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Are Renewables Effective in Promoting Growth? Evidence from 21 EU Members

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1. Introduction

The energy needs of mankind in the 19th century were essentially satisfied by the use of renewable sources, such as biomass mainly by burning wood, and animal power. Some transformation of agricultural goods was done through the exploitation of natural resources such as wind and water, using wind mills and water wheels. The 20th century was the century of high economic growth. It was a century where the use of internal combustion engines was widespread and with them the massive use of fossil fuels. The 21st century is now looking for alternative sources of energy.

Nowadays, there is a backdrop of the forecast of depleting fossil fuels in the near future, particularly oil, and climate changes, associated with large emissions of carbon dioxide. In this century, there is a great focus on renewable energy sources, with the strong support of public policies. In addition to the use of hydropower, which already has mature technology, there is a continuous process of developing technologies for harnessing the wind and photovoltaic resources. The attribution of the title of energy of the future to renewable sources is dependent on two factors. First, the achievement of their own economic sustainability will depend on the evolution of technology itself. Second, it will depend on the long-term advances in atomic energy to accomplish the nuclear fusion process on Earth.

One of the fundamental questions that arises is to assess whether this progressive change in the energy paradigm will affect the process of economic growth. The analysis of the relationship between energy consumption and economic growth is far from new in literature. Narayan & Smyth (2008) summarise the principal achievements, the absence of consensus and the diversity of methodologies. The study of the impact of using renewables on economic growth is, however, scarce (e.g. Apergis & Payne, 2010 & Menegaki, 2011). Furthermore, the literature has not focused on the energy mix, that is, on the impact of the simultaneous use of different energy sources on economic growth. Will the impact of energy on economic growth be identical, regardless of whether this energy comes from fossil fuels or renewable sources?

The literature is not unanimous regarding the relationship between income and environmental concerns. Some authors, such as Vachon & Menz, 2006 and Huang *et al.*, 2007, argued a positive effect of wealth on renewables. On the one hand, higher income

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could cushion the effect of the greater fees and costs resulting from the encouragement of Renewable Energy (hereafter RE). On the other hand, higher income levels can also represent a further financial capacity for accommodating the huge investments needed to develop the technology of energy production from renewable sources. Recently, Marques *et al*. (2011) pointed out that the effect of Gross Domestic Product (GDP) on renewables is far from uniform. In fact, this effect depends on the phase of deployment of renewables. With the exception of countries that use renewable sources on a small scale, the authors show that in general the effect of GDP on RE is negative.

Higher income levels of countries have historically been associated with the use of technology based on fossil fuels. Currently, the production structures are grounded firmly in the use of internal combustion engines, in gas turbines and more recently in fuel cells, although the latter with still little relative weight. The technology associated with these fuel cells is still evolving. Right now, this technology is very expensive and partly controversial, because hydrogen is not a primary energy source. The process for obtaining it can lead to the release of harmful gases into the atmosphere. In addition, unequivocal confirmation is still lacking as to their efficiency when compared to that of conventional combustion engines. The conversion and replacement of all these technologies with other technologies based mainly on electricity, such as electric motors, is a long and extremely costly path. More often than not, this shift to alternative technologies is not desired or it is hindered by entrenched interests, which are mostly associated with lobbying exercised for players acting in traditional sources of energy.

There are specific features identified in renewable energies. The first refers to the mechanism of price formation. Given that the contracts of exploitation of renewable sources are generally long-term, usually with prices that are defined or indexed to inflation, the volatility of those energy prices that economic agents face is well controlled, when compared with the prices of fossil sources. This mechanism may thus contribute to increased stability of the economic environment in which agents conduct their forecasts and make their investment decisions. In this way, economic growth could be stimulated. Economic growth can also be promoted by the development of a cluster associated with renewables, since production is done locally. The use of local resources is just another feature of renewables.

The third feature concerns the incentives for the development of renewables. Countries have adopted an extensive battery of measures, such as feed-in-tariffs, grants or preferential loans, to encourage the development of these sources. Walking the path of renewable technology development requires sustaining high investment costs. In one way or another, the costs of implementing these policies are passed on to the economic agents. Since resources are scarce, if the inputs become more expensive, the focus on renewables may create inefficiencies in the economy. Inefficiency can also result from the fact that greater use of RE can cause already installed production capacity to be left behind, including capacity associated with internal combustion engines. Actually, these characteristics sum up the hot debate about the benefits / need for development of renewables. Therefore, to shed some light on this debate, we consider it indispensable to test empirically the effect that different energy sources have had on economic growth.

Since the beginning of the discussion about climate change, especially since the United Nations Framework Convention on Climate Change in 1990, and the Kyoto Protocol (1997), Europe has been firmly committed to this goal. That is why, within a context of energy policy and in order to promote the use of renewables, Europe has produced strong compulsory recommendations for its Member States. In the context of the definition of climate and energy targets, to be reached in 2020, the European Union (EU) established the 20-20-20 strategy. This strategy pursues the following objectives: i) reduce greenhouse gas emissions to at least 20% below 1990 levels; ii) produce 20% of energy consumption from renewable sources; and iii) encourage energy efficiency, reducing primary energy use by 20%. Plans are still being drawn up to make the target reduction of greenhouse gas emissions even more ambitious. Regarding the analysis of the relationship between sustainable development and economic growth, it is therefore important to study the EU region. In parallel with the clear commitment to extend the use of renewables, Europe has undergone growth difficulties. The European Council in Lisbon in the year 2000, and the Spring European Council in Brussels in 2005 defined, as their main goals, sustainable economic growth and job creation.

2. The debate on economic growth within a context of energy paradigm change

All economic growth has a unique framework and, as such, it must be considered as a result of a whole. As far as the relationship between primary energy sources and economic growth is concerned, the literature assesses four main hypotheses. First, when there is a unidirectional causality running from energy to economic growth, we are in the presence of the growth hypothesis. This implies that economic growth requires energy, and as a consequence, a fall in primary energy consumption is likely to hamper economic growth. Second, once a unidirectional causality running from economic growth to energy is established, then the conservation hypothesis is verified. This means that economic growth is not totally dependent on energy consumption and therefore few or negligible effects on economic growth are expected from energy conservation policies. Third, the bidirectional causality between energy and economic growth is known as the feedback hypothesis. In other words, the rise in primary energy demand provokes economic growth and vice versa. Finally, the neutrality hypothesis sustains that policies on energy consumption have no consequences on economic growth, due to the neutral effect with respect to each other.

Indeed, economic growth could be influenced by several factors that ultimately determine its performance. The energy it uses as input, the energy dependence in relation to the outside and the volatility of its own process of evolution are driving forces in this economic growth path. Energy is traditionally identified as a key driver of economic growth but, in fact, it is unlikely that all sources of energy produce the same impact. Their different characteristics, such as the cost /benefits balance, environmental consequences, state of maturation of the technology and even their scale of production can determine the effect of each of these sources in the dynamics of the economic growth process.

2.1 Energy sources, external dependency and economic growth

The literature focusing on the relationship between energy consumption and economic growth is vast and diverse. Some studies focus on the reality of particular countries (Lee & Chang, 2007; and Wolde-Rufael, 2009), while others centre on groups of countries (Akinlo, 2008; and Chiou-Wei *et al.*, 2008). Most of them are engaged in the study of the direction of causality, both in the short and long run. The recent papers of Odhiambo (2010), Ozturk (2010), and Payne (2010) are good surveys. The empirical literature on causality between RE and economic growth has achieved mixed results. For twenty OECD countries, Apergis & Payne (2010) estimated a panel vector error correction model, and found bidirectional causality between RE and economic growth, both in the short and long run. A bidirectional causality between RE and economic growth was also detected by Apergis *et al*. (2010), for a group of 19 developed and developing countries. For the US, Menyah & Wolde-Rufael (2010) found only a unidirectional causality running from GDP to RE. Conversely, when it comes to analysing the relationship between RE and economic growth, the empirical literature is thin. Menegaki (2011) is one of the exceptions, studying the situation in Europe. Indeed, focused on 27 EU Members, using panel error correction, the author did not confirm the presence of Granger causality running from RE to economic growth, either in the short or long run. These results lead the author to conclude that the consumption of RE makes a minor contribution to GDP. In fact, it seems that the nature of the relationship between RE and economic growth still has a long way to go before consensus is achieved.

The literature on the empirical link between restraining emissions of carbon dioxide (CO2) and economic growth has shown some unexpected results. Menyah & Wolde-Rufael (2010) only found unidirectional causality running from CO2 to RE. In the same way, Apergis *et al*. (2010) conclude that the consumption of RE does not contribute to reducing CO2 emissions. Their explanation is grounded in the well-known problem of storing energy, as well as the intermittency characteristic of renewables. The failure to store energy, for example from wind or solar sources, requires the simultaneous use of established sources of energy, such as natural gas or even the highly polluting coal. This scenario leads to two effects on the installed capacity and on energy dependency. On the one hand, it implies the maintenance and even the enlargement of productive capacity that becomes idle for long periods, which generates economic inefficiencies. On the other hand, the intermittency may not even contribute to the reduction of a country's energy dependence goal, such as documented by Frondel *et al*. (2010).

The root of the lack of consensus in literature, with regard to the relationship between RE and economic growth, could come from different theoretical and practical perspectives. On the one hand, it is admissible that the effect of RE on economic growth could vary largely according to both the geographical area and the time span analysed. On the other hand, there could be a variable omission bias problem. In fact, the research may be disregarding the importance of other variables, such as the simultaneous consumption of oil, coal, nuclear or natural gas. These variable omissions could lead to wrong conclusions on causality between each energy source and economic growth, when analysed separately. The cost of this is that inconsistent and erroneous results may be achieved.

Under the well-known premise that energy plays a crucial role in the economic growth process, the question that arises is what will the particular role of renewable sources of energy be on economic growth? To find the answer to this question, as stated before, possible bias resulting from the omission of variables must be avoided, and it is necessary to assess the simultaneous explanatory power of the main sources of energy driving economic growth.

2.2 Volatility and economic growth

The problem of GDP growth analysis has a long path in economic literature. The mainstream does not sustain any relationship between economic growth and its volatility. Nevertheless, the relationship between economic growth volatility and the trend in growth has been the object of increasing attention in literature. Indeed, macroeconomists have long focused on business cycles and economic growth. The material progress of humankind is a central issue. As an economic problem, however, it has been a very complex matter. Although the core literature does not advance any reason for volatility exerting a specific effect on economic growth, this statement is not true for all authors. Some authors advance that volatility might have a reducing effect on economic growth, while others suggest that a positive effect may be observed on economic growth. In short, the literature indicates that the relationship between volatility and economic growth may be: 1) independent – the mainstream; 2) negative - e.g. Bernanke (1983), Pindyck (1991), Ramey & Ramey (1995), Miller (1996), Martin & Rogers (1997 and 2000), and Kneller & Young (2001); or 3) positive - e.g. Mirman (1971), Kormendi & Meguire (1985), Black (1987), Grier & Tullock (1989), Bean (1990), Saint-Paul (1993), Blackburn, (1999), and Fountas & Karanasos (2006). A good survey on this relationship was undertaken by Fang & Miller (2008).

Several explanations have been advanced to support this controversial link. The negative relationship could come from several paths. Volatility limits investment, which limits demand and therefore constrains economic growth (Bernanke, 1983; and Pindyck, 1991). At the same time, volatility can be harmful to human capital accumulation, which diminishes economic growth (Martin & Rogers, 1997).

A positive association between economic growth and volatility could result from diversified sources. The volatility of economic growth generates high precautionary savings (Mirman, 1971). Further specialisation tends to coexist with further economic growth volatility, as highly specialised technologies only generate investment if their expected returns are high enough to compensate for the risk (Black, 1987). This latter assumption suggests that bursts in volatility tend to be related to high economic growth. The cost of opportunity related to productivity-improving processes tends to drop in recessions resulting in a positive relationship between economic growth volatility and economic growth (Bean, 1990; and Saint-Paul, 1993). Labour market institutions, the technology of production, and the source of shocks are characteristics that increase the pace of knowledge accumulation, lowering economic growth (Blackburn, 1999; and Blackburn & Pelloni, 2004). Higher economic growth leads to higher inflation, in the short run, according to the Phillips curve approach (Fountas & Karanasos, 2006).

The explanations for economic growth volatility point out that on the one hand, monetary shocks generate economic growth fluctuations around its natural rate that reflect price misperceptions. On the other hand, technology and other real factors influence the long-run economic growth rate of potential economic growth. These two approaches consubstantiate the misperception theory of Friedman (1968), Phelps (1968), and Lucas (1972). The expectations about economic growth volatility could exert an impact on economic growth (Rafferty, 2005). In sum, the mix of results strongly suggests that theoretical and empirical developments are required to establish the nexus between economic growth and volatility growth.

3. European Union

For a long time now, the EU has taken the lead in the fight against climate change. As stated before, one of the tools that the EU has used is to set targets for the use of RE, in each of the EU Member States. Some of the important milestones along the way have been the White Paper for a Community Strategy and Action Plan, Energy for the Future: Renewable Sources of Energy", in December, 1997 and the EU Directives 2001/77/EC and 2009/28/EC. In parallel with concerns about climate change, concerns are also emerging in Europe about economic growth, which has been generally modest.

3.1 Current picture

The commitment to renewables made by the EU has been translated into real achievements with regard to the contribution of these sources to the energy supply. For the period 1990-2007, and for the EU of 27, we looked at the picture of the evolution of GDP growth rates, as well as the evolution of the contribution of renewable sources to total energy supply (CRES), as a percentage.

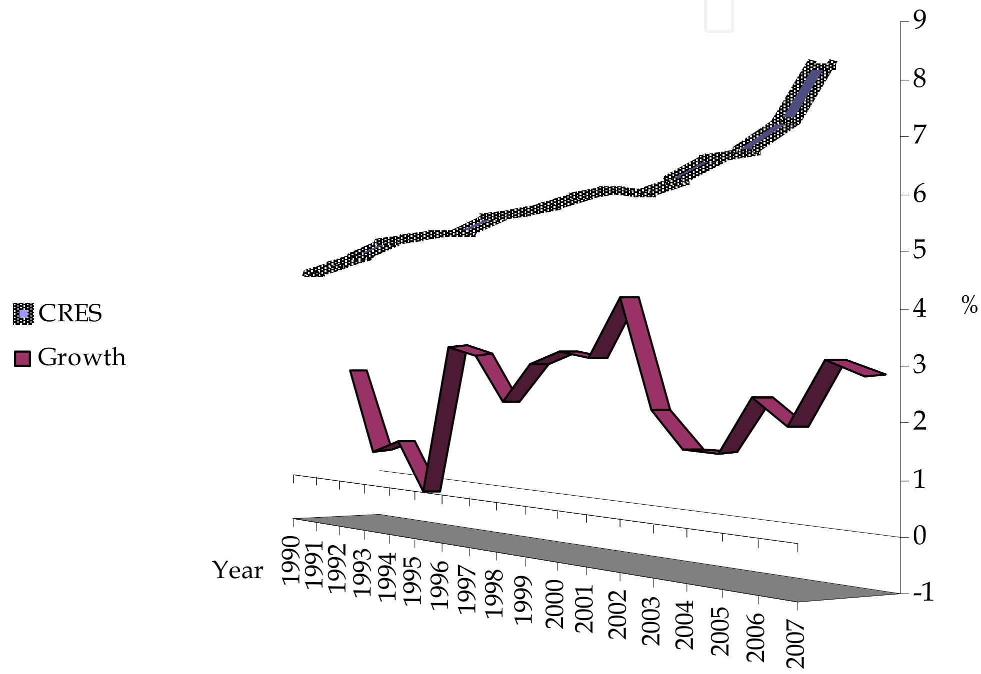

Fig. 1. Economic growth and renewable energy use in EU27

Figure 1 suggests that the rising trend in the use of RE is contemporaneous with different behaviours of economic growth. The periods of greatest growth in the use of renewable sources were simultaneous with contractions in economic growth. This gap is clearly visible in the mid-1990s and the 2000s, and the CRES variable clearly accelerates during 2000s.

When we analyse this reality in detail, we find that data is missing for some of the 27 countries, in particular with regard to variables related to the use of other energy sources. Thus, the EU Members for which the data is available, for all the variables considered and for the time span under review, are: Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, and the United Kingdom. For the time span 1990-2007, this chapter is focused on this panel of 21 EU Members. For this panel, we made a first inspection by country, into the relationship between the growth in renewables' use and economic growth. To do so, we calculated both the average rate of the growth rates of contribution of renewables to total energy supply, and the average rate of economic growth in the period 1991-2007. This information is summarised in Figure 2.

In general, it was observed that the highest rates of growth in the use of RE are associated with countries with lower economic growth. The highest average rate of economic growth during this period was found for Ireland. For this country, the rate of growth in the use of renewables (4.22%) was markedly lower than that rate of economic growth (6.48%). The highest rates of growth in the use of renewable sources in this period are usually associated with countries that have shown lower economic growth rates. Estonia, the Slovak Republic and the Czech Republic have the highest average growth rates of the use of renewables (nearly 12.1%, 11.3% and 9.5%, respectively), but they have low rates of economic growth (2.82%, 2.88% and 1.99%, respectively). Note that the average economic growth rate is 2.76% and the average growth of use of renewables is 5.17%. Germany has one of the highest growth rates of renewables (8.7%) during this period, but its average economic growth was only 1.58%.

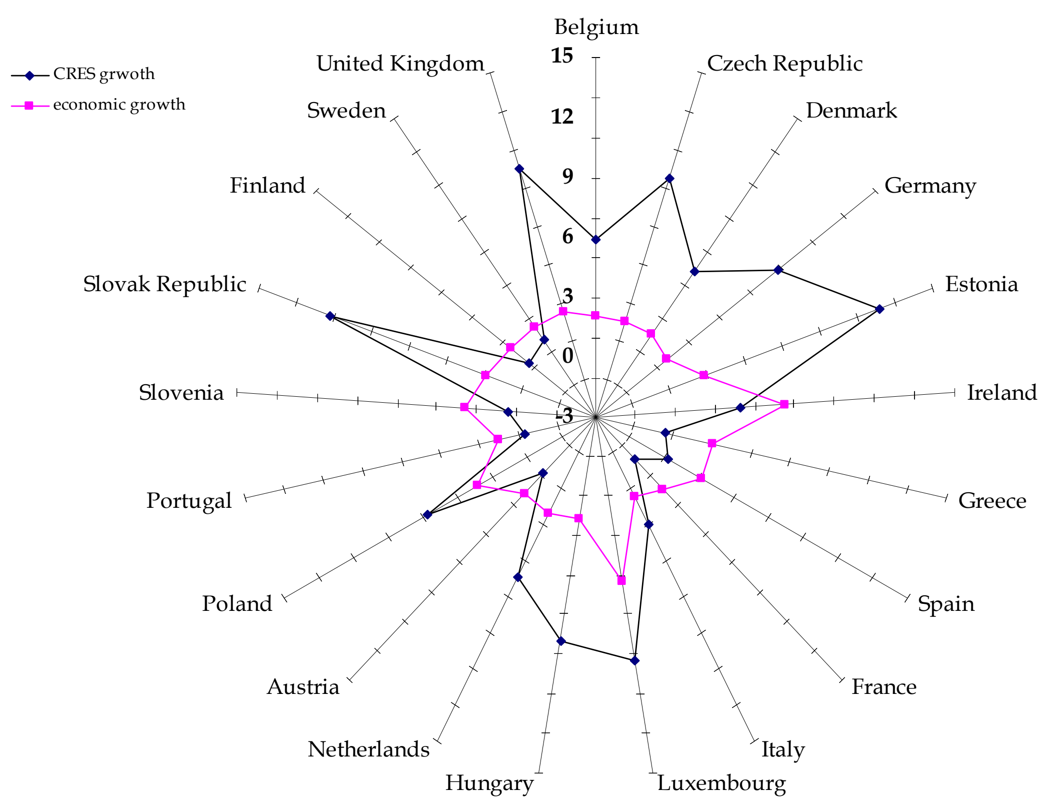

Fig. 2. Economic growth and renewable energy use

3.2 Variables

This chapter is focused on analysing the relationship between economic growth and the use of different sources of energy. We define as dependent variable the Logarithm of real Gross Domestic Product for country *c*, at period *t*, ($LGDP_{ct}$). The explanatory variables arise from the literature and are in accordance with those previously discussed. Therefore, in addition to the energy sources, we also control for energy consumption per capita, dependency on foreign energy and economic growth volatility. We then present and discuss the variables, their measurement and the expected contributions to economic growth. Given that volatility is a built variable instead of an observable one, we will explain in detail the process followed for its computation.

- *Per capita energy consumption* (*ENERGPCct*). Energy consumption could be used either as a development or an energy efficiency indicator (e.g. Toklu *et al.*, 2010). We can observe two different effects with regard to the relationship between energy consumption and economic growth. On the one hand, higher energy consumption can lead to an increase in the use of the installed capacity. Therefore, larger consumption could stimulate production, and thereby boost economic growth. This yields a positive effect of energy consumption on economic growth. On the other hand, a negative effect can be observed, which can result from two phenomena: i) the energy is consumed in activities other than production; and ii) the increase in consumption also increases the cost of energy and is likely burdening the foreign energy deficit. The expected sign is negative if the former effect prevails.
- *Import dependency of energy* (*IMPTDPct*). We control for the external energy dependence, which is often pointed out by normative literature as one of the major constraints on economic growth. Since the entire economy is closely linked to energy, the external dependency of that input not only causes huge capital flows to the outside, but also positions the country as a price-taker in the international energy markets. Thereby, we tested the hypothesis that the dependency on energy imports is limiting economic growth.
- *Per capita GDP volatility* (*VOLGDPPCct*). Volatility is not a directly observable variable. It has the additional problem of the coexistence of several definitions. To cope with these complexities, we use autoregressive conditional heteroskedasticity (GARCH) models. The GARCH models are profusely used due to their recognised ability to capture many properties of time series, such as time-varying volatility, persistence and volatility clustering. In particular, GARCH processes have often been used in empirical literature to compute risk.

GDP growth has often been modelled as an autoregressive time series with random disturbances having conditional heteroskedastic variances. GDP growth, in particular, has been modelled as a GARCH type processes. The GARCH model is, in effect, sufficient to allow different macroeconomic regimes by letting the volatility of the economic growth evolve over time. It also assumes that a large change in GDP growth, either positive or negative, is probably followed by other large changes in subsequent years. Other methods of computing volatility, such as variance (or standard deviations), imply loss of observations and have several handicaps. Alternatively, they treat positive or negative changes in some way (the squares of economic growth rates) and were therefore excluded from our analysis.

We fit an autoregressive (AR) process with GARCH errors to the natural logarithm of the GDP per capita growth rates, assuming that the distribution of the error process is the normal distribution. This option results from the well-known characteristics of persistence of GDP growth. Indeed, we begin with the simplest model, namely the AR(1)-GARCH (1,1). Given the well-known propensity of the GARCH model to generate high estimated values at the beginning and end of time span, the AR(1)-GARCH(1,1) was estimated using raw data for the time span of 1971 to 2010.

The model estimated has a mean equation and an equation for conditional variance, which are, respectively (1) and (2):

$$DLGDPPC_t = \gamma_0 + \gamma_1 DLGDPPC_{t-1} + \varepsilon_t \, , \tag{1}$$

and

$$\sigma_t^2 = \omega + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 , \tag{2}$$

where ε_t is the error term. In the above model, equation (1) is the conditional mean equation and equation (2) is the conditional variance equation. The conditional standard deviation term, σ_t, represents the measure of GDP per capita growth volatility. One can also view σ_t as a measure of economy wide risk.

Since we are more interested in the level of volatility than in the volatility itself (σ_t), we proceed to establish the trend of volatility (*VOLGDPPCct*) applying the well-known Hodrick & Prescott (1997) – HP filter to the volatility obtained from the AR(1)-GARCH(1,1). Following a standard procedure of the related literature on HP filter, we use the value of λ =100 as the smoothing parameter.

Figure 3 shows the computed trend volatility. In general, there is no uniform behaviour pattern for the countries. For the time span analysed we observe the three possible kinds of trend: increase, decrease, and stability. For example, Austria and Spain reveal a period of stability until the end of the 1990s and a marked decline thereafter. In their turn, countries like Ireland, Luxembourg, and Poland show a trajectory of declining volatility. On the contrary, countries like France and Hungary reveal an increasing path with regard to volatility.

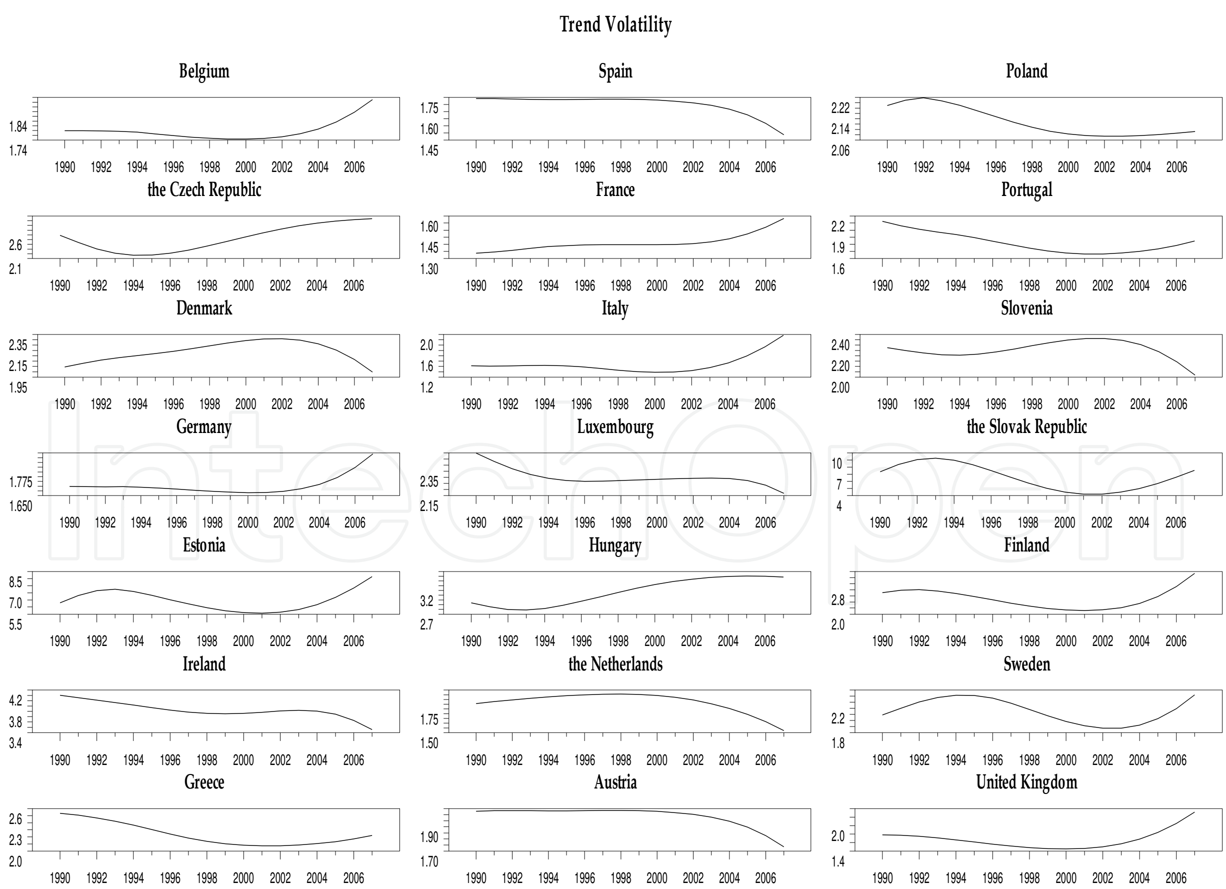

Fig. 3. Volatility trend

- *Logarithm of the contribution of renewables to total primary energy supply, lagged one period* (*LCRESct-1*). As discussed earlier, it is well known that economic growth is heavily dependent on energy use. Therefore, the contribution of each source towards economic growth should be assessed. Although renewables have yet to play a leading role in the total picture of energy sources in most countries, the relationship between renewables and economic growth must be evaluated. In reality, we are witnessing a growth rate of this source, largely as a result of public policies. On the one hand, these market opening policies or market driven policies take time to produce the desired effects and, on the other hand, the present productive structures are mostly suitable for the use of traditional sources. Thus, we control for the logarithm of the contribution of renewables to total primary energy supply, lagged one period. The effect of *LCRESct-1* can evolve in two directions. On the one hand, greater use of renewables may encourage the development of this entire industry, creating jobs and wealth locally. In this scenario, we will have a positive effect. On the other hand, greater use of renewables may involve the abandonment of fossil-based productive capacity and, therefore, we can observe a negative effect of renewables on economic growth. If the cost of the market-opening policies is excessively placed on the economy, then this negative effect can also be enlarged. If the second effect overcomes, then a negative signal is achieved.
- *Contribution of coal, oil, gas, and nuclear to electricity generation* (*SCOALEGct*, *SOILEGct*, *SGASEGct*, and *SNUCLEGct*). The conventional energy sources, including both fossil fuels and nuclear energy, are the dominant sources of energy and, as such, we control for the effect of all these sources on economic growth. Since the production structures in Europe are geared mainly towards the use of oil, we anticipate a clear positive effect for this source on economic growth. The same is expected to happen with nuclear power. With regard to coal and natural gas, given that the former source is highly inefficient and the latter is relatively recent, the expected effect may not be obvious *a priori*.

3.3 Method

This chapter makes use of panel data techniques to assess the nature of the effects of the several energy sources, and other drivers, on economic growth. Complex compositions of errors could be present in panel data analysis. The general model to estimate is:

$$LGDP_{ct} = \alpha + \delta LCRES_{ct-1} + \sum_{k=1}^{k} \beta_k X_{kct} + d_c + d_t + \mu_{ct}, \quad (3)$$

where $LCRES_{ct-1}$ is the share of renewables of country c in period t−1. The dummy variables d_c and d_t refer to country and time, respectively. In the error term $\mu_{ct} = \rho_c \mu_{c,t-1} + \eta_{ct}$, η_{ct} is serially uncorrelated, but correlated over countries.

To deal with the complexity of the errors, good econometric practices suggest performing the analysis by first making a visual inspection of the nature of the data, followed by a battery of tests to detect the possible presence of heteroskedasticity, panel autocorrelation, and contemporaneous correlation. We use the Modified Wald test (Baum, 2001) in the residuals of a fixed effect regression, to appraise the existence of groupwise heteroskedasticity. The Modified Wald test has χ^2 distribution and tests the null of: $\sigma_c^2 = \sigma^2$, for $c = 1,...,N$. The Wooldridge test assesses the presence of serial correlation. It is normally distributed $N(0,1)$ and it tests the null of no serial correlation. We use the parametric testing procedure proposed by

Pesaran (2004), the non-parametric test from Friedman (1937) and the semi-parametric test proposed by Frees (1995 and 2004), either for fixed effects or random effects, to test the countries' independence. Pesaran's test is a parametric testing procedure and follows a standard normal distribution; Frees' test uses Frees' Q-distribution; Friedman's test is a non-parametric test based on Spearman's rank correlation coefficient. All these tests - Pesaran, Frees and Friedman - test the null of cross-section independence.

Within a panel data analysis, the presence of such phenomena discourages the use of the common Fixed Effects (FE) and Random Effects (RE) estimators, due to the inefficiency in coefficient estimation and to biasedness in the estimation of standard errors they could cause. In this case, the appropriate estimators to be used are the Feasible Generalised Least Squares (FGLS) and the Panel Corrected Standard Errors (PCSE). In our sample, the number of cross sections (21) is larger than the number of time periods (18) and, therefore, the best suited estimator to deal with the presence of panel-level heteroskedasticity and contemporaneous correlation is the PCSE (Reed & YE, 2009).

The PCSE estimator allows the use of first-order autoregressive models for μ_{ct} over time in (3), it allows μ_{ct} to be correlated over the countries, and allows μ_{ct} to be heteroskedastic (Cameron and Triverdi, 2009). We begin by estimating a pooled OLS model (model *I*) and then we work on a panel data structure by applying the PCSE estimator. We will estimate the model presupposing the various assumptions about variances across panels and serial correlations, with the aim of checking the robustness of the results. The assumptions made throughout the models are as follows: model *II* - correlation over countries and no autocorrelation; model *III* – country-level heteroskedastic errors and common first-order autoregressive error (AR1); model *IV* - correlation over countries and autocorrelation AR(1); and model *V* - correlation over countries and autocorrelation country-specific AR(1).

3.4 Data

The data used in this chapter come from several sources. Table 1 summarises the variables, their sources and their descriptive statistics. The time span is 1990-2007, and we collect data for 21 EU Members, those for which there are available data for all the variables.

Variable	Definition	Source	Obs	Mean	SD	Min	Max
Dependent							
$LGDP_{ct}$	Logarithm of real Gross Domestic Product (billion dollars, 2005)	World Bank World Development Indicators, and International Financial IMF Statistics	378	5.3867	1.4966	1.9095	7.9921
Independent							
$ENERGPC_{ct}$	*Per capita* energy (kgoe/cap)	EU Energy in Figures 2010 DG TREN	378	4062.822	1590.981	1753.7	10132.98

Variable	Definition	Source	Obs	Mean	SD	Min	Max
$VOLGDPPC_{ct}$	*Per capita* GDP volatility	Own calculation. Raw data from World Bank World Development Indicators, and International Financial Statistics of the IMF	378	2.5407	1.2422	1.0622	8.7522
$LCRES_{ct-1}$	Logarithm of the factor of contribution of renewables to total primary energy supply, lagged one period	OECD Factbook 2010	376	1.5965	1.0126	-1.6094	3.4404
$IMPTDP_{ct}$	Import dependency of energy (%)	EU Energy in Figures 2010 DG TREN	378	52.2925	29.6911	-50.83	99.8
$SCOALEG_{ct}$	Contribution of coal to electricity generation	Ratio electricity generation to coal (TWh) / total elect. generation (TWh). EU Energy in Figures 2010 DG TREN	378	0.3614	0.2753	0	0.97
$SOILEG_{ct}$	Contribution of oil to electricity generation	Ratio electricity generation to oil / total elect. Generation. EU Energy in Figures 2010 DG TREN	378	0.0698	0.0983	0	0.51

Variable	Definition	Source	Obs	Mean	SD	Min	Max
$SGASEG_{ct}$	Contribution of gas to electricity generation	Ratio electricity generation to gas / total elect. Generation. EU Energy in Figures 2010 DG TREN	378	0.1694	0.1747	0	0.76
$SNUCLEG_{ct}$	Contribution of nuclear to electricity generation	Ratio electricity generation to nuclear / total elect. Generation. EU Energy in Figures 2010 DG TREN	378	0.2126	0.2306	0	0.78

Table 1. Data: definition, sources and descriptive statistics

First following a visual inspection of the data, we analyse the correlation coefficients, which are disclosed in the correlation matrix (table 2). In general, the correlation coefficients did not arouse any particular concern about the existence of collinearity among explanatory variables, although the correlation of *VOLGDPPC* with *LGDP* may be a possible exception.

Variables	$LGDP_{ct}$	$ENERGPC_{ct}$	$VOLGDPPC_{ct}$	$LCRES_{ct-1}$	$IMPTDP_{ct}$	$SCOALEG_{ct}$
$LGDP_{ct}$	1					
$ENERGPC_{ct}$	-0.1478	1				
$VOLGDPPC_{ct}$	-0.6610	-0.0209	1			
$LCRES_{ct-1}$	-0.0332	-0.0919	-0.1471	1		
$IMPTDP_{ct}$	-0.1230	0.1585	0.0574	0.0838	1	
$SCOALEG_{ct}$	-0.2211	-0.4187	0.1621	-0.1871	-0.4832	1
$SOILEG_{ct}$	0.1553	-0.4307	-0.1612	0.0342	0.3339	-0.0579
$SGASEG_{ct}$	0.1260	0.3487	-0.1024	-0.3672	0.1555	-0.3434
$SNUCLEG_{ct}$	0.1895	0.1240	0.0889	0.0640	0.0151	-0.4177
	$SOILEG_{ct}$	$SGASEG_{ct}$	$SNUCLEG_{ct}$			
$SOILEG_{ct}$	1					
$SGASEG_{ct}$	0.0495	1				
$SNUCLEG_{ct}$	-0.3642	-0.3310	1			

Table 2. Correlation matrix

In order to dispel any doubt we proceed as follows: i) we estimate the models excluding the variable volatility, concluding that there is no change in the coefficients' signals; ii) we compute the Variance Inflation Factor (VIF) test for multicollinearity (see table 3). The mean VIF is only 2.35 and the largest individual VIF is 4.21. From all this we conclude that collinearity is not a concern.

Variables	*VIF*	*1/VIF*
$SCOALEG_{ct}$	4.21	0.237790
$SNUCLEG_{ct}$	3.12	0.321027
$SGASEG_{ct}$	2.79	0.358631
$SOILEG_{ct}$	2.25	0.444951
$ENERGPC_{ct}$	1.98	0.504358
$LCRES_{ct-1}$	1.69	0.592946
$IMPTDP_{ct}$	1.65	0.604563
$VOLGDPPC_{ct}$	1.15	0.867271
Mean VIF	2.35	

Table 3. Variance Inflation Factor

Once the first inspection of the data had been made, we proceeded by testing the intrinsic characteristics of the data, namely by assessing the presence of the phenomena previously reported, i.e., heteroskedasticity, panel autocorrelation, and contemporaneous correlation. Table 4 reveals the specification tests we computed.

	Pooled	*Random Effects*	*Fixed Effects*
Modified Wald test (χ^2)			4885.68***
Wooldridge test F(N(0,1))	371.271***		
Pesaran's test		8.592***	8.069***
Frees' test		5.525***	5.749***
Friedman's test		62.200***	59.514***
Note: *** denotes 1% significance level.			

Table 4. Specification tests

From table 2, the null hypothesis of no first-order autocorrelation is rejected, as suggested by the Wooldridge test. From the Modified Wald statistic, we observe that the errors exhibit groupwise heteroskedasticity. As far as the contemporaneous correlation is concerned, all the tests are unanimous in their conclusions. They support the rejection of the null of cross-sectional independence, and thus the residuals do not appear to be spatially independent. The use of the PCSE is therefore sustained.

4. Results

After analysing the properties of the data, and since the pre-tests supported our choice for the estimations procedures, we proceeded to the presentation of estimation results, as well as their interpretation. Table 5 discloses the results and diagnostic tests.

	Dependent variable $LGDP_{ct}$				
Independent variables	*OLS*	*PCSE*			
	Model I	*Model II*	*Model III*	*Model IV*	*Model V*
$ENERGPC_{ct}$	-0.0002*** (0.0000)	-0.0002*** (0.0000)	-0.0001*** (0.0000)	-0.0001*** (0.0000)	-0.0002*** (0.0000)
$VOLGDPPC_{ct}$	-0.7972*** (0.0412)	-0.7972*** (0.0436)	-0.4913*** (0.0571)	-0.4913*** (0.0676)	-0.4456*** (0.0630)
$LCRES_{ct-1}$	-0.0256*** (0.0676)	-0.2563*** (0.0316)	-0.0916** (0.0366)	-0.0916*** (0.0303)	-0.0920*** (0.0297)
$IMPTDP_{ct}$	-0.0086*** (0.0021)	-0.0086*** (0.0011)	-0.0028* (0.0015)	-0.0028** (0.0013)	-0.0059*** (0.0015)
$SCOALEG_{ct}$	-0.6137* (0.3599)	-0.6137*** (0.2032)	-0.2811 (0.2162)	-0.2811* (0.1678)	-0.3495** (0.1702)
$SOILEG_{ct}$	2.4772*** (0.7353)	2.4772*** (0.2998)	1.0848*** (0.3197)	1.0848*** (0.2359)	1.1918*** (0.2558)
$SGASEG_{ct}$	1.0171** (0.5107)	1.0171*** (0.3332)	0.4774* (0.2452)	0.4774** (0.1893)	0.6929*** (0.2012)
$SNUCLEG_{ct}$	2.2215*** (0.3674)	2.2215*** (0.1549)	1.3139*** (0.2601)	1.3139*** (0.1988)	1.4048*** (0.1855)
CONS	8.3756*** (0.4916)	8.3756*** (0.2644)	6.9737*** (0.2506)	6.9737*** (0.2556)	6.9991*** (0.2505)
Observations	376	376	376	376	376
R^2/Pseudo R^2	0.6465	0.6465	0.8555	0.8555	0.8961
F (N(0,1))	25.61***				
Wald (χ^2)		96981.67***	170.97***	656.20***	722.13***
Exclusion tests for $VOLGDPPC_{ct}$ and $LCRES_{ct-1}$					
JST	188.35***	378.61***	76.59***	53.39***	52.11***
LRT	-1.0535*** (0.0834)	-1.0535*** (0.0559)	-0.5829*** (0.0709)	-0.5829*** (0.0825)	-0.5346*** (0.0759)
Exclusion tests for $SCOALEG_{ct}$, $SOILEG_{ct}$, $SGASEG_{ct}$, and $SNUCLEG_{ct}$					
JST	32.11***	673.23***	51.07***	58.38***	70.24***
LRT	5.1021*** (1.5008)	5.1021*** (0.7610)	2.5949*** (0.6658)	2.5949*** (0.5056)	2.9401*** (0.5212)

Notes: OLS - Ordinary Least Squares. PCSE – Panel Corrected Standard Errors. The F-test is normally distributed N(0,1) and tests the null hypothesis of non-significance as a whole of the estimated parameters. The Wald test has χ^2 distribution. It tests the null hypothesis of non-significance of all coefficients of explanatory variables; JST - Joint Significance Test. JST is a Wald (χ^2) test with the null hypothesis of $H_O : \delta = \beta_k = 0$, with δ and β_k the coefficients of $LCRES_{ct-1}$ and the other explanatory variables, respectively. LRT - Linear Restriction Test has the null hypothesis of $H_O : \delta + \beta_k = 0$. All estimates were controlled to include the time effects, although not reported for simplicity. Standard errors are reported in brackets. ***, **, *, denote significance at 1, 5 and 10% significance levels, respectively.

Table 5. Results

Globally, results reveal great consistency and they are not dependent on the assumptions we made about variances across panels and serial correlations. There are no signal changes and, in general, the explanatory variables prove to be consistently statistically significant throughout the models.

The impact of both energy consumption *per capita* and import dependency on energy on economic growth is negative and statistically significant. The effect of the volatility on economic growth is negative and statistically highly significant. This result supports the assumption that higher volatility contributes to reducing economic growth. Results also provide strong evidence that the impact of energy on economic growth is dissimilar, varying according to the source of energy. While oil and nuclear reveal a positive and statistically highly significant effect on economic growth, it seems that renewables are hampering economic growth. This negative and statistically significant relationship is consistent throughout the several models. The effect of the fossil source natural gas on economic growth is positive and statistically significant, albeit at a lower level of significance (5% and 10%). This probably comes from the fact that this source is playing a recent role as a transition source from heavily polluting sources towards cleaner ones. The effect of coal on economic growth is not always statistically significant and, when significant, it is negative.

We deepen the adequacy of use of the variables $LCRES_{ct-1}$ and $VOLGDPPC_{ct}$ since their use is not widespread in the literature. Additionally, we test the simultaneous use of $SCOALEG_{ct}$, $SOILEG_{ct}$, $SGASEG_{ct}$, and *SNUCLEGct*. For that purpose, we provide two exclusion tests: i) Joint Significant Test - JST; and ii) Linear Restriction Test -LRT. The variables $LCRES_{ct-1}$ and $VOLGDPPC_{ct}$, together, must be retained as explanatory variables. Nevertheless, the sum of the estimated coefficients could not be statistically significant in explaining economic growth. From the LRT we reject the null hypothesis and then the sum of their coefficients is different from zero. The same conclusion is reached when we test the adequacy of the simultaneous control for the variables $SCOALEG_{ct}$, $SOILEG_{ct}$, $SGASEG_{ct}$, and *SNUCLEGct*. These variables must belong to the models. Together with the appropriateness of the use of PCSE, these tests corroborate the relevance of the explanatory variables, other than energy consumption per capita and import dependency on energy, since these are well described in the literature.

5. Energy consumption, dependency and volatility

To conclude that the higher the level of energy dependency, the lower the economic growth, is more intuitive than checking that the consumption of energy has the same negative impact on economic growth. However, looking carefully at these two relationships, both effects are understandable and expected. Regarding energy consumption, it is confirmed that the negative effect outweighs the positive one. As discussed above, this may be the result of two phenomena. On the one hand, this suggests that the additional consumption of energy stems from activities other than production, such as leisure activities. On the other hand, this additional consumption could be causing an overload in the external deficit of energy, for most EU Members.

The hypothesis that the dependency on energy imports is limiting economic growth is confirmed. Additional energy dependency means that the country becomes more subject to external constraints and to the rules, terms and prices set by other countries and external markets. Meanwhile, greater volume of energy imports is matched by financial outflows.

With respect to prices and diversification of primary energy sources, if larger energy dependency confers an advantage to the country, then it is likely that this dependency could have positive effects on economic growth. The reality is somewhat different, however. On the one hand, it appears that, in general, countries are price-takers in the international energy markets and, as such, they cannot influence prices. On the other hand, diversification of energy sources can lead to the need for diversified investments, which are expensive and are not sized to take advantage of economies of scale.

One of the common-sense ways to offset this negative effect will be the replacement of imports. To do so, countries can locally produce some of their energy needs, through the use of indigenous renewable resources. However, till now, the use of these resources to convert into electricity does not seem to produce the desired effects. On the contrary, it seems to limit the economic growth capacity of countries, in contrast to what happens with fossil energy sources.

Regarding the negative effect of volatility on economic growth, this result is in line with the hypothesis that the characteristic of irreversibility that is inherent in physical capital makes investment particularly susceptible to diverse kinds of risk (Bernanke, 1983; and Pindyck, 1991). Indeed, growth volatility produces risks regarding potential demand that hamper investment, generating a negative relationship between economic growth and its volatility. Other possible explanations are based on the learning-by-doing process, which contributes to human capital accumulation and improved productivity, which was assumed to be negatively influenced by volatility (e.g. Martin and Rogers, 2000).

6. Renewables *vs* traditional sources

By the end of the 21st century, it is accepted that we will no longer be using crude oil as a primary source of energy, as a consequence of its depletion. However, the coal situation is different. The reserves are large and will remain widely available for a long time, perhaps even for a century. Unfortunately, this source is both highly polluting and not so efficient. Similarly, natural gas will be available in larger quantities than the crude oil reserves, even considering that some of its reserves remain unknown. It will remain available as a primary source of energy even until the turn of the century. The conversion of natural resources into energy, mainly into electricity, is a matter of crucial importance within this context of changing the global energy paradigm.

With regard to the impact of different energy sources on economic growth, there seems to be a dichotomy between the effects that are caused by the use of renewable and traditional sources, which include fossil and nuclear sources. Both oil and natural gas stimulate economic growth in the period and countries considered, in line with what has been pointed out by the literature (e.g. Yoo, 2006) and with *the growth hypothesis*. The effect of coal on economic growth is statistically weaker than the other fossil fuels and, when statistically significant, this source of energy constrains economic growth.

Among the fossil fuels, oil is the source that has mostly contributed to economic growth. Given that the productive structures of the industrialised nations, such as those under review here, which are highly dependent on the intensive use of internal combustion engines, this effect was expected. Natural gas also has a positive effect on economic growth, although this source of energy has been particularly significant in recent years. This is due not only to the advances concerning the discovery of new reserves, but also to the considerable increase in the network of natural gas pipelines. At the same time, the combined cycle plants, which use mainly natural gas as fuel, have been used to guarantee electricity supply within the RE development strategy. This fact has contributed to stimulating the development of this energy source. It is a cleaner source, and is considered the transition source from fossil fuels to renewable sources.

Although the fact that RE limit economic growth is an unexpected result, it is one that deserves deep reflection in this chapter. Policy makers should be made aware of the global impacts of policies promoting the use of renewables. At first glance, the development of renewables should have everything to make it a resoundingly successful strategy. With this strategy, it would be possible to fight global warming, reduce energy dependency (not only economic but also geo-political), create sustainable jobs and develop a whole renewables cluster. What these results suggest is that the effects of renewables are more normative than real, i.e., the results are far from what they should be. Indeed, the development of renewables has been supported in public policies that substantially burden the final price of electricity available for final consumption to economic agents. At the same time, the productive structures of the countries are still heavily dependent on fossil-based technologies, such as internal combustion engines. Their conversion towards other technologies is a slow and expensive path.

7. The role that renewables play and what we want them to play

It is worth discussing, in more detail, the observed effect of renewables on economic growth. The main motivations for the use of RE are diverse, as indicated above. One of the most widely claimed is that of environmental concerns. Renewables allow traditional production technologies to be replaced with other cleaner technologies, with lower emissions of greenhouse gases, in line with what is suggested by De Fillipi & Scarano (2010). The question that many countries, such as the United States of America, have raised is that this substitution severely limits the capacity for growth. This is the ultimate cause for the non-ratification of important international treaties like the Kyoto Protocol.

Moreover, it is far from unequivocally proven that more intensive use of renewables contributes decisively to the reduction of CO2 emissions, in line with what was pointed out, for example, by Apergis *et al*. (2010). In this chapter we tested the inclusion of CO2 emissions as an explanatory variable, but it proved not to be statistically significant.

Renewable sources should be placed within the mix of energy sources, requiring the simultaneous use of other sources, mostly fossil. The intermittency of renewables cannot be compensated by the use of nuclear energy. The offset of the lack of production from renewables implies the ability to frequently turn these other sources of support on and off, which is obviously not possible when it comes to nuclear energy. The counterbalance has to be made by fossil fuels, mainly natural gas and coal. The latter is a cheaper source of energy but at the same time is also highly polluting.

The growing use of RE has been heavily dependent on policy guidance. Most EU Members, either voluntarily or compulsorily, have established several mechanisms to support these alternative sources of energy. One of the most commonly used policies is the feed-in tariff, which consists of setting a special price that rewards energy from clean sources. This policy and all other public policies lead to government expenses. These costs are passed on by the regulators to the final consumer, both residential and firm consumers. When they are not passed on by regulators in the regulated market, then in the liberalised market, the producers transfer to consumers the extra costs they have when producing energy from renewable sources. This strategy of promoting RE can thus burden the economy with electricity costs that are too high and therefore hinder economic growth.

It is already clear that the overall strategy for electrification of the economy requires large volumes of financial resources, which may be diverted from other alternative projects. However, the massive investment in renewables may promote divestments, not only in the technological upgrades of other conventional sources of energy, but also in other industrial projects. In order to be able to achieve compliance with the requirements of market entry, and to keep innovating mainly through R&D, players in renewables are obliged to issue debt. Given that the available financial resources are scarce, this debt from renewables may be preventing players in other industries, with even greater multiplier effects on economic growth, from achieving fair interest rates which do not compromise the appropriate return.

In this regard, it is worth highlighting that another factor which may help explain the negative effect of renewables on economic growth is that the investment should be paid during its usable life, as good practices suggest. The reality shows that this normally does not happen. Consumers have to start to bear the cost of a wind farm or solar park almost immediately. More serious still is that the Government requires the payment for a licence allocation of power generation in advance. After that, the Government guarantees prices for the purchase of the electricity generated. Finally, the winners of the bids will capture the regulators to immediately recover these costs of entry. Overall, this has little to do with the nature of renewable technology. Instead, it is more a launch of a tax resulting from renewables diverted to electricity costs and, ultimately, on consumers and on the economy as a whole.

No less important within this discussion of the effect of renewables on economic growth is the effect brought about by renewables on the technology and production capacity already installed. In fact, greater use of renewables implies the dismantling or simply the creation of excess capacity based on conventional sources. Note that, in the past, these sources represented a major cause of the degree of development, industrialisation and prosperity of the countries. They grew mainly supported on technologies based on fossil sources of energy. The increased use of renewables can thus be causing two outcomes. On the one hand, renewables may diminish the positive effect of conventional sources on economic growth. On the other hand, renewables discourage technological upgrades of conventional sources. Nonetheless, these sources can still evolve, both as regards the level of energy efficiency (thus reducing dependency), and as regards greenhouse gas emissions.

It should be noted that the results presented in this chapter were obtained by studying evidence from 1990 to 2007. They do not allow us to unequivocally conclude that RE will not stimulate economic growth in the near future. Indeed, the studies using official statistics on energy produced from renewable sources inevitably suffer from a problem that could lead to some kind of bias in the results. The official statistics on the use of RE normally do not reveal the true contribution of these sources both to our lives and to the economy as a whole. There is a plethora of examples that illustrate this failure in the statistics. When the sun comes through the windows of our homes or businesses, effectively heating them, there are significant energy savings by avoiding the use of traditional energy sources. The statistics also do not capture the effect when the sun heats the water that we use both for bathing and industrial activities. The sunlight that enables the achievement of sporting events, entertainment and various economic activities without resorting to light bulbs is a valuable contribution of this renewable source, but it is also absent from official statistics.

Solar radiation allows the growth of plants, both for biomass and food, which in turn creates energy. Finally, it should not be forgotten that solar radiation allows the chemical process for the formation of fossil fuels. The natural resource water does not only provide the water supply for dams for electricity generation, with the particularity of this feature in allowing storage. In short, by not considering all these effects from renewables, the results that come from the use of official sources of statistics may not give the full picture of the effect of renewables. All the energy that results from natural and renewable sources is generally not included in the statistics, but it is an invaluable contribution to reducing the use of other sources, mainly polluting fossil sources.

In general, if taken together, renewables are likely to contribute positively to the process of economic growth. However, regarding the use of natural sources for electricity generation through direct human intervention, such as wind and photovoltaic facilities, it seems that the desired results are still a long way off. In fact, this may distort the conclusions about the contribution of renewables to economic growth. The immediate challenge will therefore be to strengthen the use of these renewable sources, in their natural state. In other words, both the organisation of society and the economy should be more consistent with the maximisation of benefits from these natural sources. Just two simple examples. First, more energy-efficient houses must be built. They should maximise the benefits of solar power for heating, while wind, rain and vegetation should contribute to cooling them. Second, both sports and musical shows should be performed during periods when natural light eliminates the need for artificial lighting, which consumes a great deal of electricity.

Overall, a country's decision to intensify the use of the RE mix is eminently political, rather than economic. In this process, there are two strongly related factors that will influence the role of renewables in the economy. The first concerns the evolution of technology converting energy emitted by renewable sources into usable energy, such as electricity. The second factor is of a political nature. The consequences for renewables will be rooted in this political process. We believe it is essential that the regulatory authorities do not excessively and quickly pass costs of RE production to the economy. Instead, they should commit players operating in this industry to assuming a significant part of the risks inherent in these energies.

8. Conclusion

This chapter is centred round the interaction between economic growth and its main drivers, focusing mainly on the effect of each energy source, distinguishing between traditional sources and renewables. We go on to shed some light on the relevance of developing the use of renewables in the energy mix and on their consequences in relation to economic growth. To do so, we apply panel data techniques to a set of EU 21 Members, for the time span 1990-2007. Overall, the results prove to be consistent and the use of the Panel Corrected Standard Errors estimator seems to be suitable, matching the data properties.

Both energy dependency and volatility have contributed negatively to economic growth. Conventional wisdom indicates that the use of energy generated from renewable sources can contribute both to reducing this dependency and to reducing volatility. Renewable energy is produced locally and thus contributes to energy self-sufficiency. Meanwhile, the contracts for generation from renewables are generally medium to long term, which are characterised by lower uncertainty as to price behaviour. The results suggest, however, that renewables are also hampering economic growth, in the period and for the countries analysed. This chapter discusses extensively the possible reasons for this effect caused by renewables. It is confirmed that the traditional sources of energy have been real engines of economic growth, although the role played by each of these sources is not homogeneous. Among the fossil fuels, oil has played a key role in the process of economic growth.

On a daily basis, we use renewables without noticing. Accordingly, we directly make use of renewable energy in its natural state, such as it is available on Earth, like in water heating, lighting or heating our homes. This generous contribution from nature, however, is usually absent from the statistics. With regard to the use of technology for conversion of renewable energy into usable energy, mainly from sun and wind, the conclusions are dissimilar. Using the statistics, we find that the share of renewables in total energy supply is not having the desired effect, as far as economic growth and wealth creation are concerned. Ultimately, with the current state of affairs, the decision to invest in renewable energy remains essentially political.

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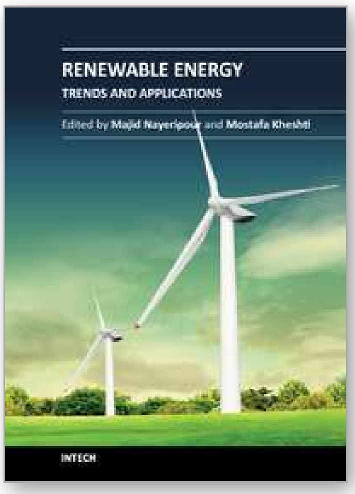

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Increase in electricity demand and environmental issues resulted in fast development of energy production from renewable resources. In the long term, application of RES can guarantee the ecologically sustainable energy supply. This book indicates recent trends and developments of renewable energy resources that organized in 11 chapters. It can be a source of information and basis for discussion for readers with different backgrounds.