, in order to conclude whether the series are stationarity or not.

The tests are based on the following hypothesis:

| Intercept | Trend and Intercept |
|---|---|
| $H_0$: DSP | $H_0$: DSP |
| $H_1$: I (0) | $H_1$: TSP |

**Table 4 - Tests hypothesis**

**Note: DSP** - difference stationarity process; **TSP** - trend stationarity process; **I(0)** - Stationary

Below it is presented a table with the results for each series and test, for the intercept and trend and intercept cases:

| | | p-values | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ADF | | PP | | KPSS | | | | | | | |
| | | | | | | Intercept | | | | Trend and Intercept | | | |
| | | Intercept | Trend and Intercept | Intercept | Trend and Intercept | t-stat | 1% | 5% | 10% | t-stat | 1% | 5% | 10% |
| GDP | PT | 0,64 | 0,27 | 0,82 | 0,64 | 0,92 | 0,74 | 0,46 | 0,35 | 0,09 | 0,22 | 0,15 | 0,12 |
| | SP | 0,49 | 0,19 | 0,76 | 0,63 | 0,92 | 0,74 | 0,46 | 0,35 | 0,13 | 0,22 | 0,15 | 0,12 |
| $CO_2$ Emissions | PT | 0,71 | 0,29 | 0,71 | 0,78 | 0,89 | 0,74 | 0,46 | 0,35 | 0,09 | 0,22 | 0,15 | 0,12 |
| | SP | 0,27 | 0,93 | 0,32 | 0,85 | 0,86 | 0,74 | 0,46 | 0,35 | 0,13 | 0,22 | 0,15 | 0,12 |
| RES | PT | 1,00 | 1,00 | 1,00 | 1,00 | 0,53 | 0,74 | 0,46 | 0,35 | 0,17 | 0,22 | 0,15 | 0,12 |
| | SP | 1,00 | 1,00 | 1,00 | 1,00 | 0,61 | 0,74 | 0,46 | 0,35 | 0,20 | 0,22 | 0,15 | 0,12 |
| Hydro | PT | 0,78 | 0,002 | 0,62 | 0,002 | 0,91 | 0,74 | 0,46 | 0,35 | 0,18 | 0,22 | 0,15 | 0,12 |
| | SP | 0,02 | 0,08 | 0,14 | 0,13 | 0,86 | 0,74 | 0,46 | 0,35 | 0,23 | 0,22 | 0,15 | 0,12 |
| TRES | PT | 0,60 | 0,03 | 0,45 | 0,03 | 0,87 | 0,74 | 0,46 | 0,35 | 0,21 | 0,22 | 0,15 | 0,12 |
| | SP | 0,007 | 0,97 | 0,07 | 0,48 | 0,80 | 0,74 | 0,46 | 0,35 | 0,24 | 0,22 | 0,15 | 0,12 |
| Oil Prices | | 0,36 | 0,57 | 0,33 | 0,54 | 0,25 | 0,74 | 0,46 | 0,35 | 0,10 | 0,22 | 0,15 | 0,12 |

**Table 5 - Unit root tests**

We consistently find that we cannot reject the hypothesis of non-stationarity at the 5% level of significance for all variables, although there are some controversial results, mainly for the KPSS test with a trend and intercept, which indicates that all variables are TSP at least at one percent level of significance. So, we can conclude that all series are non-stationarity (DSP), although this is not so obvious for the Hydro and TRES series.

## 5.3 Cointegration analysis

### 5.3.1 Optimal lag lenght

In order to test for cointegration among the different variables of the system for each country, firstly we need to select the optimal lag length for the VAR model, applying the lag exclusion Wald tests at a maximum of 10% significance level and the LR test.

For Portugal and Spain, using aggregate energy consumption (total RES), both tests suggest that the optimal lag length is two and if it is considered disaggregate energy production (RES and Hydro), the Wald tests at a 5% level select one as the optimal lag length, but for 10% it suggests two lags. The LR test gives different results for each country: for Portugal it selects one as the optimal lag length and for Spain it considers two as the optimal lag. These results are presented in the table below and for more details see the Appendix 9.

| Country | Info Criteria | Aggregate Energy Production | Disaggregate Energy Production |
|---|---|---|---|
| | | Total RES | RES+Hydro |
| **PT** | **Wald tests** | Lag 2 | Lag 1 (5%) and Lag 2 (10%) |
| | **LR test** | | Lag 1 |
| **SP** | **Wald tests** | Lag 2 | Lag 1 (5%) and Lag 2 (10%) |
| | **LR test** | | Lag 2 |

**Table 6 - Optimal lag lenght**

### 5.3.2 Johansen method

Next, it is carried out the Johansen cointegration test for each country, firstly with total RES considering two lags and after with RES and hydro separately, considering the optimal lag as being equal to one for Portugal and two for Spain.

As it can be seen in the table below and more detailed in the outputs at Appendix 10, for Portugal with disaggregate energy and for Spain with aggregate energy and following the AIC criteria, the best model is the 5th[2] for a number of cointegrating vectors of r=1 and r=3, respectively, and for Portugal with aggregate energy and for Spain with

[2] 1st model: $\beta' y_t$ and VECM without deterministic components, no intercept and no trend; 2nd model: $\beta' y_t$ with intercept and VECM without trend ($y_t$ without trend); 3rd model: $\beta' y_t$ and VECM with intercept ($y_t$ with stochastic/linear trend); 4th model: $\beta' y_t$ with intercept and trend and VECM with trend ($y_t$ with deterministic/linear trend); 5th model: $\beta' y_t$ and VECM with intercept and trend ($y_t$ with quadratic trend).

disaggregate energy, the best model is the 4th for r=2 and r=1, respectively. Considering the SIC, the most suitable models are the 1st and the 2nd for r=0.

| Country | Info Criteria | Aggregate Energy Production | | Disaggregate Energy Production | |
|---|---|---|---|---|---|
| | | Total RES | | RES+Hydro | |
| PT | AIC | r=2 | 4th model | r=3 | 5th model |
| | SIC | r=0 | 1st and 2nd models | r=0 | 1st and 2nd models |
| SP | AIC | r=1 | 5th model | r=1 | 4th model |
| | SIC | r=0 | 1st and 2nd models | r=0 | 1st and 2nd models |

**Table 7 - Johansen method (Information criteria)**

Now, it is presented a table with the results for the Trace and Max-Eig tests, in order to conclude for the existence or not of cointegration between the variables.

| | | Aggregate Energy Production Total RES | | | | Disagregate Energy Production RES+Hydro | | | |
|---|---|---|---|---|---|---|---|---|---|
| Info Criteria | | SIC | | AIC | | SIC | | AIC | |
| Test Type | | 1st Model | 2nd Model | 4th Model | 5th Model | 1st Model | 2nd Model | 4th Model | 5th Model |
| PT | Trace | 0 | 0 | 1 | | 0 | 2 | | 1 |
| | Max-Eig | 0 | 1 | 1 | | 0 | 0 | | 0 |
| SP | Trace | 0 | 0 | | 0 | 0 | 0 | 0 | |
| | Max-Eig | 0 | 0 | | 0 | 0 | 0 | 1 | |

**Table 8 - Johansen method (Trace and Max-Eig tests)**

According to the cointegration tests trace and Max-Eig, both for the 1st and the 2nd models, it suggests that there isn't cointegration for series that are non-stationarity I (1).

Although, the information criteria give different results, I only have into account the SIC because the literature claims that it is more reliable than AIC.

So, in this dissertation, it is applied a SVAR model with variables in first-differences (relative variations for GDP, $CO_2$ Emissions and Oil prices and absolute variations for energy) and considering some restrictions based on the energy literature.

## 5.4 SVAR model

As it was done for cointegration analysis, the optimal lag length was estimated by applying the lag exclusion tests and the lag length criteria (based on LR test) and it was concluded that the optimal lag is one, as it can be seen in the table below. The outputs of the optimal lag lenght can be seen on Appendix 11.

| Country | Info Criteria | Aggregate Energy Production | Disaggregate Energy Production |
|---|---|---|---|
| | | Total RES | RES+Hydro |
| PT | Wald tests | Lag 1 | Lag 1 |
| | LR test | | |
| SP | Wald tests | Lag 1 | Lag 1 |
| | LR test | | |

**Table 9 - Optimal lag lenght in first differences**

### 5.4.1 Dummies

For the estimation of the model, in order to capture some important events that influences the observed data, we considered important to include some dummies in each series for specific years, due to the fact that the series have a short time period and they are not stable, showing large fluctuations over time. Below are presented the graphs in variations and a table for Portugal and Spain with the dummies included in each series.

### *5.4.1.1 Portugal*

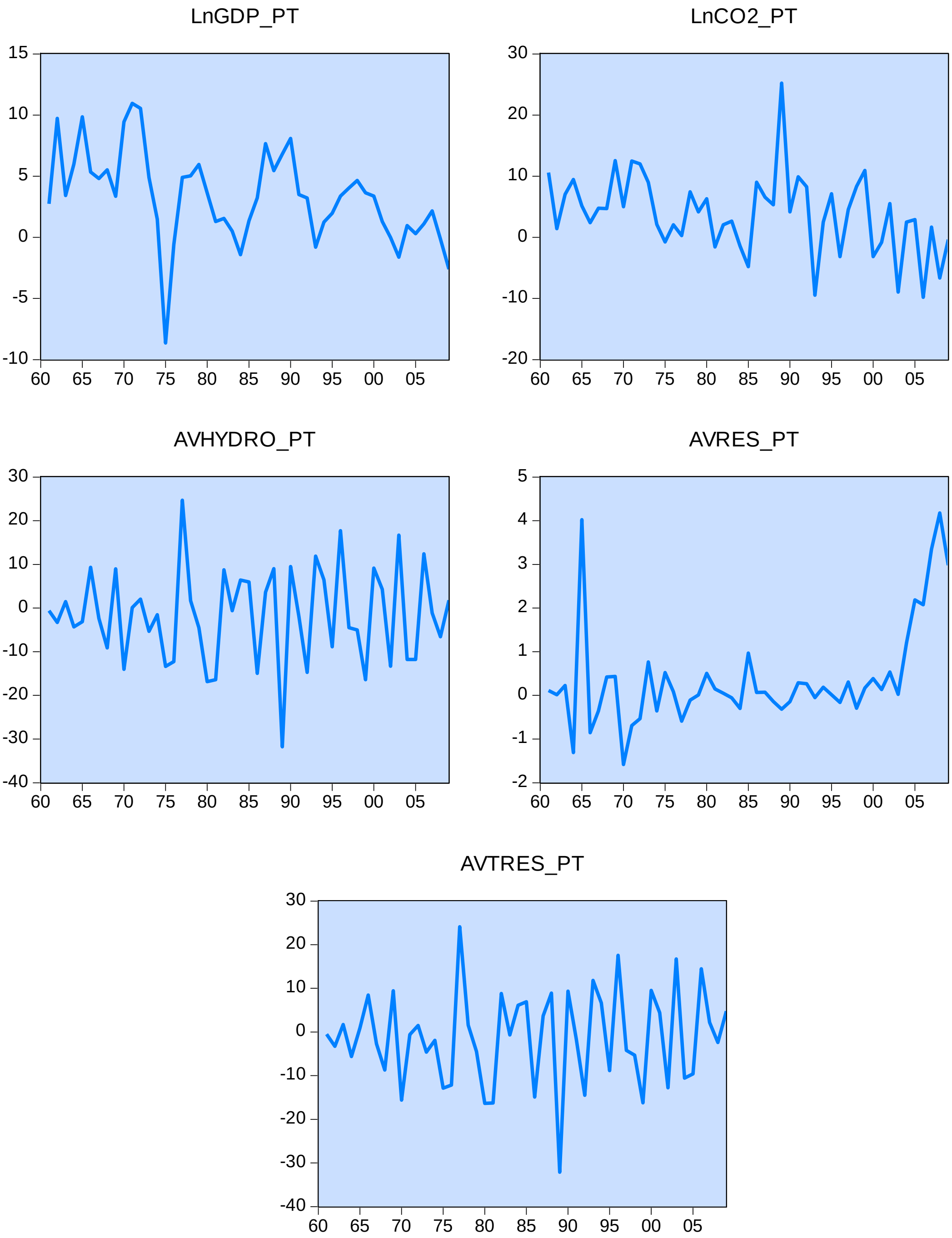


**Figure 7 - Series for Portugal in variations**

| GDP | $CO_2$ Emissions | Hydro | RES | TRES |
|---|---|---|---|---|
| 1975 - ↘ | 1989 - ↗ | 1977 – ↗ | 1965 – ↗ | 1977 – ↗ |
| | | 1989 - ↘ | >=2004 - ↗ | 1989 -↘ |

**Table 10 - Dummies for Portugal**

Beginning with GDP, the inclusion of a dummy in 1975 is due to a gap in economic growth in this year, which can be explained by the Carnation Revolution of 25th April of 1974, which had a negative impact in the economic growth in Portugal.

Analyzing the graphs of TRES and hydro it is possible to see a peak in 1977, which led to the inclusion of a dummy in this year. Comparing with the series of rainfall it appears that this year was very rainy, which led to the increase of water in dams and consequently the increase in electricity production from hydroelectric sources.

A dummy in 1989 due to a gap in energy production from RES and a peak in $CO_2$ emissions is explained by the increase of production from fossil fuels, which generate more pollution and consequently the increase of these emissions.

A dummy in 1965 due to a high positive peak in renewables and this is what generates dummy effect on oil prices.

From 2004 on there was a significant growth in RES, which can be explained by the implementation of the Kyoto Protocol commitments. Although it was created in 1997, it only entered into force in 2005 and seeks to fight global warming and consequently to decrease $CO_2$ emissions and increase energy production from RES.

### *5.4.1.2 Spain*

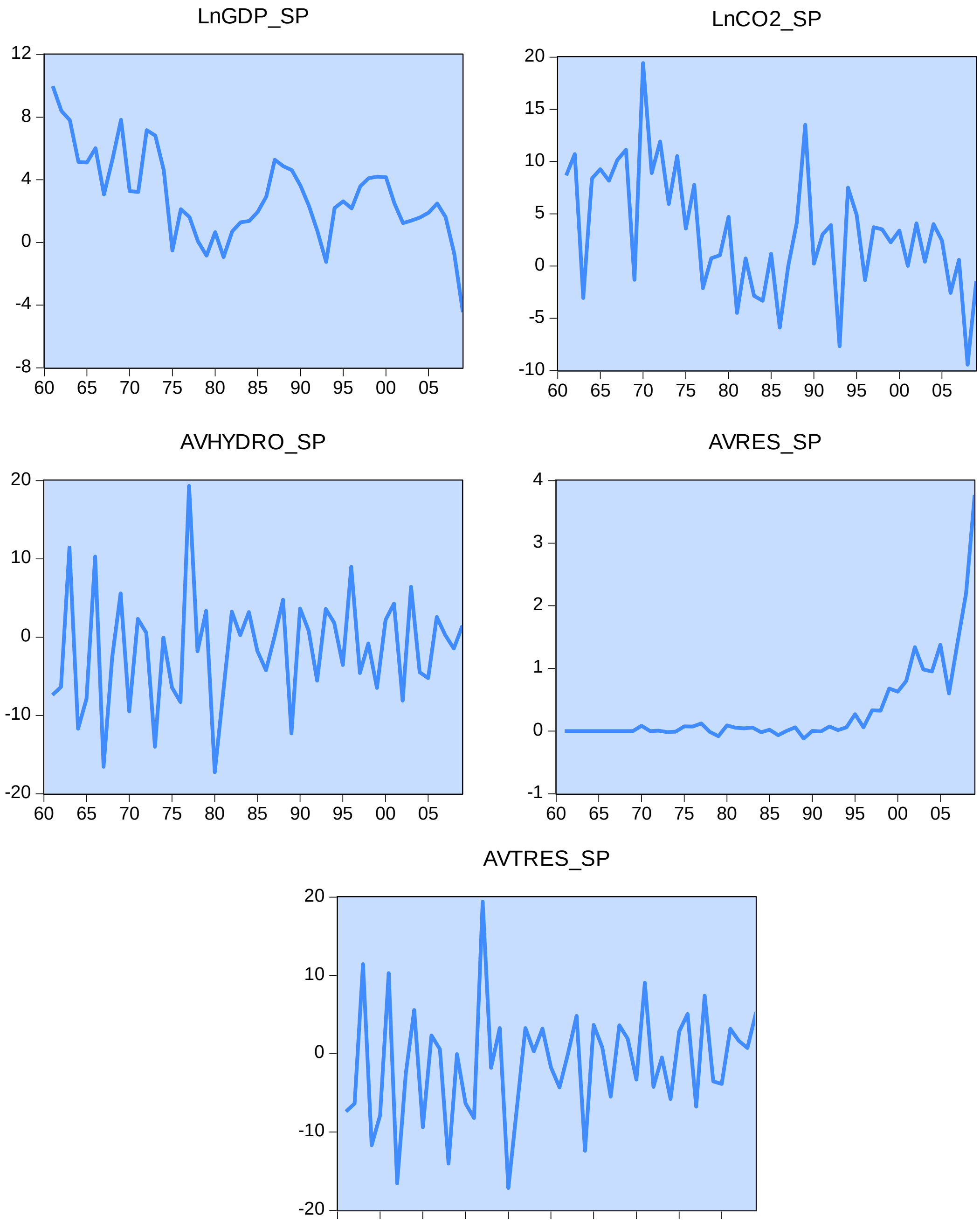


**Figure 8 - Series for Spain in variations**

| GDP | $CO_2$ | Hydro | RES | TRES |
|---|---|---|---|---|
| >=2007 - ↘ | 1970 - ↗ | 1977 – ↗ | >2007 - ↗ | 1977 – ↗ |
| | | 1980 - ↘ | | 1980 -↘ |

**Table 11 - Dummies for Spain**

In terms of the GDP series the dummy from 2007 on is due to the economic crisis that affected economic growth in many countries in Europe as well as in the USA.

A dummy in 1970, due to a peak in $CO_2$ emissions is perhaps due to the fact that renewables decrease in this year and the energy production from fossil fuels increase, which generated more pollution.

A dummy in 1977 is due to a peak in total RES, mainly in hydroelectric sources, as occurred for Portugal and can be explained by the fact that this year was very rainy.

A dummy in 1980 is due to a gap in hydroelectric sources because this year had low precipitation.

As happened for Portugal, from 2007 on we have seen exponential growth in energy production from RES, which can be explained by the transposition of EU Directives related to the Kyoto Protocol for the United Nations Framework Convention on Climate Change.

### 5.4.2 Oil shocks effects

For Portugal, lagged oil prices only have a significant impact on $CO_2$ emissions. In particular, a 1% increase on oil prices decrease $CO_2$ emissions in 0.07% if we consider aggregate analysis and a 0.05% decrease if we consider RES separated from hydro.

| | $\Delta CO_2$ Emissions | |
|---|---|---|
| | With total RES | With RES+Hydro |
| $\Delta$Oil Prices | -0.070338 | -0.052859 |

**Table 12 - Oil shocks effects in Portugal**

For the case of Spain, lagged oil prices, only have a significant impact on GDP (decreases in 0.03%).

| | $\Delta$GDP | |
|---|---|---|
| | With total RES | With RES+Hydro |
| $\Delta$Oil Prices | -0.031676 | -0.032255 |

**Table 13 - Oil shocks effects in Spain**

### 5.4.3 Estimated parameters ($A_0$ and B)

As we can observe from Appendix 13, only the growth rate of $CO_2$ emissions receives a contemporaneous impact from the other variables. In general, TRES/Hydro have a negative impact on $CO_2$ emissions whereas GDP has a positive one. For Portugal, the impact on emissions is of about a quarter percentage and for Spain it is a third. For every percentage point increase on GDP it is expected an increase of 0.63 pp in emissions in Portugal and of 1.15 in Spain. The estimated equations taken from the Appendix are given next.

#### *5.4.3.1 Portugal*

##### 5.4.3.1.1 With total RES

$$\Delta CO_2 Emissions = -0{,}278703 \Delta TRES + 0{,}631832 \Delta GDP + \cdots VAR\ lags \ldots \quad (10)$$

##### 5.4.3.1.2 With RES + Hydro

$$\Delta CO_2 Emissions = -0{,}264994 \Delta Hydro + 0{,}626768 \Delta GDP + \cdots VAR\ lags \ldots \quad (11)$$

#### *5.4.3.2 Spain*

##### 5.4.3.2.1 With total RES

$$\Delta CO_2 Emissions = -0{,}367596 \Delta TRES + 1{,}148582 \Delta GDP + \cdots VAR\ lags \ldots \quad (12)$$

##### 5.4.3.2.2 With RES + Hydro

$$\Delta CO_2 Emissions = -0{,}369166 \Delta Hydro + 1{,}154897 \Delta GDP + \cdots VAR\ lags \ldots \quad (13)$$

### 5.4.4 Impulse-Response Functions

This sub-section presents the impulse-response functions (IRF) estimated for the SVAR model to examine the effects on an endogenous variable of the economic system from an exogenous shock affecting this same system. The shock should be considered as unexpected. Furthermore, these functions are used to analyze the endogenous variables in the process of a dynamic transition, where a shock is introduced in a single period, in order to conclude about the behavior of the variables to achieve the long-run equilibrium (if it will be achieved).

To estimate the impulse-response functions, E-views constructs bootstrap percentile 95% confidence intervals to illustrate parameter uncertainty and it was considered responses of up to 10 years ahead.

IRF was estimated for all the series in variations and for each country, considering the aggregate energy production (total RES) and disaggregate energy production (RES+Hydro), as it happened along this dissertation.

Since the main goal of this dissertation is to study the impact of RES in the others variables, for each case we begin with the analysis of the graphs that report this situation.

### *5.4.4.1 Portugal*

#### 5.4.4.1.1 With total RES

Below it is presented the IRF graphs for Portugal considering the aggregate energy production.

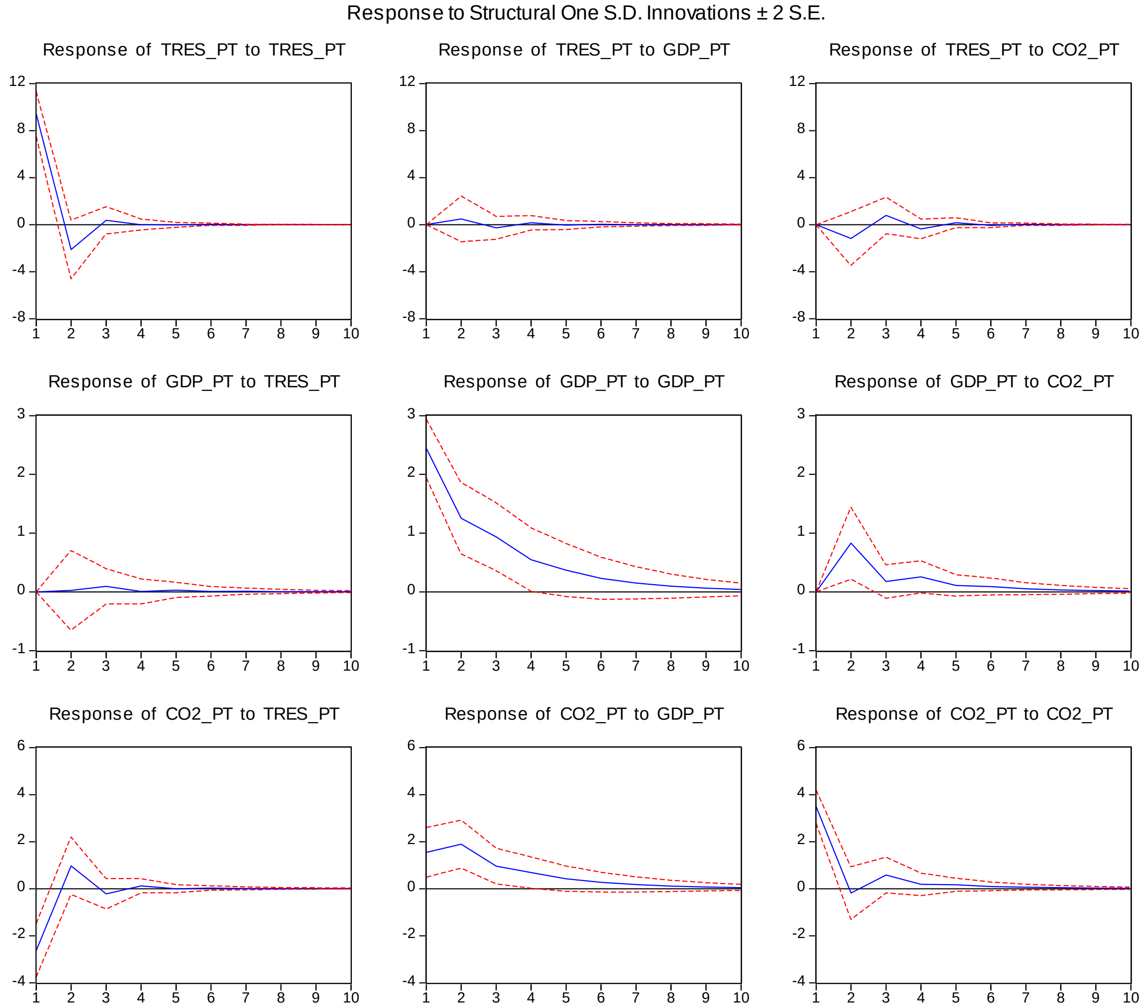


**Figure 9 - IRF for Portugal with aggregate energy**

Contrary to what was expected, the response of GDP on TRES shock and the impact of TRES on GDP shock are statistically insignificant, which means that the increase on energy production from renewable sources does not affect economic growth in Portugal, nor does the increase on economic growth affect energy production from renewable sources.

Another important conclusion that we can take from the graphs is the response of $CO_2$ emissions on TRES shock, which is negative during the first year about -2,5% and becomes positive during the second year (1%) from where it becomes statistically insignificant.

The case of the response of TRES to a shock on $CO_2$ emissions is negative during two years and half, achieving -1,5% in the second year, from where the impact becomes positive (1%) and from the fourth year it becomes statistically insignificant.

The GDP has a positive effect to a shock on $CO_2$ emissions during at least seven years, from where it becomes statistically insignificant. The biggest effect occurs on the second year, achieving a point of almost 1% of response.

The response of TRES to a shock on its own, we can verify that during the first year the impact is positive, about 9%, and in the second year it becomes negative, about -2%, and from the third year on the response of a shock becomes statistically insignificant and the equilibrium is achieved.

In terms of the response of GDP to a shock on its own we verify that the impact is positive over the first eight years, although it begins with a response of 2,5% and it is decreasing along the time until becomes zero in the eighth year.

The response of $CO_2$ emissions to a shock on its own has a positive impact over the first four years, beginning with a response of 3,5%, until IT becomes practically zero in the fourth year.

#### 5.4.4.1.2 With RES + Hydro

Now, the case of disaggregate energy in order to assess if there are differences between these two types of data or not.

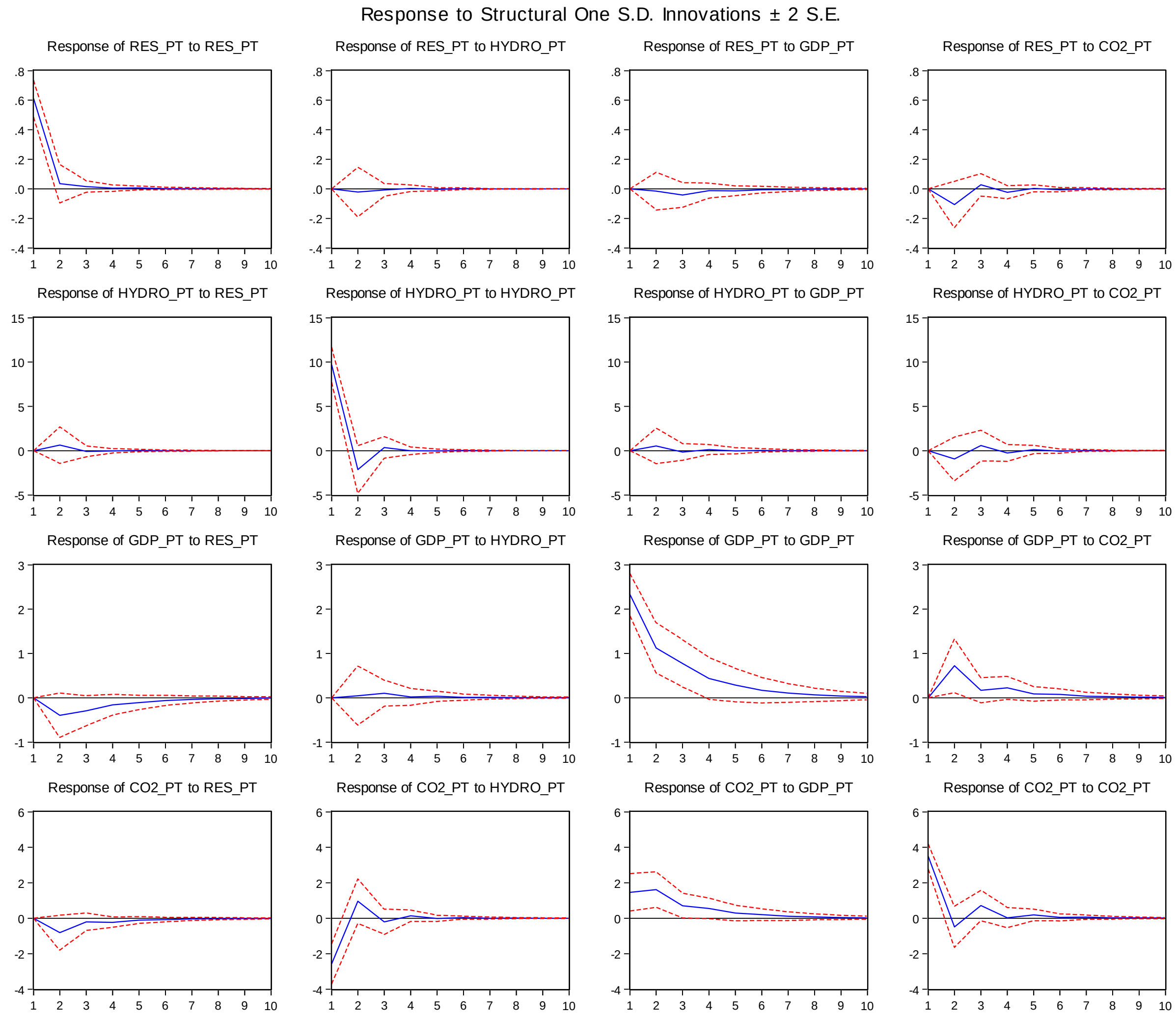


**Figure 10 - IRF for Portugal with disaggregate energy**

We can verify that the impacts of RES to Hydro, RES to GDP, RES to $CO_2$ emissions, Hydro to RES, Hydro to GDP, Hydro to $CO_2$ emissions, GDP to RES, GDP to Hydro, GDP to $CO_2$ emissions and $CO_2$ emissions to RES are statistically insignificant. In other words, this means that if a shock occurs in one of these second variables the other remains unchanged.

The response of $CO_2$ emissions to a shock on Hydro has a negative impact during the first year, drop of -2,5%, and a positive impact of 1% during the second year and from this moment on it becomes statistically insignificant as it occurs for TRES, because hydro is the variable that has a biggest weight on TRES.

The impact of $CO_2$ emissions to a shock on GDP is positive, though declining, during the first seven years, until it reaches equilibrium.

The response of RES to a shock on its own only has a short positive impact, about 0,6%, during the first year.

In relation to an impact of hydroelectric sources on its own the graph shows that during the first and half year the impact is positive, about 9%, and from the second year to the third the impact becomes negative, about -2%, and after this it reaches equilibrium.

In terms of the response of GDP on its own, GDP to $CO_2$ emissions, $CO_2$ emissions to GDP and $CO_2$ emissions on its own, the conclusions are the same as described for aggregate energy.

### *5.4.4.2 Spain*

#### 5.4.4.2.1 With total RES

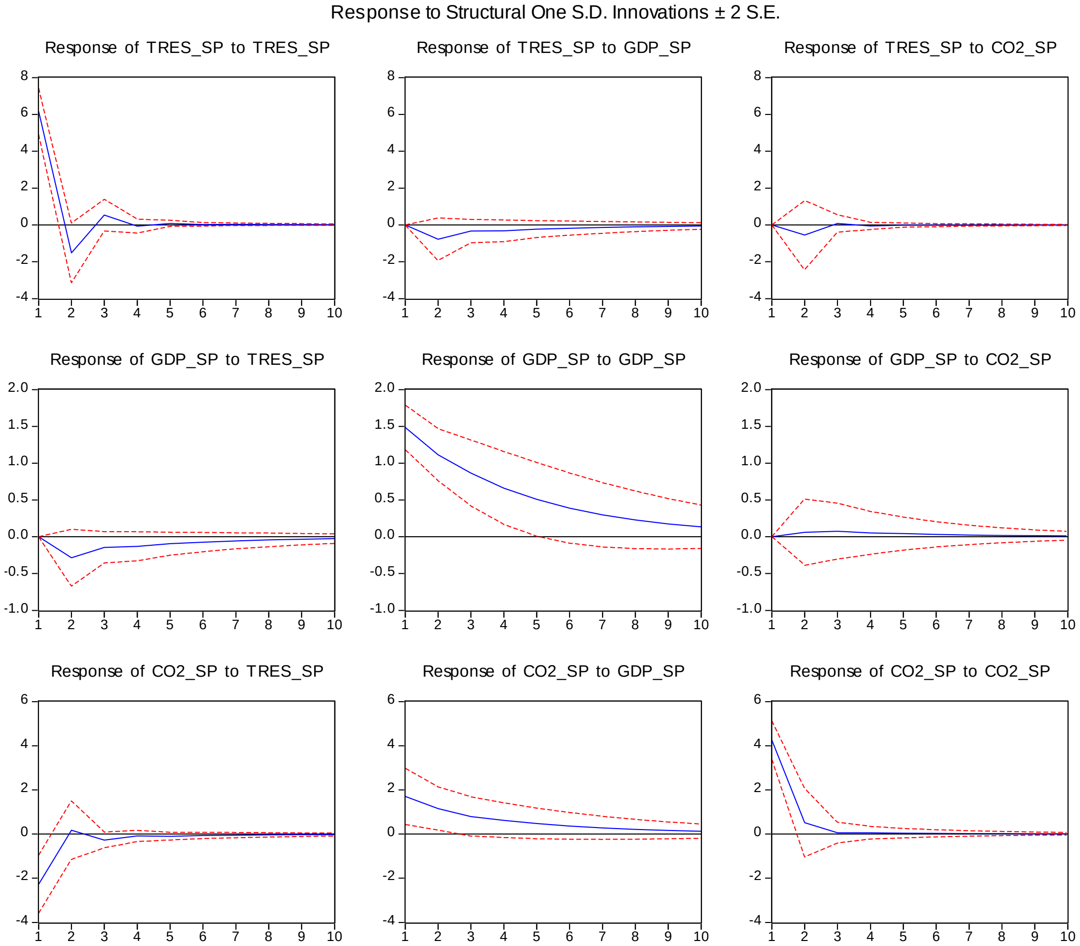


**Figure 11 - IRF for Spain with aggregate energy**

As described for Portugal, we can verify that some variables have a statistically insignificant impact if it occurs a shock in another variable. This situation is true for the response of TRES on GDP, TRES on $CO_2$ emissions, GDP on TRES and GDP on $CO_2$ emissions.

The response of $CO_2$ emissions to a shock on TRES is negative during the first year, about -2%, and becomes zero in the second year when the equilibrium is reached.

A shock on GDP causes a positive response on $CO_2$ emissions, though declining, during the first seven years, being the response at the first year of about 2%.

Observing the first graph that describes the response of TRES to a shock on its own, we can conclude that the response is positive, about 6%, during the first year, and negative about -1,5% during the second year until it reaches equilibrium.

If it occurs a shock on GDP the response of it is positive during the first ten years, though declining, beginning during the first year with a response of 1,5%.

In terms of the response of $CO_2$ emissions to a shock on its own it is positive during the first three years, beginning with a response of 4% during the first year that decreases until reach the equilibrium.

### 5.4.4.2.2 With RES + Hydro

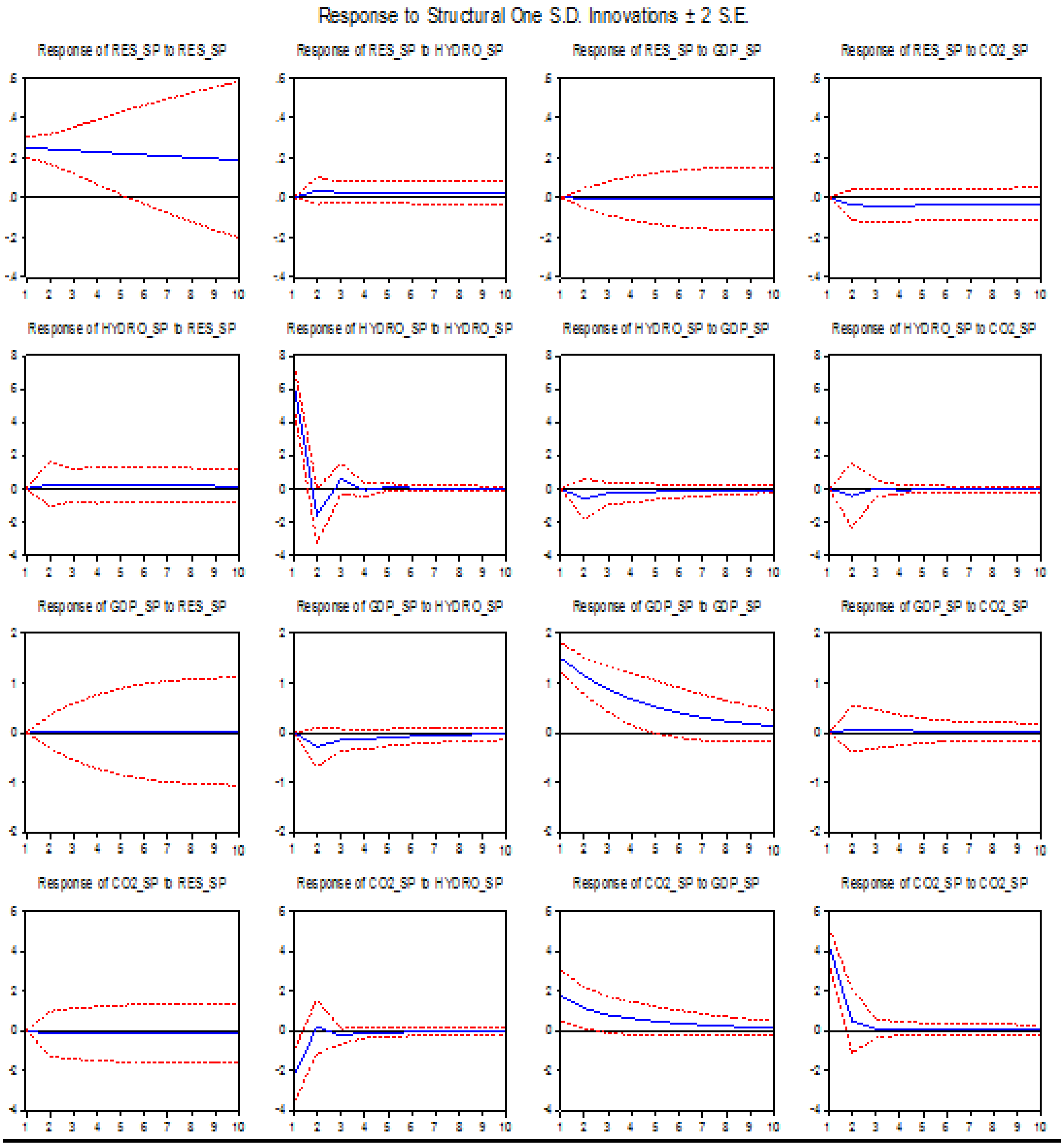


**Figure 12 - IRF for Spain with disaggregate energy**

As it was described for Portugal, we also observe for Spain that there are some variables that remain unchanged if there is a shock in one variable of the system. This fact is verified in the following situations: impact of RES to a shock on Hydro, RES to GDP, RES to $CO_2$ emissions, Hydro to RES, Hydro to GDP, Hydro to $CO_2$ emissions, GDP to RES, GDP to Hydro, GDP to $CO_2$ emissions and $CO_2$ emissions to RES.

The response of $CO_2$ emissions to a shock on Hydro is negative of about -2 % during the first year, and it has an insignificant impact from the second year on.

The impact of $CO_2$ emissions to a shock on GDP is positive, though declining, during the first seven years, until it reaches equilibrium.

So, the main conclusions for Portugal and Spain are similar. We must highlight the fact that, contrary to what was expected, a shock on energy, considering TRES or RES and hydro separately, does not have a significant impact on GDP; TRES and hydro only affect negatively $CO_2$ emissions during the first year. This situation led to conclude that hydroelectric sources dominate TRES, meaning that RES separately from hydro does not have any important impact on the others variables. Another important conclusion is the positive impact of $CO_2$ emissions to a shock on GDP that occurs at least during six years.

### 5.4.5 Variance Decomposition

In this sub-section it will be discussed the results for the variance decomposition which determines which shocks are the main cause for the forecast variability of endogenous variables of the system. As for the IRF case results are shown with aggregate energy and disaggregate energy.

#### *5.4.5.1 Portugal*

##### 5.4.5.1.1 With total RES

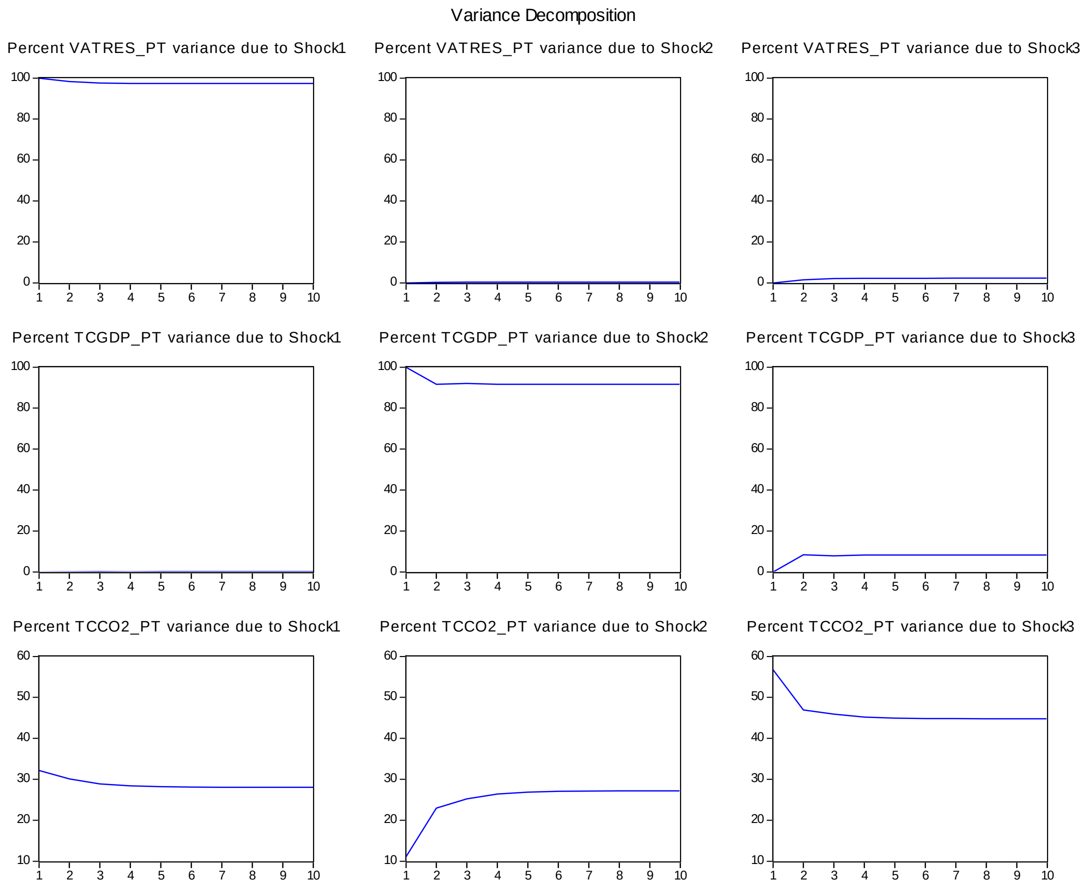


**Figure 13 - Variance decomposition for Portugal with aggregate energy**

Observing the first three upper graphs related to the variance in the growth rate of total RES, it appears that about 97% is caused by itself, 2,5% is due to shocks on $CO_2$ emissions and only 0,5% is caused by shocks on GDP, over the ten years window.

Analyzing the three graphs in the middle related to the variance in the growth rate of GDP, we can observe that about 91,5% is caused by itself, 8,4% is caused by the growth rate of $CO_2$ emissions and only 0,1% is due to shocks on TRES. It is important to refer that TRES seem not to have any impact on the variability of the economic growth of Portugal.

The last three graphs show the variance in the growth rate of $CO_2$ emissions, which suggest that about 30% is caused by the shocks in TRES and from the second year on, of about 25% due to a shock on GDP and 45% is caused by a shock on itself.

Thus, it is possible to conclude that there is a large amount of uncertainty in the forecast of the growth rate of $CO_2$ emissions due to TRES and almost no uncertainty in predicting the growth rate of TRES and GDP.

#### 5.4.5.1.2 With RES + Hydro

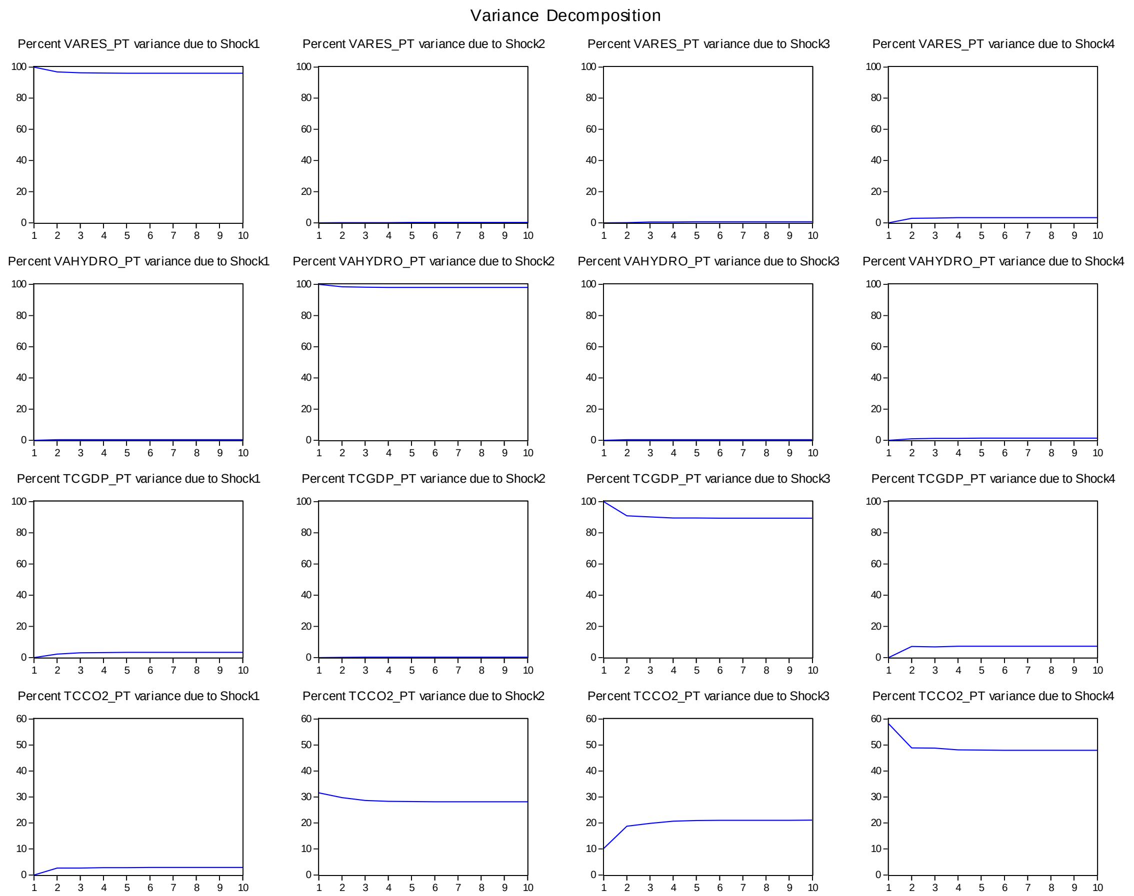


**Figure 14 - Variance decomposition for Portugal with disaggregate energy**

Observing the first fourth upper graphs related to the variance in the growth rate of RES, it appears that about 96% is caused by itself, 3% is due to shocks on $CO_2$ emissions, 0,6% due to shocks on GDP and only 0,4% is caused by shocks on hydroelectric sources.

Analyzing the fourth upper middle graphs related to the variance in the growth rate of hydroelectric sources, we can observe that about 98% is caused by itself, 1% is caused by the growth rate of $CO_2$ emissions, 0,6% by RES shocks and only 0,4% is due to shocks on GDP.

The fourth lower middle graphs related to the variance in the growth rate of GDP suggest, that about 90% is caused by itself, 7% is caused by the growth rate of $CO_2$ emissions, 2,9% by RES shocks and only 0,1% is due to shocks on hydro.

The last fourth graphs show the variance in the growth rate of $CO_2$ emissions, which suggest that about 48% is caused by the shocks in itself, about 28% due to a shocks on hydro, about 22% due to shocks on GDP and 2% is caused by a shock on RES.

From the results obtained in the graphs above, it is possible to conclude that there is a large uncertainty in the forecast of the growth rate of $CO_2$ emissions mainly due to a shock on hydro and almost no uncertainty in predicting the growth rate of RES, Hydro and GDP.

### *5.4.5.2 Spain*

#### 5.4.5.2.1 With total RES

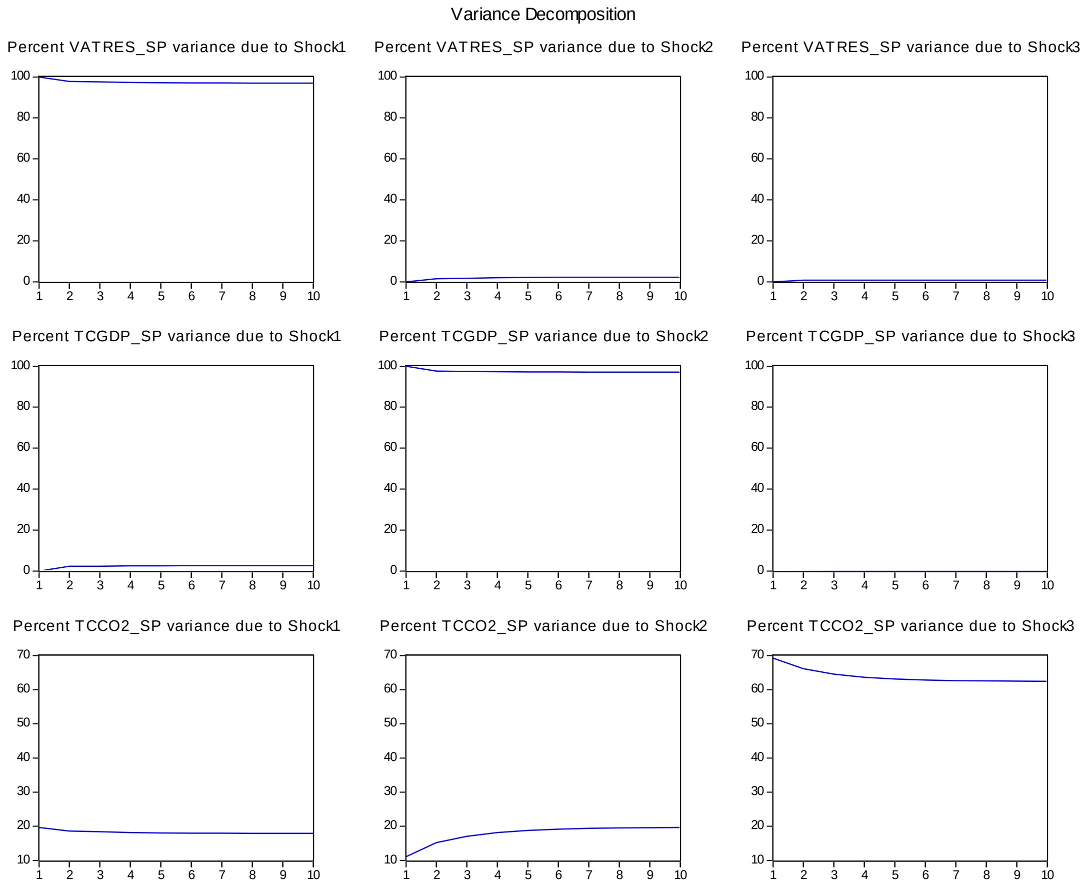


**Figure 15 - Variance decomposition for Spain with aggregate energy**

In the case of Spain, observing the first three upper graphs we conclude that about 97% of the variance in TRES is caused by itself, 1% is due to shocks in GDP and 1% to a shocks in $CO_2$ emissions.

Analyzing the three middle graphs related to the variance in the growth rate of GDP, we can observe that about 97% is caused by itself, 2,5% is caused by the growth rate of TRES and only 0,5% is due to shocks in $CO_2$ emissions.

The last three graphs show the variance in the growth rate of $CO_2$ emissions, which suggest that about 65% is caused by the shocks in itself, about 20% due to a shocks on TRES and 15% is caused by shocks on GDP.

Thus, it is possible to conclude that there is a large amount of uncertainty in the forecast of the growth rate of $CO_2$ emissions, mainly due to a shock on TRES, as it occurs for Portugal but to a smaller extend (20% in Portugal and 30% in Spain) and almost no uncertainty in predicting the growth rate of TRES and GDP.

### 5.4.5.2.2 With RES + Hydro

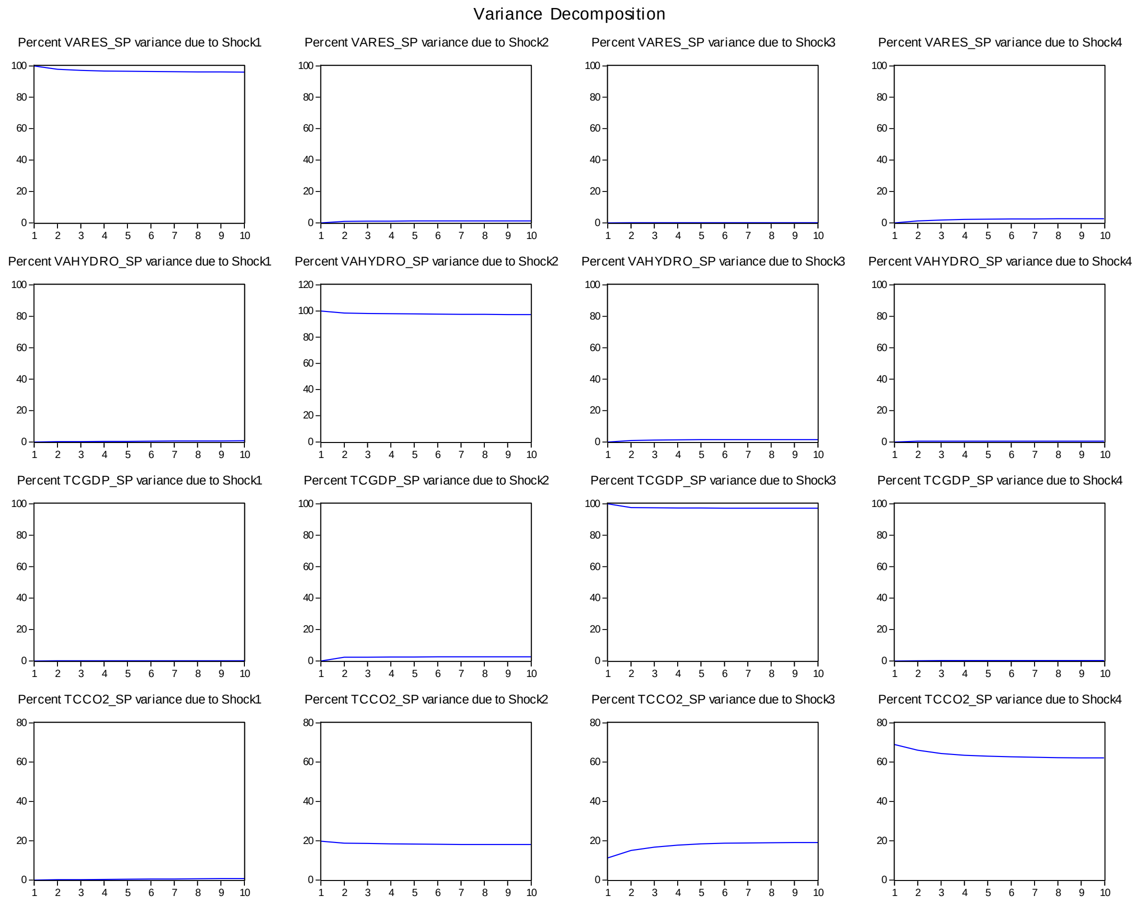


**Figure 16 - Variance decomposition for Spain with disaggregate energy**

Beginning with the analysis of the first fourth upper graphs, which show the variance decomposition of RES, we can conclude that about 96% of the variability is due to a shocks on itself, about 2,5% is caused by shocks on $CO_2$ emissions, 1% is due to shocks on hydro and only 0,5% is due to shocks on GDP.

The fourth upper middle graphs are related with the variance in hydroelectric sources, which suggest that 97,5% of the variability occurs due to a shocks on itself, 1,5% is due to a shocks on GDP, 0,5% is caused by a shocks on RES and also 0,5% is caused by shocks on $CO_2$ emissions.

Analyzing the fourth lower middle graphs which are related with the variance in GDP, they show that about 97% is caused by itself, 2,5% is caused by shocks on hydroelectric sources, 0,7% by $CO_2$ emissions shocks and only 0,3% is due to shocks on RES.

The last fourth graphs show the variance in the growth rate of $CO_2$ emissions, which suggest that about 61,5% is caused by the shocks in itself, about 19,5% due to a shocks on hydro, about 18% due to shocks on GDP and 0,5% is caused by a shock on RES.

Thus, we conclude, as for the case of Portugal, that the forecast of $CO_2$ emissions has much more uncertainty than the others variables of the system, being hydro the main responsible for this uncertainty.

Moreover, it is possible to conclude that hydroelectric sources are the main responsible for the variation in $CO_2$ emissions, as we can observe in the graphs of these series showed in 5.4.1, where we see that in some specific years, like 1989 in the case of Portugal, when hydroelectric decreases $CO_2$ emissions increase substantially, because energy production is generated mainly from fossil fuels, which have a higher negative impact on environment.

# 6. Conclusions and policy implications

This dissertation seeks to investigate the linkages between energy production from renewable sources, economic growth and $CO_2$ emissions in the Iberian Peninsula (Portugal and Spain) for the period 1960-2009. It also includes the oil prices series as an exogenous variable in order to ascertain whether it has an impact in any endogenous variable.

Two distinct analyses are considered, one taking aggregate energy production, including the total of renewable energy sources and another for disaggregated energy sources, considering hydroelectricity separately from the other renewable sources.

To achieve the objectives of this study, the SVAR model approach is used, since it considers the interactions among all variables in the model according to economic theory.

The empirical results of this study reveal that the SVAR model estimated for aggregate energy show that, in the long term, only GDP and energy production have impact on $CO_2$ emissions. The first variable has a positive impact and the second a negative one. For disaggregated analysis, the results show that hydroelectric shocks and GDP shocks have a negative and positive impact, respectively, on $CO_2$ emissions. The variance decomposition analysis showed a large amount of uncertainty in the forecast of the growth rate of $CO_2$ emissions due to TRES and almost no uncertainty in predicting the growth rate of energy production and GDP due to other factors.

Apparently, TRES has no impact on economic growth. This is all true for Portugal and Spain.

In terms of oil prices, for Portugal, it is possible to conclude that an increase on this variable has a negative and although smaller impact on $CO_2$ emissions, which makes sense because an increase in oil prices lead to a decrease in energy consumption from fossil fuels and consequently a decrease in $CO_2$ emissions. For Spain, an increase in oil prices has a negative impact on GDP, mainly because oil prices are a key factor in explaining economic fluctuations.

On the policy implications of the obtained results it is important to say that increasing economic, environmental and societal concern over issues related to energy security and global warming imply that, in the future there will be a greater reliance on the energy production from renewable sources (like wind, solar, geothermal, biomass, wave and tidal).

As for the limitations of this study, it is possible to mention the quality of the older data, especially regarding $CO_2$ emissions for which official national calculations are very recent, so that the World Bank data provides only estimates. A possible extension is to build an SVAR model in a joint panel of Portugal and Spain, as the energy market in the Iberian Peninsula is linked through the MIBEL.

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# 8. Appendices

## Appendix 1 – Feed-in tariffs for Portugal

| Resource | | Technology | Support level [€cents/kWh] | Duration [up to years that an investor is entitled to support] |
|---|---|---|---|---|
| Wind | | onshore | 7.4 | 15 years |
| | | offshore | 7.4 | 15 years |
| Solar | PV | | 31-45 | 15 years |
| | CSP | Up to 10 MW | 26.3-27.3 | 15 years |
| Hydroelectric | | small | 7.5 | 20 years |
| Biomass | | solid | 11 | 15 years |
| | | Gasification (biogas) | 10.2 | 15 years |
| Wave | | | 26-7.6 | 15 years |

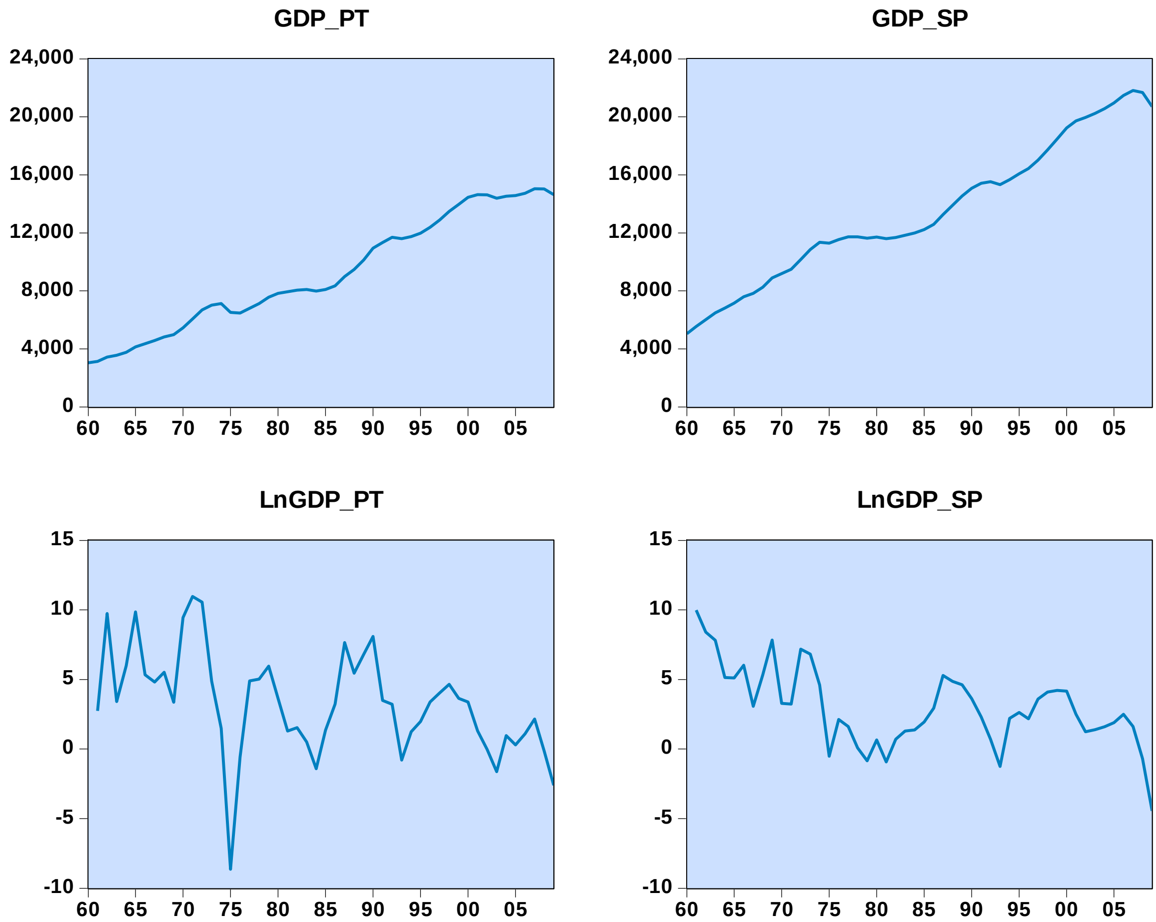
**Source: Decree-law 33-A/2005**

## Appendix 2 – Feed-in tariffs for Spain

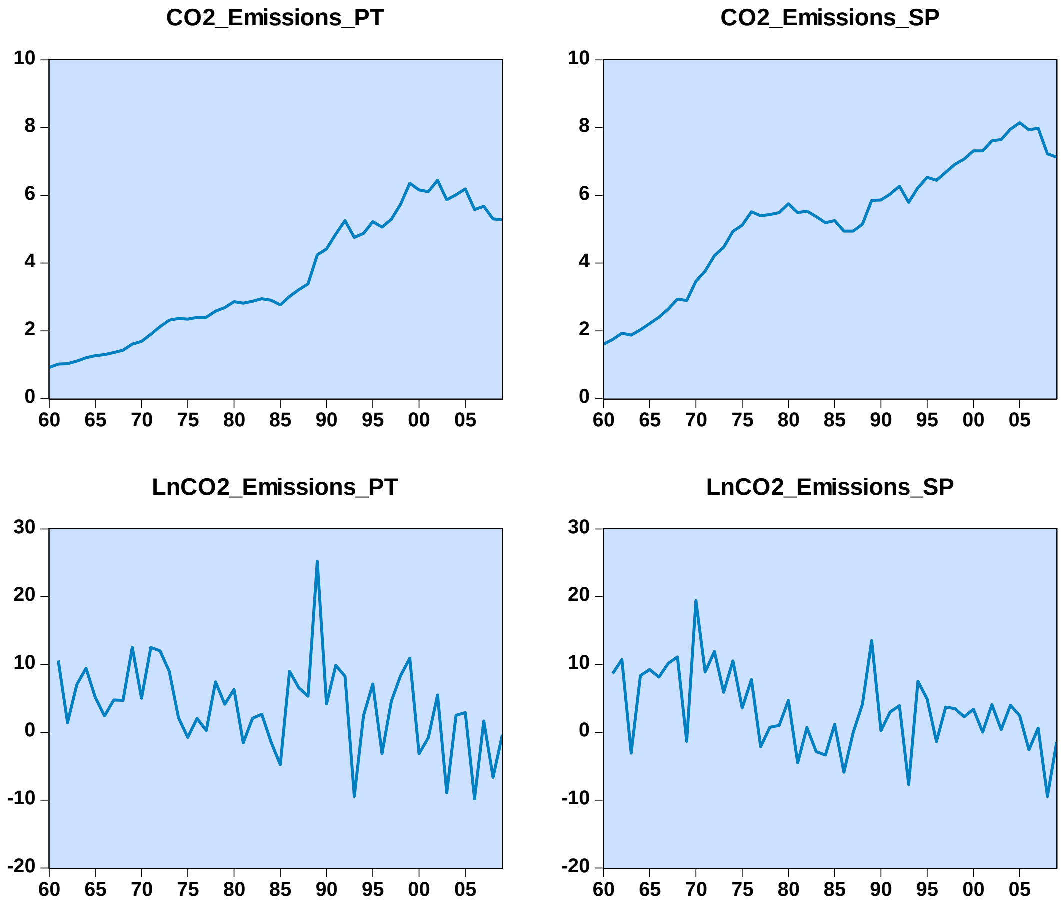
| Resource | Tariffs |
|---|---|
| Wind | • For 20 years: 7.9084 €cent/kWh<br>• After 20 years: 6.6094 €cent/kWh |
| Solar | PV<br>• For 25 years: 13.4585 – 28.8821 €cent/kWh<br>Thermoelectric<br>• For 25 years: 29.0916 €cent/kWh<br>• After 25 years: 23.2731 €cent/kWh |
| Hydroelectric | • For 25 years: 8.4237 €cent/kWh<br>• After 25 years: 7.5814 €cent/kWh |
| Biomass | • For 15 years: 7.0284 – 17.1596 €cent/kWh<br>• After 15 years: 7.0284 – 12.7362 €cent/kWh |
| Biogas | • For 15 years: 8.6311 – 14.1141 €cent/kWh<br>• After 15 years: 7.0306 €cent/kWh |
| Geothermal | • For 20 years: 7.441 €cent/kWh<br>• After 20 years: 7.0306 €cent/kWh |

**Source: Royal Decree 661/2007**

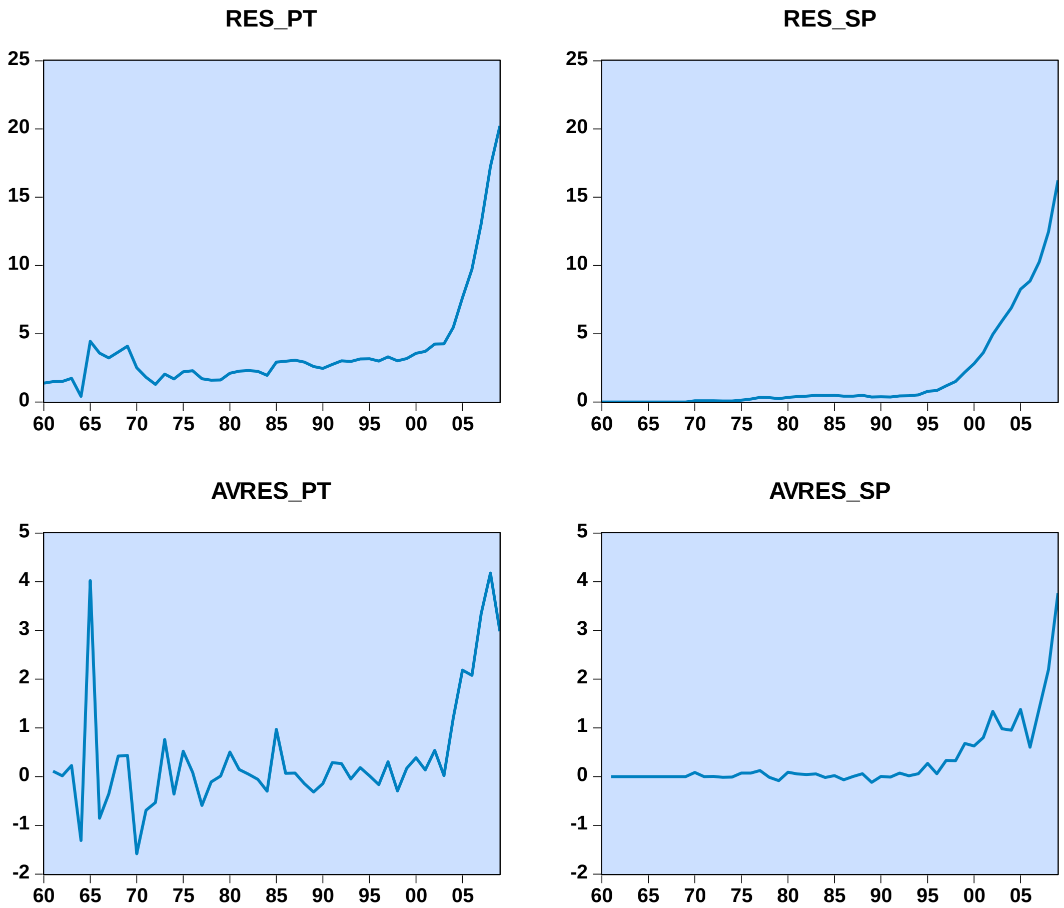
## Appendix 3 – GDP series for Portugal and Spain



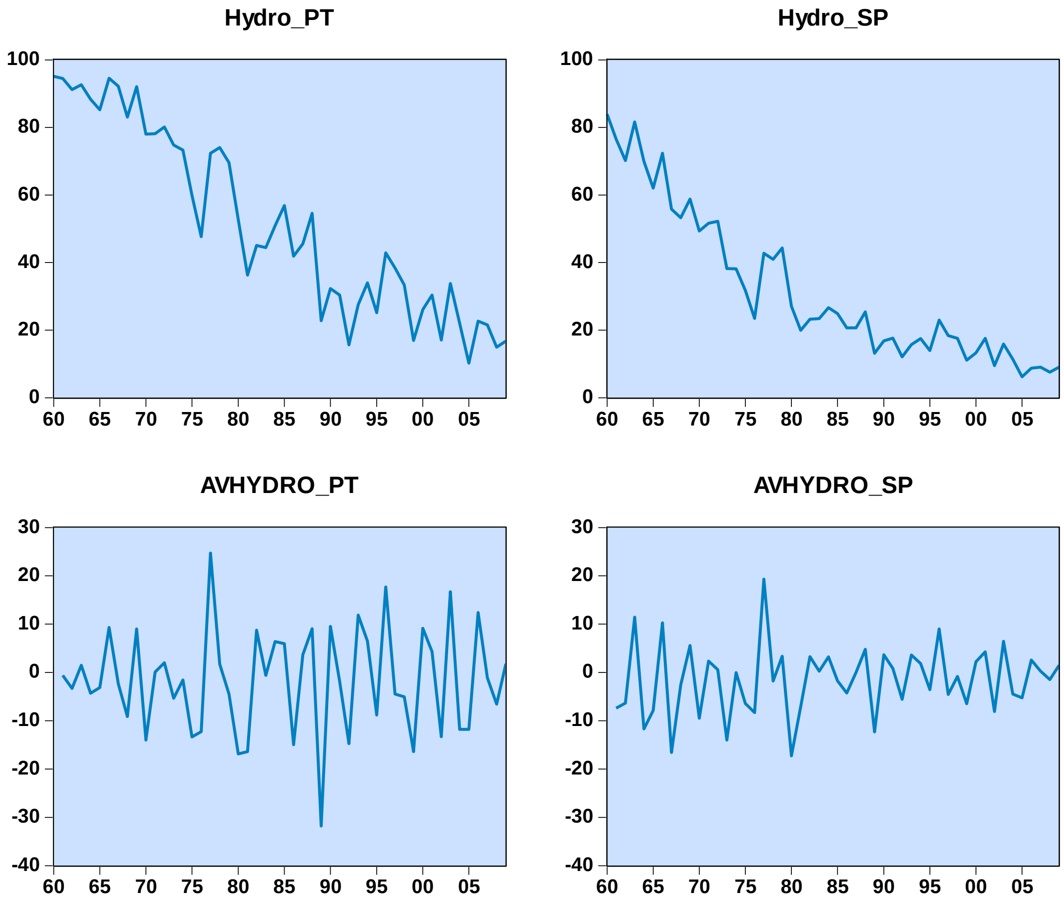
## Appendix 4 – $CO_2$ emissions series for Portugal and Spain



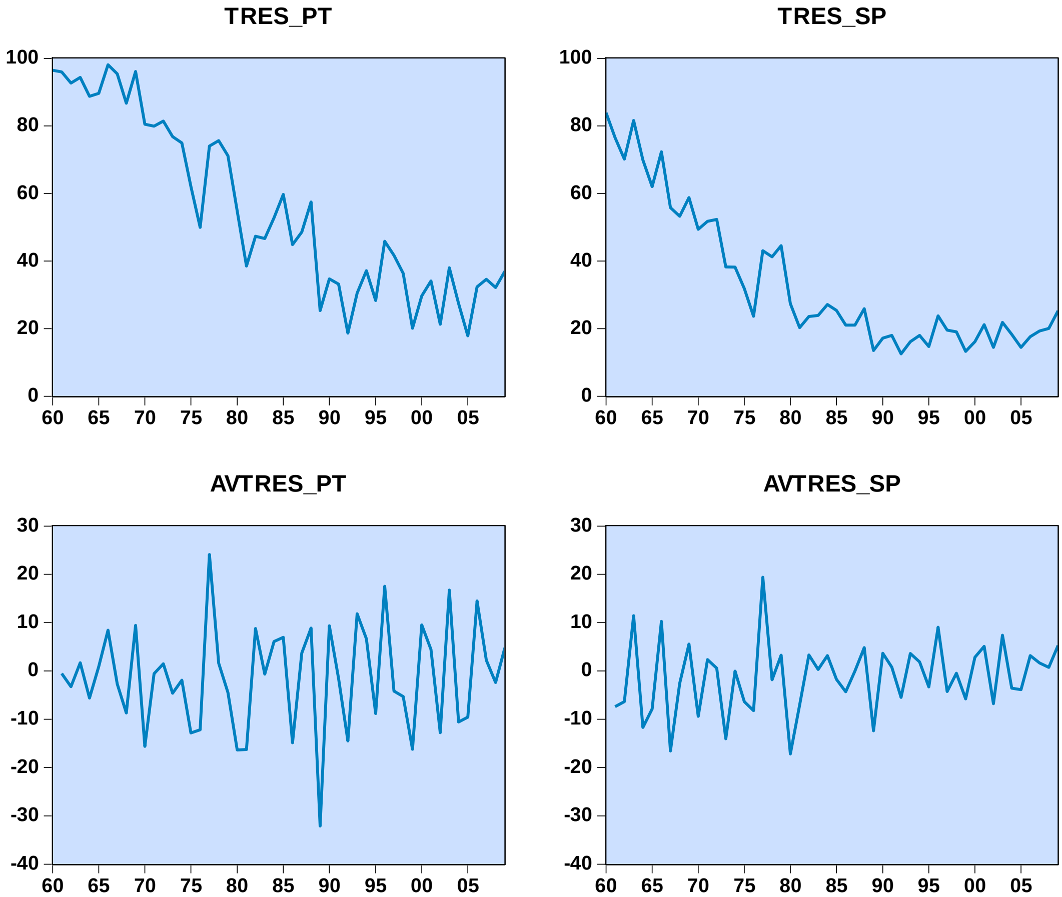
# Appendix 5 – Renewable energy sources series for Portugal and Spain



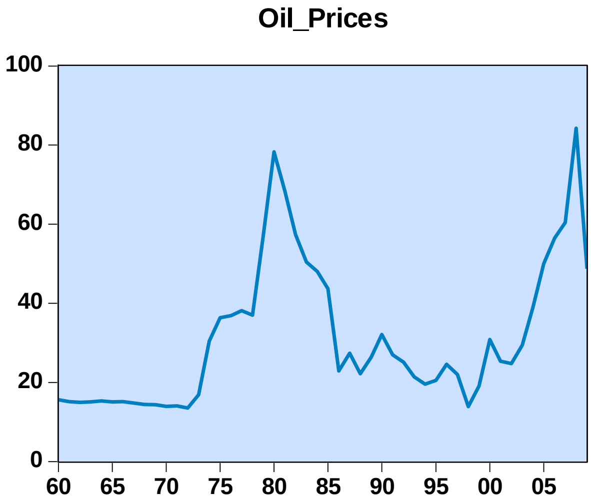
## Appendix 6 – Hydroelectric series for Portugal and Spain

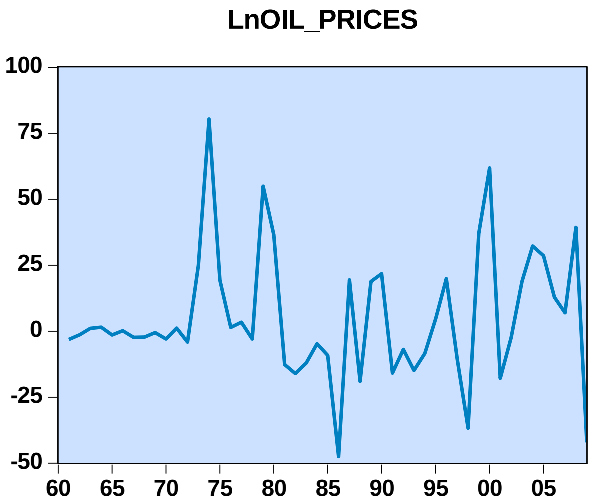


## Appendix 7 – Total renewable energy sources for Portugal and Spain



## Appendix 8 – Oil prices series



## Appendix 9 – Cointegration analysis – optimal lag length

- **Portugal - With RES+Hydro**

VAR Lag Exclusion Wald Tests
Sample: 1960 2009
Included observations: 47

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

| | CO2_PT | GDP_PT | RES_PT | HYDRO_PT | Joint |
|---|---|---|---|---|---|
| Lag 1 | 27.00882<br>[ 1.98e-05] | 97.16161<br>[ 0.000000] | 31.46013<br>[ 2.47e-06] | 4.823952<br>[ 0.305843] | 148.4546<br>[ 0.000000] |
| Lag 2 | 0.329962<br>[ 0.987799] | 8.547640<br>[ 0.073456] | 2.398647<br>[ 0.662872] | 6.434243<br>[ 0.168981] | 24.09086<br>[ 0.087539] |
| Lag 3 | 2.455714<br>[ 0.652583] | 3.046439<br>[ 0.550084] | 0.919121<br>[ 0.921802] | 5.893767<br>[ 0.207224] | 13.19043<br>[ 0.658787] |
| df | 4 | 4 | 4 | 4 | 16 |

VAR Lag Order Selection Criteria
Endogenous variables: CO2_PT GDP_PT RES_PT HYDRO_PT
Exogenous variables: C OIL_PRICES
Sample: 1960 2009
Included observations: 48

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -737.1418 | NA | 3.58e+08 | 31.04758 | 31.35944 | 31.16543 |
| 1 | -532.0529 | 358.9056* | 136301.0* | 23.16887* | 24.10447* | 23.52244* |
| 2 | -517.0662 | 23.72893 | 144979.2 | 23.21109 | 24.77043 | 23.80037 |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

- **Portugal - With total RES**

VAR Lag Exclusion Wald Tests
Sample: 1960 2009
Included observations: 47

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

| | CO2_PT | GDP_PT | TRES_PT | Joint |
|---|---|---|---|---|
| Lag 1 | 28.91512<br>[ 2.33e-06] | 104.9171<br>[ 0.000000] | 9.405145<br>[ 0.024362] | 137.7438<br>[ 0.000000] |
| Lag 2 | 1.010997<br>[ 0.798591] | 10.02334<br>[ 0.018369] | 4.806482<br>[ 0.186528] | 23.38884<br>[ 0.005380] |
| Lag 3 | 3.525353<br>[ 0.317489] | 2.408584<br>[ 0.492039] | 7.961139<br>[ 0.046822] | 13.26803<br>[ 0.150849] |
| df | 3 | 3 | 3 | 9 |

VAR Lag Order Selection Criteria
Endogenous variables: CO2_PT GDP_PT TRES_PT
Exogenous variables: C OIL_PRICES
Sample: 1960 2009
Included observations: 48

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -631.9580 | NA | 70286903 | 26.58158 | 26.81548 | 26.66997 |
| 1 | -480.4432 | 271.4640 | 185741.5 | 20.64347 | 21.22822* | 20.86445 |
| 2 | -466.7937 | 22.74914* | 154125.8* | 20.44974* | 21.38534 | 20.80330* |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

- **Spain - With RES+Hydro**

VAR Lag Exclusion Wald Tests
Sample: 1960 2009
Included observations: 47

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

| | CO2_SP | GDP_SP | RES_SP | HYDRO_SP | Joint |
|---|---|---|---|---|---|
| Lag 1 | 19.93849<br>[ 0.000514] | 116.0134<br>[ 0.000000] | 53.62638<br>[ 6.30e-11] | 4.070637<br>[ 0.396531] | 191.0421<br>[ 0.000000] |
| Lag 2 | 5.289287<br>[ 0.258882] | 15.73581<br>[ 0.003395] | 5.896841<br>[ 0.206986] | 0.442150<br>[ 0.978883] | 25.64245<br>[ 0.059271] |
| Lag 3 | 7.196790<br>[ 0.125847] | 5.305252<br>[ 0.257386] | 2.297798<br>[ 0.681170] | 2.808450<br>[ 0.590375] | 22.58362<br>[ 0.125327] |
| df | 4 | 4 | 4 | 4 | 16 |

VAR Lag Order Selection Criteria
Endogenous variables: CO2_SP GDP_SP RES_SP HYDRO_SP
Exogenous variables: C OIL_PRICES
Sample: 1960 2009
Included observations: 48

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -750.4925 | NA | 6.25e+08 | 31.60385 | 31.91572 | 31.72171 |
| 1 | -470.8022 | 489.4579 | 10620.16 | 20.61676 | 21.55236* | 20.97033* |
| 2 | -453.7226 | 27.04278* | 10352.96* | 20.57178* | 22.13111 | 21.16105 |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

- **Spain - With total RES**

VAR Lag Exclusion Wald Tests
Sample: 1960 2009
Included observations: 47

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

| | CO2_SP | GDP_SP | TRES_SP | Joint |
|---|---|---|---|---|
| Lag 1 | 37.04439<br>[ 4.50e-08] | 111.3173<br>[ 0.000000] | 7.954783<br>[ 0.046956] | 151.1006<br>[ 0.000000] |
| Lag 2 | 1.984886<br>[ 0.575550] | 14.01394<br>[ 0.002886] | 0.973001<br>[ 0.807784] | 20.40435<br>[ 0.015575] |
| Lag 3 | 2.554083<br>[ 0.465596] | 3.740141<br>[ 0.290926] | 5.367638<br>[ 0.146773] | 13.22011<br>[ 0.152897] |
| df | 3 | 3 | 3 | 9 |

VAR Lag Order Selection Criteria
Endogenous variables: CO2_SP GDP_SP TRES_SP
Exogenous variables: C OIL_PRICES
Sample: 1960 2009
Included observations: 48

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -669.3095 | NA | 3.33e+08 | 28.13790 | 28.37180 | 28.22629 |
| 1 | -482.9003 | 333.9832 | 205764.7 | 20.74584 | 21.33059* | 20.96682 |
| 2 | -469.0841 | 23.02695* | 169558.9* | 20.54517* | 21.48077 | 20.89874* |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

## Appendix 10 – Johansen Cointegration Test

- **Portugal - With total RES**

Sample: 1960 2009
Included observations: 47
Series: CO2_PT GDP_PT TRES_PT
Exogenous series: OIL_PRICES
Warning: Rank Test critical values derived assuming no exogenous series
Lags interval: 1 to 2

Selected (0.05 level*) Number of Cointegrating Relations by Model

| Data Trend: | None | None | Linear | Linear | Quadratic |
|---|---|---|---|---|---|
| Test Type | No Intercept No Trend | Intercept No Trend | Intercept No Trend | Intercept Trend | Intercept Trend |
| Trace | 0 | 0 | 0 | 1 | 1 |
| Max-Eig | 0 | 1 | 0 | 1 | 1 |

*Critical values based on MacKinnon-Haug-Michelis (1999)

Information Criteria by Rank and Model

| Data Trend: | None | None | Linear | Linear | Quadratic |
|---|---|---|---|---|---|
| Rank or No. of CEs | No Intercept No Trend | Intercept No Trend | Intercept No Trend | Intercept Trend | Intercept Trend |
| | Log Likelihood by Rank (rows) and Model (columns) | | | | |
| 0 | -467.0240 | -467.0240 | -461.4177 | -461.4177 | -460.0192 |
| 1 | -462.2480 | -454.5634 | -452.4420 | -448.2664 | -447.0848 |
| 2 | -459.9377 | -452.0495 | -450.9975 | -440.6302 | -439.6853 |
| 3 | -458.5405 | -450.6510 | -450.6510 | -439.1860 | -439.1860 |
| | Akaike Information Criteria by Rank (rows) and Model (columns) | | | | |
| 0 | 20.63932 | 20.63932 | 20.52841 | 20.52841 | 20.59656 |
| 1 | 20.69140 | 20.40695 | 20.40179 | 20.26665 | 20.30148 |
| 2 | 20.84841 | 20.59785 | 20.59564 | 20.23958* | 20.24193 |
| 3 | 21.04427 | 20.83621 | 20.83621 | 20.47600 | 20.47600 |
| | Schwarz Criteria by Rank (rows) and Model (columns) | | | | |
| 0 | 21.34789* | 21.34789* | 21.35507 | 21.35507 | 21.54132 |
| 1 | 21.63616 | 21.39108 | 21.46464 | 21.36887 | 21.48243 |
| 2 | 22.02936 | 21.85753 | 21.89468 | 21.61735 | 21.65906 |
| 3 | 22.46141 | 22.37144 | 22.37144 | 22.12932 | 22.12932 |

- **Portugal - With RES+Hydro**

Sample: 1960 2009
Included observations: 47
Series: CO2_SP GDP_SP RES_SP HYDRO_SP
Exogenous series: OIL_PRICES
Warning: Rank Test critical values derived assuming no exogenous series
Lags interval: 1 to 2

Selected (0.05 level*) Number of Cointegrating Relations by Model

| Data Trend: | None | None | Linear | Linear | Quadratic |
|---|---|---|---|---|---|
| Test Type | No Intercept<br>No Trend | Intercept<br>No Trend | Intercept<br>No Trend | Intercept<br>Trend | Intercept<br>Trend |
| Trace | 0 | 0 | 0 | 0 | 0 |
| Max-Eig | 0 | 0 | 0 | 1 | 1 |

*Critical values based on MacKinnon-Haug-Michelis (1999)

Information Criteria by Rank and Model

| Data Trend: | None | None | Linear | Linear | Quadratic |
|---|---|---|---|---|---|
| Rank or No. of CEs | No Intercept<br>No Trend | Intercept<br>No Trend | Intercept<br>No Trend | Intercept<br>Trend | Intercept<br>Trend |
| | Log Likelihood by Rank (rows) and Model (columns) | | | | |
| 0 | -455.7112 | -455.7112 | -449.2417 | -449.2417 | -445.5066 |
| 1 | -446.6189 | -445.5680 | -439.3314 | -432.5677 | -429.6366 |
| 2 | -438.9323 | -437.1651 | -435.0447 | -426.6087 | -423.7363 |
| 3 | -435.9545 | -432.8909 | -432.6238 | -422.3230 | -420.2989 |
| 4 | -435.9469 | -431.9744 | -431.9744 | -420.2969 | -420.2969 |
| | Akaike Information Criteria by Rank (rows) and Model (columns) | | | | |
| 0 | 20.75367 | 20.75367 | 20.64858 | 20.64858 | 20.65986 |
| 1 | 20.70719 | 20.70502 | 20.56729 | 20.32203* | 20.32496 |
| 2 | 20.72053 | 20.73043 | 20.72531 | 20.45143 | 20.41431 |
| 3 | 20.93423 | 20.93153 | 20.96272 | 20.65204 | 20.60846 |
| 4 | 21.27434 | 21.27551 | 21.27551 | 20.94881 | 20.94881 |
| | Schwarz Criteria by Rank (rows) and Model (columns) | | | | |
| 0 | 22.01334* | 22.01334* | 22.06572 | 22.06572 | 22.23445 |
| 1 | 22.28178 | 22.31898 | 22.29935 | 22.09345 | 22.21447 |
| 2 | 22.61004 | 22.69867 | 22.77228 | 22.57714 | 22.61874 |
| 3 | 23.13866 | 23.25405 | 23.32461 | 23.13203 | 23.12781 |
| 4 | 23.79369 | 23.95231 | 23.95231 | 23.78307 | 23.78307 |

- **Spain - With Total RES**

Sample: 1960 2009
Included observations: 47
Series: CO2_SP GDP_SP TRES_SP
Exogenous series: OIL_PRICES
Warning: Rank Test critical values derived assuming no exogenous series
Lags interval: 1 to 2

Selected (0.05 level*) Number of Cointegrating Relations by Model

| Data Trend: | None | None | Linear | Linear | Quadratic |
|---|---|---|---|---|---|
| Test Type | No Intercept<br>No Trend | Intercept<br>No Trend | Intercept<br>No Trend | Intercept<br>Trend | Intercept<br>Trend |
| Trace | 0 | 0 | 0 | 0 | 0 |
| Max-Eig | 0 | 0 | 0 | 0 | 0 |

*Critical values based on MacKinnon-Haug-Michelis (1999)

Information Criteria by Rank and Model

| Data Trend: | None | None | Linear | Linear | Quadratic |
|---|---|---|---|---|---|
| Rank or<br>No. of CEs | No Intercept<br>No Trend | Intercept<br>No Trend | Intercept<br>No Trend | Intercept<br>Trend | Intercept<br>Trend |
| | Log Likelihood by Rank (rows) and Model (columns) | | | | |
| 0 | -463.7978 | -463.7978 | -458.0382 | -458.0382 | -453.8055 |
| 1 | -457.1481 | -456.8929 | -453.4101 | -446.6983 | -442.4661 |
| 2 | -453.1723 | -452.8928 | -452.7243 | -442.1023 | -441.7290 |
| 3 | -453.0371 | -452.6714 | -452.6714 | -441.7283 | -441.7283 |
| | Akaike Information Criteria by Rank (rows) and Model (columns) | | | | |
| 0 | 20.50203 | 20.50203 | 20.38461 | 20.38461 | 20.33215 |
| 1 | 20.47439 | 20.50608 | 20.44298 | 20.19993 | 20.10494* |
| 2 | 20.56052 | 20.63373 | 20.66912 | 20.30222 | 20.32889 |
| 3 | 20.81009 | 20.92219 | 20.92219 | 20.58418 | 20.58418 |
| | Schwarz Criteria by Rank (rows) and Model (columns) | | | | |
| 0 | 21.21060* | 21.21060* | 21.21127 | 21.21127 | 21.27691 |
| 1 | 21.41914 | 21.49020 | 21.50583 | 21.30214 | 21.28588 |
| 2 | 21.74147 | 21.89341 | 21.96816 | 21.67999 | 21.74603 |
| 3 | 22.22722 | 22.45742 | 22.45742 | 22.23751 | 22.23751 |

- **Spain - With RES+Hydro**

Sample: 1960 2009
Included observations: 48
Series: CO2_SP GDP_SP HYDRO_SP RES_SP
Exogenous series: OIL_PRICES
Warning: Rank Test critical values derived assuming no exogenous series
Lags interval: 1 to 1

Selected (0.05 level*) Number of Cointegrating Relations by Model

| Data Trend: | None | None | Linear | Linear | Quadratic |
|---|---|---|---|---|---|
| Test Type | No Intercept No Trend | Intercept No Trend | Intercept No Trend | Intercept Trend | Intercept Trend |
| Trace | 0 | 0 | 0 | 0 | 0 |
| Max-Eig | 0 | 0 | 0 | 0 | 0 |

*Critical values based on MacKinnon-Haug-Michelis (1999)

Information Criteria by Rank and Model

| Data Trend: | None | None | Linear | Linear | Quadratic |
|---|---|---|---|---|---|
| Rank or No. of CEs | No Intercept No Trend | Intercept No Trend | Intercept No Trend | Intercept Trend | Intercept Trend |
| | Log Likelihood by Rank (rows) and Model (columns) | | | | |
| 0 | -477.1672 | -477.1672 | -471.8504 | -471.8504 | -468.1534 |
| 1 | -468.2753 | -467.8249 | -463.6227 | -458.3071 | -455.5297 |
| 2 | -462.1897 | -460.5494 | -456.4636 | -450.8824 | -448.1302 |
| 3 | -458.4491 | -454.6271 | -454.0387 | -444.0252 | -442.3833 |
| 4 | -458.3619 | -453.7226 | -453.7226 | -441.7767 | -441.7767 |
| | Akaike Information Criteria by Rank (rows) and Model (columns) | | | | |
| 0 | 20.54863 | 20.54863 | 20.49377 | 20.49377 | 20.50639 |
| 1 | 20.51147 | 20.53437 | 20.48428 | 20.30446* | 20.31374 |
| 2 | 20.59124 | 20.60622 | 20.51932 | 20.37010 | 20.33876 |
| 3 | 20.76871 | 20.73446 | 20.75161 | 20.45938 | 20.43264 |
| 4 | 21.09841 | 21.07178 | 21.07178 | 20.74070 | 20.74070 |
| | Schwarz Criteria by Rank (rows) and Model (columns) | | | | |
| 0 | 21.17237* | 21.17237* | 21.27343 | 21.27343 | 21.44199 |
| 1 | 21.44707 | 21.50895 | 21.57581 | 21.43498 | 21.56120 |
| 2 | 21.83870 | 21.93166 | 21.92272 | 21.85147 | 21.89809 |
| 3 | 22.32805 | 22.41075 | 22.46688 | 22.29160 | 22.30384 |
| 4 | 22.96961 | 23.09891 | 23.09891 | 22.92377 | 22.92377 |

# Appendix 11 – VAR in first differences – optimal lag lenght

- **Portugal - With Total RES**

VAR Lag Order Selection Criteria
Endogenous variables: TCGDP_PT TCCO2_PT VATRES_PT
Exogenous variables: C TCOIL_PRICES
Sample: 1960 2009
Included observations: 46

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -428.3849 | NA | 31978.94 | 18.88630 | 19.12482 | 18.97565 |
| 1 | -409.1695 | 34.25352* | 20560.11* | 18.44215* | 19.03845* | 18.66553* |
| 2 | -400.1779 | 14.85563 | 20735.52 | 18.44252 | 19.39659 | 18.79992 |
| 3 | -395.5235 | 7.082868 | 25492.80 | 18.63146 | 19.94331 | 19.12288 |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

VAR Lag Exclusion Wald Tests
Sample: 1960 2009
Included observations: 46

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

| | TCGDP_PT | TCCO2_PT | VATRES_PT | Joint |
|---|---|---|---|---|
| Lag 1 | 26.19121 | 6.923150 | 9.252712 | 41.16894 |
| | [ 8.70e-06] | [ 0.074388] | [ 0.026113] | [ 4.66e-06] |
| Lag 2 | 0.662344 | 0.614204 | 8.193680 | 10.28144 |
| | [ 0.882023] | [ 0.893173] | [ 0.042174] | [ 0.328185] |
| Lag 3 | 1.528034 | 2.981499 | 3.701587 | 7.413142 |
| | [ 0.675815] | [ 0.394486] | [ 0.295543] | [ 0.594188] |
| df | 3 | 3 | 3 | 9 |

- **Portugal - With RES+Hydro**

VAR Lag Order Selection Criteria
Endogenous variables: TCGDP_PT TCCO2_PT VARES_PT VAHYDRO_PT
Exogenous variables: C TCOIL_PRICES
Sample: 1960 2009
Included observations: 46

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -499.1671 | NA | 44331.69 | 22.05074 | 22.36877* | 22.16988 |
| 1 | -471.8669 | 47.47870* | 27279.73* | 21.55943* | 22.51350 | 21.91683* |
| 2 | -457.5610 | 22.39178 | 30024.81 | 21.63309 | 23.22321 | 22.22876 |
| 3 | -448.3032 | 12.88036 | 42377.45 | 21.92623 | 24.15240 | 22.76017 |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

VAR Lag Exclusion Wald Tests
Sample: 1960 2009
Included observations: 46

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

| | TCGDP_PT | TCCO2_PT | VARES_PT | VAHYDRO_PT | Joint |
|---|---|---|---|---|---|
| Lag 1 | 27.69674 | 10.53441 | 4.874410 | 9.260229 | 48.82181 |
| | [ 1.44e-05] | [ 0.032326] | [ 0.300428] | [ 0.054914] | [ 3.53e-05] |
| Lag 2 | 0.191310 | 1.886444 | 4.636119 | 7.830945 | 13.65792 |
| | [ 0.995707] | [ 0.756635] | [ 0.326711] | [ 0.097971] | [ 0.624181] |
| Lag 3 | 3.296908 | 1.555808 | 6.356655 | 2.341433 | 13.86780 |
| | [ 0.509422] | [ 0.816712] | [ 0.174049] | [ 0.673236] | [ 0.608562] |
| df | 4 | 4 | 4 | 4 | 16 |

- **Spain - With Total RES**

VAR Lag Order Selection Criteria
Endogenous variables: TCGDP_SP TCCO2_SP VATRES_SP
Exogenous variables: C TCOIL_PRICES
Sample: 1960 2009
Included observations: 46

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -393.2807 | NA | 6950.475 | 17.36003 | 17.59855 | 17.44938 |
| 1 | -373.6325 | 35.02507* | 4385.337 | 16.89707 | 17.49336* | 17.12044* |
| 2 | -363.4564 | 16.81265 | 4200.742* | 16.84593* | 17.80001 | 17.20333 |
| 3 | -360.0753 | 5.145174 | 5458.490 | 17.09023 | 18.40208 | 17.58166 |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

VAR Lag Exclusion Wald Tests
Sample: 1960 2009
Included observations: 46

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

| | TCGDP_SP | TCCO2_SP | VATRES_SP | Joint |
|---|---|---|---|---|
| Lag 1 | 24.48183 | 1.461454 | 7.024614 | 33.92801 |
| | [ 1.98e-05] | [ 0.691195] | [ 0.071117] | [ 9.20e-05] |
| Lag 2 | 2.812252 | 4.805497 | 2.742334 | 11.36150 |
| | [ 0.421487] | [ 0.186606] | [ 0.433081] | [ 0.251741] |
| Lag 3 | 2.607177 | 0.986098 | 0.839850 | 5.455902 |
| | [ 0.456233] | [ 0.804616] | [ 0.839914] | [ 0.792895] |
| df | 3 | 3 | 3 | 9 |

- **Spain - With RES+Hydro**

VAR Lag Order Selection Criteria
Endogenous variables: TCGDP_SP TCCO2_SP VARES_SP VAHYDRO_SP
Exogenous variables: C TCOIL_PRICES
Sample: 1960 2009
Included observations: 46

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | -436.1617 | NA | 2864.327 | 19.31138 | 19.62940 | 19.43051 |
| 1 | -376.1432 | 104.3800* | 424.9623* | 17.39753* | 18.35160* | 17.75493* |
| 2 | -363.4878 | 19.80849 | 502.5215 | 17.54295 | 19.13307 | 18.13862 |
| 3 | -355.1670 | 11.57665 | 738.7590 | 17.87683 | 20.10300 | 18.71077 |

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

VAR Lag Exclusion Wald Tests
Sample: 1960 2009
Included observations: 46

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

| | TCGDP_SP | TCCO2_SP | VARES_SP | VAHYDRO_SP | Joint |
|---|---|---|---|---|---|
| Lag 1 | 26.66500 | 3.039083 | 26.50165 | 8.462235 | 60.37717 |
| | [ 2.32e-05] | [ 0.551306] | [ 2.51e-05] | [ 0.076040] | [ 4.52e-07] |
| Lag 2 | 2.377367 | 6.099884 | 1.526697 | 3.637930 | 14.29474 |
| | [ 0.666721] | [ 0.191812] | [ 0.821902] | [ 0.457218] | [ 0.576767] |
| Lag 3 | 4.906227 | 2.428818 | 0.745768 | 0.867577 | 12.80946 |
| | [ 0.297055] | [ 0.657426] | [ 0.945567] | [ 0.929166] | [ 0.686635] |
| df | 4 | 4 | 4 | 4 | 16 |

## Appendix 12 – VAR in first differences Estimation Results

- **Portugal - With Total RES**

Vector Autoregression Estimates
Sample (adjusted): 1962 2009
Included observations: 48 after adjustments
Standard errors in ( ) & t-statistics in [ ]

| | VATRES_PT | TCGDP_PT | TCCO2_PT |
|---|---|---|---|
| VATRES_PT(-1) | -0.319138 | 0.069024 | 0.088269 |
| | (0.16721) | (0.04339) | (0.08443) |
| | [-1.90864] | [ 1.59091] | [ 1.04549] |
| TCGDP_PT(-1) | 0.410881 | 0.362251 | 0.808990 |
| | (0.47655) | (0.12365) | (0.24063) |
| | [ 0.86220] | [ 2.92956] | [ 3.36201] |
| TCCO2_PT(-1) | -0.337647 | 0.237866 | -0.053530 |
| | (0.32661) | (0.08475) | (0.16492) |
| | [-1.03380] | [ 2.80678] | [-0.32459] |
| C | -1.366853 | 1.461908 | 1.206407 |
| | (2.00199) | (0.51947) | (1.01087) |
| | [-0.68275] | [ 2.81424] | [ 1.19343] |
| TCOIL_PRICES(-1) | -0.002700 | -0.021147 | -0.070338 |
| | (0.06694) | (0.01737) | (0.03380) |
| | [-0.04033] | [-1.21747] | [-2.08095] |
| D75 | -11.75733 | -9.309303 | 2.780835 |
| | (10.7797) | (2.79708) | (5.44304) |
| | [-1.09069] | [-3.32822] | [ 0.51090] |
| D77 | 22.52679 | 4.025866 | 0.832399 |
| | (9.78832) | (2.53984) | (4.94245) |
| | [ 2.30139] | [ 1.58509] | [ 0.16842] |
| D89 | -28.39140 | 1.085030 | 17.78049 |
| | (9.78868) | (2.53993) | (4.94263) |
| | [-2.90043] | [ 0.42719] | [ 3.59737] |

- **Portugal - With RES+Hydro**

Vector Autoregression Estimates
Sample (adjusted): 1962 2009
Included observations: 48 after adjustments
Standard errors in ( ) & t-statistics in [ ]

| | VARES_PT | VAHYDRO_PT | TCGDP_PT | TCCO2_PT |
|---|---|---|---|---|
| VARES_PT(-1) | 0.056981 | 1.033698 | -0.644946 | -1.335481 |
| | (0.10643) | (1.69012) | (0.40589) | (0.81093) |
| | [ 0.53537] | [ 0.61161] | [-1.58898] | [-1.64686] |
| VAHYDRO_PT(-1) | -0.010275 | -0.289517 | 0.059602 | 0.062115 |
| | (0.01097) | (0.17424) | (0.04184) | (0.08360) |
| | [-0.93644] | [-1.66162] | [ 1.42440] | [ 0.74301] |
| TCGDP_PT(-1) | 0.012359 | 0.398164 | 0.352961 | 0.780710 |
| | (0.03122) | (0.49580) | (0.11907) | (0.23789) |
| | [ 0.39582] | [ 0.80307] | [ 2.96434] | [ 3.28181] |
| TCCO2_PT(-1) | -0.030426 | -0.265301 | 0.206978 | -0.139637 |
| | (0.02223) | (0.35294) | (0.08476) | (0.16935) |
| | [-1.36889] | [-0.75168] | [ 2.44191] | [-0.82457] |
| C | 0.053756 | -1.870050 | 1.632727 | 2.119376 |
| | (0.14958) | (2.37528) | (0.57043) | (1.13967) |
| | [ 0.35937] | [-0.78730] | [ 2.86227] | [ 1.85963] |
| TCOIL_PRICES(-1) | -0.000452 | -0.010210 | -0.017120 | -0.052859 |
| | (0.00458) | (0.07279) | (0.01748) | (0.03493) |
| | [-0.09860] | [-0.14025] | [-0.97931] | [-1.51340] |
| D65 | 4.214279 | -1.002926 | 3.590128 | -1.732179 |
| | (0.64081) | (10.1757) | (2.44372) | (4.88235) |
| | [ 6.57650] | [-0.09856] | [ 1.46912] | [-0.35478] |
| D75 | 0.554161 | -10.77594 | -9.994523 | 0.137526 |
| | (0.72419) | (11.4997) | (2.76169) | (5.51763) |
| | [ 0.76522] | [-0.93706] | [-3.61899] | [ 0.02492] |
| D77 | -0.704802 | 23.72464 | 3.851962 | -0.145874 |
| | (0.64037) | (10.1686) | (2.44203) | (4.87897) |
| | [-1.10062] | [ 2.33312] | [ 1.57736] | [-0.02990] |
| D89 | -0.184229 | -28.10551 | 1.189925 | 17.84725 |
| | (0.63619) | (10.1023) | (2.42610) | (4.84715) |
| | [-0.28958] | [-2.78208] | [ 0.49047] | [ 3.68201] |
| D04 | 2.392367 | -4.072122 | 0.949723 | -0.383302 |
| | (0.37478) | (5.95125) | (1.42921) | (2.85545) |
| | [ 6.38343] | [-0.68425] | [ 0.66451] | [-0.13424] |

- **Spain - With total RES**

Vector Autoregression Estimates
Sample (adjusted): 1962 2009
Included observations: 48 after adjustments
Standard errors in ( ) & t-statistics in [ ]

| | VATRES_SP | TCGDP_SP | TCCO2_SP |
|---|---|---|---|
| VATRES_SP(-1) | -0.294256 | -0.040804 | 0.072418 |
| | (0.14548) | (0.03498) | (0.11697) |
| | [-2.02266] | [-1.16647] | [ 0.61912] |
| TCGDP_SP(-1) | -0.371790 | 0.734085 | 0.637222 |
| | (0.44768) | (0.10765) | (0.35995) |
| | [-0.83048] | [ 6.81949] | [ 1.77032] |
| TCCO2_SP(-1) | -0.130048 | 0.014286 | 0.121825 |
| | (0.21950) | (0.05278) | (0.17648) |
| | [-0.59247] | [ 0.27068] | [ 0.69029] |
| C | -0.007674 | 0.773438 | 0.871775 |
| | (1.55612) | (0.37417) | (1.25116) |
| | [-0.00493] | [ 2.06708] | [ 0.69677] |
| TCOIL_PRICES(-1) | 0.018082 | -0.031676 | -0.011106 |
| | (0.04090) | (0.00983) | (0.03289) |
| | [ 0.44209] | [-3.22088] | [-0.33771] |
| D70 | -5.001300 | -3.015828 | 13.31902 |
| | (6.77635) | (1.62937) | (5.44837) |
| | [-0.73805] | [-1.85091] | [ 2.44459] |
| D77 | 18.78794 | -1.115698 | -4.688572 |
| | (6.35945) | (1.52913) | (5.11317) |
| | [ 2.95433] | [-0.72963] | [-0.91696] |
| D80 | -17.36742 | 2.360909 | 4.624434 |
| | (6.83156) | (1.64265) | (5.49276) |
| | [-2.54223] | [ 1.43726] | [ 0.84191] |
| D07 | 2.533122 | -2.837827 | -5.891674 |
| | (4.79216) | (1.15228) | (3.85303) |
| | [ 0.52860] | [-2.46280] | [-1.52910] |

- **Spain - With RES+Hydro**

Vector Autoregression Estimates
Sample (adjusted): 1962 2009
Included observations: 48 after adjustments
Standard errors in ( ) & t-statistics in [ ]

| | VARES_SP | VAHYDRO_SP | TCGDP_SP | TCCO2_SP |
|---|---|---|---|---|
| VARES_SP(-1) | 0.959646 | 1.028690 | 0.073882 | -0.739730 |
| | (0.11002) | (2.70899) | (0.65385) | (2.18326) |
| | [ 8.72210] | [ 0.37973] | [ 0.11300] | [-0.33882] |
| VAHYDRO_SP(-1) | 0.002239 | -0.297017 | -0.040830 | 0.072604 |
| | (0.00596) | (0.14677) | (0.03542) | (0.11828) |
| | [ 0.37566] | [-2.02374] | [-1.15262] | [ 0.61381] |
| TCGDP_SP(-1) | 0.008304 | -0.310499 | 0.737581 | 0.612461 |
| | (0.01865) | (0.45911) | (0.11081) | (0.37001) |
| | [ 0.44532] | [-0.67631] | [ 6.65623] | [ 1.65526] |
| TCCO2_SP(-1) | -0.009094 | -0.100418 | 0.015318 | 0.114518 |
| | (0.00905) | (0.22277) | (0.05377) | (0.17954) |
| | [-1.00515] | [-0.45076] | [ 0.28488] | [ 0.63784] |
| C | 0.041135 | -0.772993 | 0.737052 | 1.129441 |
| | (0.07267) | (1.78913) | (0.43183) | (1.44192) |
| | [ 0.56610] | [-0.43205] | [ 1.70682] | [ 0.78329] |
| TCOIL_PRICES(-1) | 0.000869 | 0.005691 | -0.032255 | -0.007006 |
| | (0.00177) | (0.04346) | (0.01049) | (0.03503) |
| | [ 0.49228] | [ 0.13094] | [-3.07476] | [-0.20002] |
| D70 | -0.046803 | -4.751856 | -3.005646 | 13.24692 |
| | (0.27782) | (6.84046) | (1.65102) | (5.51294) |
| | [-0.16846] | [-0.69467] | [-1.82048] | [ 2.40288] |
| D77 | 0.084066 | 18.96843 | -1.102405 | -4.782703 |
| | (0.26088) | (6.42331) | (1.55034) | (5.17675) |
| | [ 0.32224] | [ 2.95306] | [-0.71107] | [-0.92388] |
| D80 | 0.090109 | -15.87437 | 2.440452 | 4.061145 |
| | (0.29010) | (7.14274) | (1.72398) | (5.75656) |
| | [ 0.31061] | [-2.22245] | [ 1.41559] | [ 0.70548] |
| D07 | 1.152529 | -1.678841 | -2.991544 | -4.803125 |
| | (0.24543) | (6.04298) | (1.45854) | (4.87023) |
| | [ 4.69589] | [-0.27782] | [-2.05105] | [-0.98622] |

## Appendix 13 – SVAR Estimation Results

- **Portugal - With total RES**

Structural VAR Estimates
Sample (adjusted): 1962 2009
Included observations: 48 after adjustments
Estimation method: method of scoring (analytic derivatives)
Convergence achieved after 11 iterations
Structural VAR is over-identified (1 degrees of freedom)

Model: Ae = Bu where E[uu']=I
Restriction Type: short-run text form
@e1 = C(1)*@u1
@e2 = C(2)*@u2
@e3 = -C(3)*@e1 - C(4)*@e2 + C(5)*@u3
where
@e1 represents VATRES_PT residuals
@e2 represents TCGDP_PT residuals
@e3 represents TCCO2_PT residuals

| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| C(3) | 0.278703 | 0.053456 | 5.213655 | 0.0000 |
| C(4) | -0.631832 | 0.206016 | -3.066905 | 0.0022 |
| C(1) | 9.412450 | 0.960654 | 9.797959 | 0.0000 |
| C(2) | -2.442308 | 0.249267 | -9.797959 | 0.0000 |
| C(5) | -3.485962 | 0.355784 | -9.797959 | 0.0000 |

| | | | | |
|---|---|---|---|---|
| Log likelihood | -414.7458 | | | |
| LR test for over-identification: | | | | |
| Chi-square(1) | 1.018298 | | Probability | 0.3129 |

Estimated A matrix:

| | | |
|---|---|---|
| 1.000000 | 0.000000 | 0.000000 |
| 0.000000 | 1.000000 | 0.000000 |
| 0.278703 | -0.631832 | 1.000000 |

Estimated B matrix:

| | | |
|---|---|---|
| 9.412450 | 0.000000 | 0.000000 |
| 0.000000 | 2.442308 | 0.000000 |
| 0.000000 | 0.000000 | 3.485962 |

- **Portugal - With RES+Hydro**

Structural VAR Estimates
Sample (adjusted): 1962 2009
Included observations: 48 after adjustments
Estimation method: method of scoring (analytic derivatives)
Convergence achieved after 13 iterations
Structural VAR is over-identified (4 degrees of freedom)

Model: Ae = Bu where E[uu']=I
Restriction Type: short-run text form
@e1 = C(1)*@u1
@e2 = C(2)*@u2
@e3 = C(3)*@u3
@e4 = -C(4)*@e2 -C(5)*@e3 + C(6)*@u4
where
@e1 represents VARES_PT residuals
@e2 represents VAHYDRO_PT residuals
@e3 represents TCGDP_PT residuals
@e4 represents TCCO2_PT residuals

| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| C(4) | 0.264994 | 0.051860 | 5.109827 | 0.0000 |
| C(5) | -0.626768 | 0.215944 | -2.902449 | 0.0037 |
| C(1) | 0.611123 | 0.062373 | 9.797959 | 0.0000 |
| C(2) | 9.704292 | 0.990440 | 9.797959 | 0.0000 |
| C(3) | -2.330513 | 0.237857 | -9.797959 | 0.0000 |
| C(6) | -3.486696 | 0.355859 | -9.797959 | 0.0000 |

| | | | | |
|---|---|---|---|---|
| Log likelihood | -458.4436 | | | |
| LR test for over-identification: | | | | |
| Chi-square(4) | 7.377694 | | Probability | 0.1172 |

Estimated A matrix:

| | | | |
|---|---|---|---|
| 1.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 1.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 1.000000 | 0.000000 |
| 0.000000 | 0.264994 | -0.626768 | 1.000000 |

Estimated B matrix:

| | | | |
|---|---|---|---|
| 0.611123 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 9.704292 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 2.330513 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 3.486696 |

- **Spain - With total RES**

Structural VAR Estimates
Sample (adjusted): 1962 2009
Included observations: 48 after adjustments
Estimation method: method of scoring (analytic derivatives)
Convergence achieved after 15 iterations
Structural VAR is over-identified (1 degrees of freedom)

Model: Ae = Bu where E[uu']=I
Restriction Type: short-run text form
@e1 = C(1)*@u1
@e2 = C(2)*@u2
@e3 =-C(3)*@e1 -C(4)*@e2 + C(5)*@u3
where
@e1 represents VATRES_SP residuals
@e2 represents TCGDP_SP residuals
@e3 represents TCCO2_SP residuals

| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| C(3) | 0.367596 | 0.099563 | 3.692083 | 0.0002 |
| C(4) | -1.148582 | 0.414070 | -2.773883 | 0.0055 |
| C(1) | -6.172841 | 0.630013 | -9.797959 | 0.0000 |
| C(2) | 1.484260 | 0.151487 | 9.797959 | 0.0000 |
| C(5) | -4.257990 | 0.434579 | -9.797959 | 0.0000 |

| | | | | |
|---|---|---|---|---|
| Log likelihood | -380.1931 | | | |
| LR test for over-identification: | | | | |
| Chi-square(1) | 1.974058 | | Probability | 0.1600 |

Estimated A matrix:

| | | |
|---|---|---|
| 1.000000 | 0.000000 | 0.000000 |
| 0.000000 | 1.000000 | 0.000000 |
| 0.367596 | -1.148582 | 1.000000 |

Estimated B matrix:

| | | |
|---|---|---|
| 6.172841 | 0.000000 | 0.000000 |
| 0.000000 | 1.484260 | 0.000000 |
| 0.000000 | 0.000000 | 4.257990 |

- **Spain - With RES+Hydro**

Structural VAR Estimates
Sample (adjusted): 1962 2009
Included observations: 48 after adjustments
Estimation method: method of scoring (analytic derivatives)
Convergence achieved after 20 iterations
Structural VAR is over-identified (4 degrees of freedom)

Model: Ae = Bu where E[uu']=I
Restriction Type: short-run text form
@e1 = C(1)*@u1
@e2 = C(2)*@u2
@e3 = C(3)*@u3
@e4 = -C(4)*@e2 -C(5)*@e3 + C(6)*@u4
where
@e1 represents VARES_SP residuals
@e2 represents VAHYDRO_SP residuals
@e3 represents TCGDP_SP residuals
@e4 represents TCCO2_SP residuals

| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| C(4) | 0.369166 | 0.099668 | 3.703962 | 0.0002 |
| C(5) | -1.154897 | 0.412941 | -2.796762 | 0.0052 |
| C(1) | 0.252923 | 0.025814 | 9.797959 | 0.0000 |
| C(2) | -6.227395 | 0.635581 | -9.797959 | 0.0000 |
| C(3) | -1.503053 | 0.153405 | -9.797959 | 0.0000 |
| C(6) | 4.300141 | 0.438881 | 9.797959 | 0.0000 |

| | | | | |
|---|---|---|---|---|
| Log likelihood | -383.8171 | | | |
| LR test for over-identification: | | | | |
| Chi-square(4) | 3.975028 | | Probability | 0.4094 |

Estimated A matrix:

| | | | |
|---|---|---|---|
| 1.000000 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 1.000000 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 1.000000 | 0.000000 |
| 0.000000 | 0.369166 | -1.154897 | 1.000000 |

Estimated B matrix:

| | | | |
|---|---|---|---|
| 0.252923 | 0.000000 | 0.000000 | 0.000000 |
| 0.000000 | 6.227395 | 0.000000 | 0.000000 |
| 0.000000 | 0.000000 | 1.503053 | 0.000000 |
| 0.000000 | 0.000000 | 0.000000 | 4.300141 |