Master's Thesis

MSc Engineering and Policy Analysis

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Linkages between environmental innovation and policy measures in the EU15

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PREFACE

The present document constitutes the final report of the Master Thesis Project which marks the conclusion of my MSc education in Engineering and Policy Analysis at Delft University of Technology. The project has been conducted for the Department of Technology, Strategy and Entrepreneurship and its main goal is to study the policy instruments influencing the promotion of renewable technologies within the European Union of 15. The scope of studying the national innovation systems of the EU15 is to frame the driving forces of their innovation and, hopefully, define appropriate policy instruments to promote the renewable energy in order to secure the energy supply and abate pollution. Results from the different research stages can be found in chapters four and five while chapter six is dedicated to the policy implications. Finally, chapter seven presents the conclusions and further research stemming from the current findings. Figures and tables related to the empirical study are included in the appendices C, D and E of the report.

Part of the evaluation committee of this project is:

Professor and first supervisor: Prof. Cees van Beers (Department Technology, Strategy and Entrepreneurship).

Second supervisor: Dr. Scott Cunningham (Department Policy Analysis).

Third supervisor: Ir. Adriana Diaz Arias (Department Economics of Innovation).

I would like to express my appreciation to those who have supported me during the development of this project: my first supervisor, Dr. Cees van Beers for his confidence and advice during the project's completion, his interest and enthusiasm made the whole procedure exciting and creative. To my second, Dr. Scott Cunningham, all my gratitude for the healthy scepticism and the abundance of information on the policy options which boosted the course of the study. Many thanks to Ir. Adriana Diaz Arias, for her undivided help and support during the whole project: from the conceptualisation to the statistical model.

I am, also, very grateful to my fellow classmates and friends for keeping me company and helping me improve in my presentational skills. Finally, I want to thank my parents for their infinite support during all these years.

Konstantina

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EXECUTIVE SUMMARY

In March 2007, the European Commission presented the "Renewable Energy Roadmap", a document establishing a binding target for all European Union's Member States to increase their renewable energy consumption rates from sources such as wind, solar, hydro or biomass. The overall value (for all EU Members) was set at 20 percent and should be reached by the year 2020. The renewable energy production was introduced in the energy production sector just after the energy crises of the 1970s as private attempts of few countries to deal with prospective energy security issues. In addition, renewable energy technologies contributed in pollution abatement, which has been a challenging issue for the European Commission ever since, due to their non-depletable nature and the decreased amount of greenhouse gas emissions compared to the ones produced by fossil fuels.

In December 2008 the European Union adopted the proposal of the Commission (2008), which stated each Member country's target share of renewable energy consumption, calculated on the basis of per capita gross domestic product. The Directive included in-between targets (such as 25 percent of the overall target between 2011 and 2012) but no binding constraints on their implementation.

Besides the increase of the Renewables share, another solution which has been proposed by the European Commission has been the concept of "energy efficiency". This idea is defined as decreasing the energy consumption by 20% by the year 2020. In contrast to the renewable concept, energy efficiency has been implemented following regulations suggested by the European Commission. The general policy instruments which have been used remain the same with those of Renewables but they have been more clearly defined for all sectors (households, industries, transports and services). Despite the fact that the Renewables have proceeded as a concept, energy efficiency has been adopted widely and faster. These two trends have been the most representative concerning the energy changes which the European Union started promoting the last decades. Their effect is multi-oriented: prevention from energy depletion and dependence on foreign countries and pollution abatement, according to the directions of the Kyoto protocol.

The success of the implementation of environmental friendly technologies has been related to the technological change in the energy field. Many researchers tried to connect environmental innovation with various characteristics, such as R&D expenditures or policy instruments, in order to suggest effective means for their promotion. Characteristic researches have been these of Popp (2005) with "lessons" over environmental innovation and connection of innovation to energy prices, Brunnermeier and Cohen (2003) who modeled, for the US industrial sector, the determinants of environmental innovation, Vries and Withagen (2005) who connected environmental innovation to stringency policies and Johnstone et al. (2008) who modelled the environmental innovation determinants and specified their research in policy instruments.

Johnstone et al. (2008) tried to define a relation between environmental innovation and energy policies for the Renewables using an empirical model. The model included some general variables, such as electricity prices or energy consumption, and then defined binary variables to operationalise the policy measures. The environmental innovation was defined as the number of patent counts for specific classes of the International Patent Classification. The present study's model is based on Johnstone's et al (2008) model. It follows the main lines of their research by using the same innovation output, i.e. the

patent counts, and by having two sets of variables: the general ones and the policy-related ones. The patent counts were considered to be the most appropriate output indicator for this empirical study, as well, as they provided the necessary information to modelling (such as priority date and country of application) and were widely available (from the European Patent Office - EPO).

Johnstone et al. (2008) defined a simple “input-output” model for six renewable energy sources. For each one of the sources, they used a specific classification in order to gather all patent counts relevant to each source. They also included seven policy types which were implemented for the renewable energies for a specific time period. Finally, they included a set of “explanatory” variables, which were considered as input innovation indicators. This study based on their model also used patent counts as innovation output. The main “modelling” differences are the introduction of more explanatory variables, such as R&D personnel, international trade indicator or R&D intensity, the different policy instrument operationalisation (from binary to semi-quantitative) and the empirical analysis methods. Also, Johnstone’s model is implemented for a different set of countries and a different time period than the one we examine. Our focus is on the effects of policies on environmental innovation for the EU15. The reason for that is that it is interesting to measure the effects of policies within the borders of the European Union (for policy recommendations) and that the data collected are from the EPO. Johnstone et al (2008) mention that, *when coming from non-European country it is less likely to patent at the EPO.* Also, our information is set for a shorter period of time for practical reasons (there was no available information before 1990 for the renewable sector and, by definition the European Commission has not started yet promoting the Renewables). The new framework has been yet once modified in order to include the effects on energy efficiency energy trend. Using the same variables, we created a new output set in order to incorporate the policy measures implemented for this second energy trend.

Using a logarithmic scale, we performed two types of regression analysis to model our data, the linear regression using the ordinal least squares, which provides a linear relationship between the dependent variable (our output) and the independent variables (our input) and gives the best-fitting relation by minimising the least squares error and the general linear regression, which takes into account possible attributes of the dataset, such as heteroscedasticity or correlation, and, is also more efficient in analysing datasets with cross sectional data (such as time series) included in our model.

The model used for both energy trends several explanatory variables, determinants of patenting activities. From these we extracted valuable information concerning the R&D input, the energy consumption and the electricity prices. R&D was measured in two separate ways: the R&D intensity, which reflects the R&D expenditures ratio, spent on each energy trend and R&D personnel. Both of these variables showed a positive linkage to the output. Positive impact also came from energy consumption. As for the electricity ratio, a subsidy for the electricity prices for households and industries, the results diverged, depending on the energy sector. For the renewable energy, the electricity ratio had a negative impact denoting the importance of the industry electricity price as innovation determinant and for energy efficiency; the electricity ratio had a positive impact denoting the importance of household prices as innovation determinants. At the same time, we should mention the fact that policy instruments follow this observation: for energy efficiency, most measures are implemented in the household sector, while on renewable energy most measures affect the industry sector.

The regression analyses showed interesting results concerning the policy instruments for both energy trends. While the renewables favour price based instruments, such as taxes and tariffs, the energy efficiency favours legislative (like quotas) and financial (like grants and subsidies). This observation is very important as it shows the tendencies of the last 17 years to promote different energy trends. For renewables, which were boosted right after the energy crises, the measures have a more obligatory character in order to succeed. This information combined with the fact that renewables were mostly promoted in the industry sector (which by definition consumes the largest amount of energy) links renewable innovation to stringency policies. On the contrary, energy efficiency has a more liberate character. This is also connected to the fact that it is mostly implemented in households. After the conclusions, the policy measures provide a clearer picture of how environmental innovation is linked to them.

In conclusion, the environmental innovation is strongly related to existing policy measures, and, in fact, different policy instruments have greater effect on different environmental friendly energy trends than others. Price based measures are most effective in inducing innovation for renewable energy technologies, while legislative and financial measures are most effective on energy saving innovation. During the study, there were found no significant results on voluntary measures. In general, public policies are linked directly to these two energy trends. This conclusion could urge the promotion of the two trends in parallel so that the targets (pollution abatement and security of supply) of the European Commission are achieved as scheduled.

CHAPTER 1
INTRODUCTION

1.1. Introduction

Renewable energy technologies also known as RETs have been included officially in the EU's portfolio since 1997. The European countries, though, have started promoting RETs earlier than the mentioned date. Late research indicates the use of renewables since 1978 for many European countries such as Germany, United Kingdom, France etc (OECD, 2008) due to the energy crisis of the 1970s. These countries following their own policies have tried to include RET in their prosaism. EU voted through the first White Paper on RETs ("Energy for the future: renewable sources of energy") in 1997. Since then, the Commitee has been frequently referred to the renewables[1] promoting directives and frameworks in their favour. In 2001, the EU adopted the "directive on promotion of electricity produced from renewable energy sources" and on 2003, the "biofuel directive". During that period, the EU has been constantly monitoring each member's initiatives and actions promoting the RETs.

All members had to demonstrate their plans according to the targets fixed by the EU ("Screening process[2]"). On the 23rd of January 2008, the Commission decided to boost even more the RETs in the European market in order to increase the current 8.5 percent to the target 20 percent by 2020. This would be achieved by the use of an "energy mix", i.e. the combination of different energy resources, including especially the renewables. The choice of the renewables in the energy mix is uncontested for two reasons. The first is to ensure energy security, due to the conventional energy sources future deficiency. The second is to abate pollution as referenced by the Kyoto protocol. Due to the severity of both reasons, the European Commission decided to get in action by publishing the Directives for the achievement of these to goals.

Thus, each one of the 27 member states should increase its share of renewables according to their gross domestic product – GDP (Table 1 Appendix A). This procedure should be impemented gradually by setting intermediate targets (e.g. 25 percent of the target between 2011 and 2012). Each country has the liberty to design its own "action plan", based on indicator provided by the EU, in three sectors: electricity, heating and cooling and transport (Figure 1). The present research does not focuses on the implementation of the directives for transportation. Instead, it concerns the cases of the residential and industry sectors.

[1] Renewables is another way to refer to the RETs. Another term used in the study is RES defining the renewable energy sources
[2] The screening process is constituted by a template created by EU institutes, which concentrates the results of each country's action plan on energy. This project is implemented by the Energy Efficiency Watch – EEW (Schuehe, 2007)

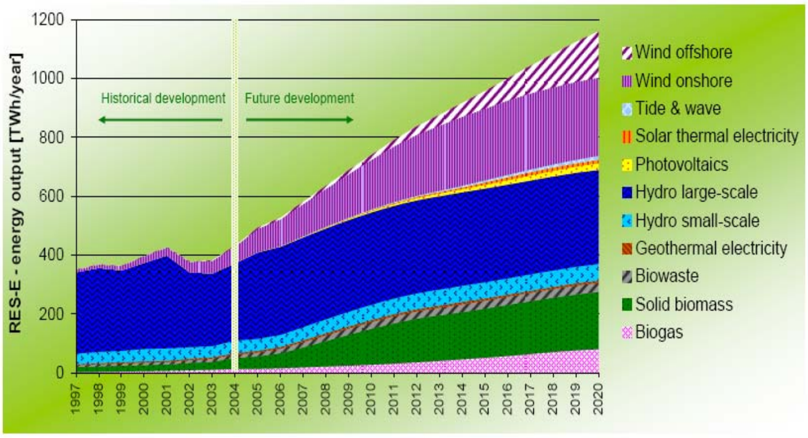

FIGURE 1 – RENEWABLES GROWTH PROJECTION BY 2020 (EUROPEAN COMMISSION, 2007)

The European Commission does not assign specific instructions for the implementation of the RETs targets (besides the case of biofuels in the transportation sector). Instead, it lets every country to design its own measures in order to reach its goal. Therefore, different countries implement different policies for different kinds of RETs. Different policies, in their turn, seem to have different results on the indicators of RETs. In order to achieve the optimal result, thus reaching, or even surpassing the 20 percent target set by the EU, the existing policies should be examined so as to reveal their effectiveness on the technological progress of EU members. In order to measure the policies efficiency, we need to define a framework whose input includes these policies and output is expressed in terms to define innovation performance. The measure selected as the output of the framework is the number of patents per innovation sector (renewable energy type). In the following part, we examine the relativeness of innovation and the patents, so as to reinsure that patents are a suitable tool to measure the technological change in the RETs field.

1.2. MOTIVATION, RESEARCH PROBLEM AND SCOPE

A major aspect of this research study is the dependence of environmental innovation and the renewable technology concerning policies implemented at that specific time. In his paper, Johnstone (2008), explains the relationship using a negative binomial model. To estimate his formula, which is comprised by different independent variables, Johnstone used the number of patents as the output of environmental innovation. More specifically, the dependent variables of the formula are: the policy measures on the Renewables, the R&D expenditures on the specific technologies by the national public sector, the electricity consumption, the price of electricity and the overall patenting activity, as shown in Figure 2.

According to Johnstone, these are the relative variables which reflect environmental innovation. The first two are the principal variables of the policy sector as they express whether policy instruments have been implemented and how each country has invested on them. In the model the policy instruments such as taxes, tariffs, and subsidies and so on are expressed through a binary variable. The electricity consumption denotes the "returns on innovation", meaning that there should be a depiction of increasing in patenting activity, as the electricity market is growing. The same connection should exist between the electricity price and the output. As the electricity price rises, the tendency to invest in Renewables is growing, thus, there will be an increased patenting activity as well. The overall patenting activity is showing the tendency of a country to patent. Johnstone uses for his research, which includes data since 1978, the European Patent Office database.

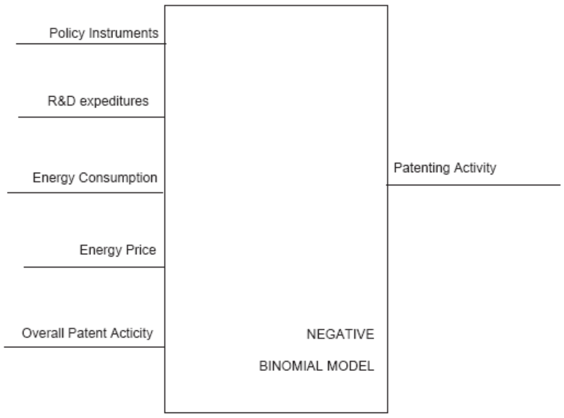

FIGURE 2 – JOHNSTONE'S MODEL

The basis of this research is that patent data can be used as output innovation measure. This assumption is based on the research of Popp (Popp, 2005). In his paper, Popp presents the theoretical background to link the economic incentives to technological change, and, in further to justify that innovation can be counted by the patent activity. In following studies (OECD, 2008) patents have been established as one of the most successful innovation measures since they provide numerable information about the invention and its features (such as publication area, date, country, inventor, citations etc). In addition, these data are available, in large databases such as ESP, and discrete, thus easily used for statistical analysis.

Taking that in mind, Johnstone is proceeding by using a count data model, the negative binomial model, for estimating the patenting activity as an event count following a negative binomial distribution (A.C. Cameron, 1998) in a specific innovation framework. His produced formula presents the results of the regression analysis to the existing statistical data. This research has revealed some issues concerning its accuracy. In his paper (N.Johnstone, January 2008), Johnstone has efficiently solved some aspects of its problems (like multicollinearity issues or interactive effects). As a next step, the paper uses different methods of regression analysis (J.F. Hair, 1998), such as clustering or Principal Component Analysis (PCA) to optimize the existing results.

The main idea stemming from Johnstone's research is to use this model and expand it, if possible, by focusing in the policy instruments part in the EU15. In that way, by examining the different policies, one can define their influence on technological change within the EU15. This defines the original framework on which all the findings of this research are based. Depending on the results, many different theories can be drawn up for each one of the countries such as the measures that they favour, the RETs that are more suitable etc.

In different case, if technological change is not expressed effectively through the formula, one should expand the original framework in different directions and create new hypotheses such as the lock-in effect to traditional energy resources instead of investing to renewable technologies, by using energy efficiency (GREEN PAPER, 2005) in both industries and households. Energy efficiency has been an energy trend promoted at the same time by the European Commission to decrease energy consumption levels. If this hypothesis is correct, that saving energy creates a barrier in producing renewable energy, how could the renewable energy be enforced and not "crowded-out" so as to avoid complete dependence on the conventional energy sources, imported or not.

The framework created as an extension to this of Johnstone's is, as mentioned above, using the patent counts as innovation output measure. Since, the present study uses the same measure, it is essential to search in the literature for possible disadvantages of our choice. Despite the fact that patents can be a valuable tool concerning data acquisition, there are some drawbacks from their use (N.Johnstone, 2008) analysed in the second chapter. First of all, it is very hard to correlate the patents to their market value. Even if a patent is granted, there might be years after its market value is revealed. In some cases, the patent itself has no market value at all, or is complementary to another technology. This fact is bounding the present research as well. The assumption is that the market value will not be determining the value of the patent itself. Each granted patent concerning the renewables belongs to the dataset of this essay. Other difficulties, such as different patent regimes are resolved by strictly defining the boundaries of the research (geographical and organization dependent). In further, different patent regimes will not be examined since the dataset is exclusively created by the EPO database (EPO, 2009). Finally, the dataset is bounded also geographically, meaning that the research is conducted for the EU15.

1.3. KNOWLEDGE GAPS AND RESEARCH QUESTIONS

The above research, as already mentioned, is the basis for the present study. According to the existing methodology, more phenomena concerning the environmental policies and innovation shall be examined. At first, it is principal to discover possible correlations of the policy measures implemented in EU15 Member Countries and the patenting activity. Until now, policies have been defined in conventional terms using instruments such as taxes, tarriffs, voluntary programs, tradable certificates etc. Member states have been completely free to create their own policies with the constraint to fulfill their target values (Table 1 – Appendix A) without emphasising on their actual impact. Besides the connection of policy instruments to patenting activity, one more target of this research is to provide an, as much as possible, integrated framework, covering the most important aspects of national (in EU15) innovation systems using variables such as the R&D expenditures, energy consumption, electricity etc.

In consequence to the general framework, a new one has been created to include all the aspects of the present research[3]. In order to do so, most of the concepts of the general framework have been operationalised, not only because of a clearer depiction of the actual system, but also because of the values needed to define and, eventually, optimise the system. Not all of the aspects of the general framework have been used in the current modelling. Instead, some assumptions have been made. One of the first assumptions, due to the methodology used i.e. patenting activity, has been that the relation of our output and the actual market cannot be clearly defined (N.Johnstone, January 2008).

[3] The framework is presented in the conceptualisation chapter (chapter 3) and is named the REIS framework (Renewable Energy Innovation System)

The output of the original framework is as mentioned above the total number of patents as an operationalisation of innovation concept. In this research, a more specific part of this framework is examined, the one concerning the renewable energy innovation sector.

The original framework shall be redefined after the results of the statistical analysis, in case some of the input variables are not highly correlated to the output or there is new evidence which influences the final output, such as possible "lock-in" effects, including one more energy trend: energy efficiency (abbreviated ENEF, also referred as energy savings)[4]. Energy efficiency has the same input such as renewable energy. This fact makes it easily comparable to renewable energy as well.

The hypothesis is when energy efficiency R&D is increased, then one should probably remark stability or even decrease in the number of patents as output for renewable innovation. This seems quite obvious since investing on how to preserve the existing energy (lock in effect) gives less room to invest on producing renewable energy.

Following the above statements, the main research question can be defined as:

What is the impact of environmental policies on technological progress in renewable energy and energy efficiency trends within the EU-15, and how is this affecting the current and future policy making in the EU's directives.

Therefore the main research question is divided into two separate parts, both affecting the existing regimes of the EU in the energy efficiency sector and renewables sector. The conclusions of the above question aim to help in integrating the current policies and, in the end, to achieve the target value of 20 percent until 2020 for the renewable energy usage. In order to answer the main research question we use the technique of "divide and conquer", splitting our main question into separate subquestions. These qustions so as the methodology followed to illustrate them are listed in the next section.

1.4. METHODOLOGY

This part aims to securing the best methodology to treat our data, in order to provide answers to our research questions. The order to methodology is different than the one presented in the previous section as the two parts, defined above, are combined. Our methodology is divided as follows: at first, we present a literature review on the terms and the theory included in this study. The literature review aims at clearing out the economical background of the model, creating motivation for research and defining the framework of the study.

More specifically, the literature review examines the two methodologies followed until now to create the regulatory framework, best-fitting for the EU15 in order to achieve the goals[5] defined by the European Commission. At first, we examine existing measures and their results by measuring eco-innovation, and then, we propose the most appropriate towards both environment and industry measures to follow. The first part is answered through induced innovation hypothesis and the second through evolutionary approach as explained in Chapter 2. Then, the second part includes the statistical analysis. This procedure is separated into several parts. At first, data should be collected using the EPO database (EPO). The research will be involving the field of the invention (its class e.g. F24J2/04), the publication

[4] This framework is named "Lock-in" framework.

[5] As mentioned in the Introduction Chapter, the general goals of the European Commission are the **pollution abatement** and the **energy security**.

date, the applicant (i.e. the company that applies for the invention) and the country where it belongs (the country is defined in the first two letters of the patent code or the applicant. The following table is an example of the above:

Publication number	Publication date	Applicant(s)	European classification
EP2026017	2009-02-18	SOLAR CENTURY HOLDINGS LTD [GB]	F24J2/04; F24J2/52; F24J2/04

TABLE 1 – EXAMPLE OF PATENT APPLICATION (EPO)

The primary search defines the classes (or subclasses) of renewable technologies. Knowing that, the applicant name and the date are combined to create the dataset (in Microsoft Excel) for the statistical analysis questions. The results of the database query are exported to an excel file. Having collected the data, the next step is to analyse them (statistical treatment) using the Stata software. After that, using the same software, regression analysis is following, so as to create a model. The regression analysis is conducted for the treated data following two methods: the ordinal least squares (OLS) and the general least squares (GLS). The reason we use the GLS method is to treat the data as a panel set (defined by country and year).

Finally, after the statistical findings, the next step is to return to policy recommendations and future research which could ameliorate our results. The methodology overview is presented in the table[6] below:

Research Question	**Task**	**Methodology**
How is eco-innovation defined? What are the main economic concepts?	Term definition and explanation	Literature review
What kind of market failures can influence innovation, creating path-dependencies and probable "lock-in" effects?	Term definition and explanation	Literature review
How is lock-in effect defined? What are their sources? How can a technology (such as renewable energy) escape from being locked-in?	Term definition and explanation	Literature review
What are the policy characteristics for the models (driving forces, policy instruments available for RES and ENEF, main characteristics of each policy instrument, policy instruments which are used in the present research)?	Identification of policy measures	Literature review, data collection
Which is the best-fitting model to incorporate our system, what is the input and output and how is it operationalised.	Construction of the REIS framework	Literature review, data collection, data treatment, regression analysis
How can we embody one more subsystem in order to correlate its function to the original framework	Construction of the Lock-in framework	Literature review, data collection, data treatment, regression analysis
How are the models operationalised for both frameworks and what conclusions come from that? (limitations, system variables, main	Model construction, statistical analysis	Data collection, data normalisation, regression

[6] The table includes all the research questions defined in each chapter, the tasks that should be fulfilled and the methodology followed.

features of the created datasets, data treatment, method of data analysis)		analyses
Is there an obvious connection between the subsystems and what are the implications for both frameworks?	Model implementation, Result analysis	Deductive analysis from regressions, comparative analysis of the two models
Is the model robust? What are possible extensions?	Implementation of model	Post regressions analyses
What are the policy implications?	Analysis of the regression results for the existing policies	Deductive analysis
What are the models' main conclusions?	Analysis of the regression results for all variables	Deductive analysis
What is suggested as further research?	Identification of research gaps and suggestions for future research approaches	Deductive analysis

TABLE 2 – RESEARCH QUESTIONS

1.5. STRUCTURE OF THE THESIS

The sequence of the thesis phases follows as below: the first chapter, as expected introduces to the research problem and its affiliation to existing research, especially referring to the model of Johnstone et al., conducted for the OECD (N.Johnstone, January 2008). This chapter is also presenting the methodology and the steps to go.

The second chapter of this essay is an analytical description of background theory which is used to define properly our system and lead to the next chapter, the creation of the framework. The chapter includes the theory behind eco-innovation, the economical approaches to deal with it and the explanation of the lock-in effects.

The third chapter builds up the framework used in this research (the REIS framework) so as its extension (the Lock-in framework). This chapter includes the basic theory behind an innovation model construction, so as the detailed description of the research's frameworks.

The forth chapter aims to operationalise the frameworks described in chapter 3. The operationalisation (specification) includes the definition of the variables, with an emphasis on the policy instruments, and a preliminary analysis before the data empirical analysis.

The fifth chapter the results of the empirical analysis including the data treatment, the data regressions with two statistical methods (as mentioned above) and the post regression testings.

Finally, the last chapter sums up and provides policy recommendations and future research possibilities. The statistical analysis procedures and steps will be thoroughly described in the appendices D and E.

CHAPTER 2
THEORETICAL BACKGROUND

2.1. INTRODUCTION

Many economists have distinguished the need of defining innovation to better understand the innovation process, from its incentives to its economic impacts. In order to frame “innovation” the European Committee has published the Oslo Manual (harmonised with OECD), i.e. proposed guidelines for collecting and interpreting technological innovation data. This manual includes the necessity of defining innovation, the different aspects (process, product, marketing and organisational) of innovation, how to measure innovation and other information. Due to the broadness of the definition, innovation in terms of environment had to be redefined so as to include social and institutional aspects.

The firms have initially started to invest in innovation projects to get an advantage over their competitors. In case it represents utility goods (such as electricity) investment in innovation has been rather non-profit oriented. Either because of positive knowledge spillovers and appropriateness problems due to public good character of knowledge, a firm could be unable to maintain the benefits of innovating making the production/ distribution costs higher than the end-users costs. For that reason, governments have turned to policy instruments so as to boost innovation within these utility projects. The first step has been public funding in Research and Development (R&D). This action led to the design of new economic models of innovation, not only profit-oriented, which resulted to the evolutionary approach. In times of increasing concern over climate change and decreasing impact of economic activity the main argument is to create “win-win” situation between the environment and the profits. This approach left room to innovate and led to various technological outcomes. Due to this “freedom”, firms have been capable to innovate following different directions, also known as “technological trajectories” from a strict market with only one equilibrium point in profit maximisation to a more liberal market, with different objectives and multiple regulations to balance the complexity of the system, where firms are not trying for optimal results but for satisfactory ones (Dosi, 1982).

In this thesis, we examine a specific case of innovation, eco-innovation (or environmental innovation). Besides the different features of its definition, environmental innovation includes a very interesting characteristic: the regulatory push, described in the next section of this chapter. This element is of high importance to the present research which is focused on regulations concerning innovatory trends in different energy fields.

Eco-innovation theory is divided into two schools: the neoclassical and the evolutionary. Each method is described, followed by an overall critique which focuses on the implications from its implementation. From these two approaches, we decide to study the innovation trends from the evolutionary perspective for the policy making. The theory behind evolutionary approach can help in defining the optimal outcome, which is a “win-win” situation for both firms and the environment. This study poses the question which could be the best-fitting regulatory framework for the EU-15 Members in order to achieve the goals defined by the European Commission. This question is divided into two parts: the examination of existing measures and their results by measuring eco-innovation, and then, the proposal of the most appropriate, according to the economical theories, towards both environment and industry, measures to follow. The first part of this chapter describes the economic ideas behind eco-innovation. Also, it includes the processes of innovation which show where the regulations take lace and which are the probable barriers to meet in order to create an integrated framework for the next chapter. Then, possible reasons for market failures are presented in order to avoid repeating the same techniques for innovation adoption.

The second part of this chapter describes the “lock-in” phenomenon, which has been affecting in great degree eco-innovation, and more specifically, the energy innovation sector. At first, the technical description of lock-in effects is presented as analyzed by Arthur (Arthur B. W., 1989) and how it influences the renewable energy sector (Cowan & Kline, 1996). Then findings on the ways to escape a lock-in are numbered in the articles of (Cowan & Hulten, 1996) and (Unruh, 2002) for general cases and then, specified for the energy sector. Finally, the relations between lock-in and innovation are examined in techno-institutional terms, pointing out the policies which can promote innovation.

2.2. From Innovation to Eco-innovation

The traditional definition of innovation[7] in Oslo-Manual (Oslo Manual, 1997) is limitedly applicable to environmental innovation. The redefinition of environmental innovation was made by (Klemmer, Lehr, & Loebbe, 1999) as following:

> “*Eco-innovations are all measures of relevant actors (firms, politicians, unions, associations, churches, private households), which;*
>
> *Develop new ideas, behaviour, products and processes, apply or introduce them and*
>
> *, which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets*”.

The features of eco-innovation (Klemmer, Lehr, & Loebbe, 1999) are that they can be developed by firms or non-profit organisations, they can be traded on markets or not and their nature can be technological, organisational, social and institutional. The first two are equivalent to the traditional definition of innovation. The social aspect (Scherhorn, Reisch, & Schroedl, 1997) is the lifestyle shift towards a more sustainable attitude (e.g. less energy consumption) and the institutional aspect refers to the institutional changes regarding sustainable[8] attitude. These range from local networks to new regimes of global governance and international trade (Rennings, Koschel, Brockmann, & Kuehn, 1998). Further remarks on eco-innovation are that regulations have a strong impact on the output of innovation[9] and it is not self-enforcing. Figure 2 defines the framework of the determinants of eco-innovation.

[7] The traditional definition, according to OECD, includes four aspects of innovation: the innovation process (the given output can be produced with less input), the product innovation (improvement or development of new goods), the organizational innovation (dealing with the organizational structure, e.g. new forms of management) and the marketing innovation (new marketing methods in product design, product promotion etc.).

[8] Sustainability is stated here according to the definition of the Brundtland report (UNCED, 1992)

[9] See also (Popp D. , Lessons from patents: using patents to measure technological change in environmental models, 2005)

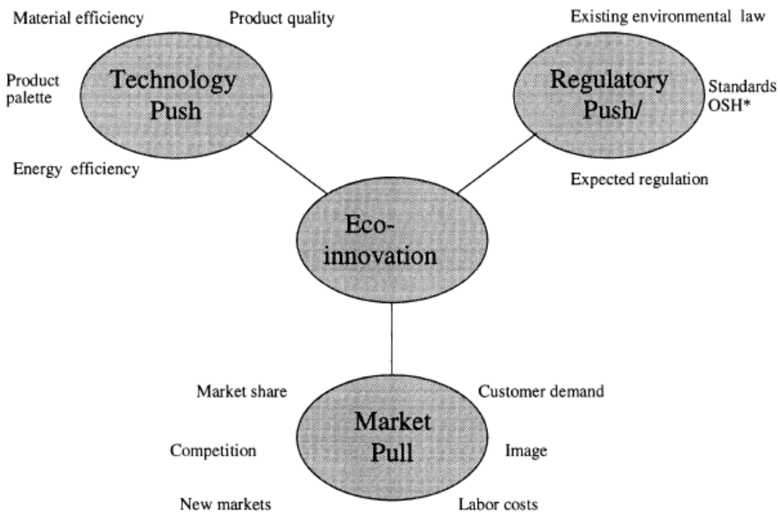

FIGURE 3[10] – DETERMINANTS OF ECO-INNOVATION (RENNINGS, 2000)

As shown in the above figure, the main determinants of eco-innovation are the technology- push and the market-pull[11] combined by a regulatory-push. The most important element is the regulatory push which distinguishes eco-innovation from innovation. Without regulatory support the balances between the other determinants cannot be kept as the outcome will be opposed to the definition of eco-innovation, which is, as mentioned in the Oslo Manual, *reduction of environmental burdens*.

Eco-innovation[12] has become the centre of work for many economists. Rennings (2000) *identifies three peculiarities of eco-innovation: the double externality* problem*, the regulatory push/ pull effect and the increasing importance of social and institutional innovation*. The first concerns the positive (beneficial impact) and negative externalities (e.g. external cost and damaging impact) respectively. The second represents the need of regulation as mentioned above. As for the third characteristic, it denotes that increasing impact of social and institutional innovation focus on how to enact sustainable policies (Freeman, 1992).

In the next section, we present the two methods of approaching eco-innovation. The first based on neo-classical theory, reflects profit maximization and the second one, the ecological economic theory, reflects satisficing but not optimal outcomes in returns.

2.2.1. THE TWO APPROACHES OF ECO-INNOVATION

Jaffe et al. in (Jaffe, Newell, & Stavins, 2003) refer to innovation using two different approaches: the “induced innovation” (neoclassical approach) and the evolutionary approach.

2.2.1.1. THE NEOCLASSICAL APPROACH

The neoclassical approach is based on the fact that R&D is a *profit-motivated investment*, thus *it is likely to respond to changes in relative prices*. Since all policy instruments affect directly or indirectly the relative prices, there is a strong interaction between *environmental policy and technology* and

[10] OSH means Occupational Safety and Health.
[11] How technology is evolving in terms of technology-push and demand-pull is described by Dosi in (Dosi, 1982). The demand for including sustainability in the determinants of energy technologies has been highlighted by Martin in (Martin J. M., 1996).
[12] The term of eco-innovation is short for environmental innovation.

technological change can act *as a criterion to evaluate the different policy measures.* This *induced-innovation hypothesis* has been first defined by Sir John Hicks in 1932 (Hicks, 1932). Its relation to research and development has not been assigned until 1960 by Ahmad and later by Binswanger (Binswanger, 1974).

Induced innovation is defined as innovation activities of firms in order to economise on a production factor that has become expensive. R&D investment on innovative products is often bound due to insufficient financing from external sources and spillover effects. In order to overcome these issues, the firms choose to use patenting or other forms of intellectual property. Concerning the public R&D investments, governments try to initiate different policies (such as subsidies, tariffs or taxes) so as to increase the social returns in R&D.

General purpose technologies which have many different applications (and can influence an entire economy), such as energy applications (steam engine, electricity etc.) expect, in high rate, positive returns on investment, thus increasing the R&D activity. In such case, policies are designed to attribute these returns to R&D again, by establishing the institutional environment[13].

Besides R&D investment, environmental innovation has also been compared to the change in energy prices. Newell, Jaffe and Stavins in 1999 (Newell, Jaffe, & Stavins, 1999) examined the correlation of energy efficiency trend for home appliances and its modification due to energy prices, by using energy patents as their innovation measure. Induced innovation in such case is the implementation of a model to reduce the costs of energy efficiency. According to their research, e*nergy patents, as a measure of energy innovation are placing the lower bound on the fraction of the overall response of energy use to changing prices that is associated with innovation*.

Besides its direct connection to the energy price, energy innovation can have other effects as well. That can be demonstrated through the pollution abatement, i.e. the decrease of polluting emissions, which can implicitly translated in price value (policy instruments representing this type are the tradable permits or emission taxes). .

2.2.1.2. The evolutionary approach

The evolutionary approach has come as a consequence to the fact that R&D optimisation[14] concerning the investments was difficult to achieve. Instead, firms used “rules of thumb” and “routines” so as to calculate the R&D investment. Since the model has not entirely profit-oriented, then probable changes in policies affect differently the firms. The question here is whether is it possible that an environmental policy can lead to profit increase, creating a “win-win” situation, also referred as Porter hypothesis (Porter & van der Linde, 1995). Porter and van der Linde focus on the importance of regulation in eco-innovation. Regulation according to them, provides a stimulus *to companies about their resource inefficiencies and* directs them to come up with *potential technological improvements*, a measure to draw *attention to pollution* issues, a mean to *generate and distribute freely information*, a way to *reduce uncertainty about the payoffs to investments in eco-innovation* and, finally, a manner to *create pressure* on firms in order to overcome the “inertia” state.

[13] Despite the fact that patents are an ambiguous innovation indicator, the authors do not deny that it has also been the primary non-fiscal mechanism for encouraging innovation. For a detailed review on the appropriateness of patents as an innovation measure see the next section.
[14] Instead of optimizing firms there are satisfying firms.

Evolutionary approaches are connected to radical innovations[15]. Radical innovation, until now, has created the "black box" where surprising conditions, such as irreversibility, path-dependencies, lock-in effects, change the technological trajectories in unpredictable ways. Evolutionary approaches are implemented to untangle these situations by using case studies and ex-post analyses without trying to predict future situations (Rennings, 2000).

2.2.1.3. SYNOPSIS

In the end, both of the methods have their positive features. Jaffe et al. in (Jaffe, Newell, & Stavins, 2003) sum up these theories in *areas of agreement and disagreement*. There has also been an attempt to link these theories (Rennings, 2000). The most representative study was conducted by Kemp (Kemp, 1997). Kemp uses elements of both approaches to create hybrid models: *uncertainty, specific technology characteristics and shifting consumer preferences* in the neoclassical theory and r*ational choice and optimisation in the evolutionary approach for technological regime shifting*. **The question is, in our case, which is the most appropriate approach to analyse environmental innovation according to our framework**.

In order to define the links between environmental policies and innovation, we use the "induced innovation" hypothesis, but for the policy options after the empirical analysis, the present research is based on the evolutionary approach. "Induced innovation" hypothesis can be used to connect environmental policy and technology and operate as a filter for evaluating the different policy instruments (Popp et al., 2009). Also, from the definition of eco-innovation, it is not only concerned of how to reduce costs by innovating in product, process or organisation. Eco-innovation is interested in suggesting sustainable solutions within a solid social and institutional framework. This long-term sustainable perspective can be really valuable to the European Commission for policy implementation. As the Commission is the leading actor, it is rather interested in solving the problems of environmental pollution and energy security, than providing the maximum profits to the energy industry, without overriding the involved actors (from energy producers and suppliers to end-users) and their interests.

2.3. MARKET FAILURES

There are many cases where the technology is not adopted as expected. The technical definition of market failure is the "persistence of inefficiency over time" (Promley, 2007) where inefficiency is the "difference between the actual level of investment and the higher level that would be cost-beneficial from the consumer's point of view" (Brown, 2001). Specifically for the energy sector, there are various reasons which create market malfunctions[16]. In (Brown, 2001) there are numbered five causes: misplaced incentives, distortionary fiscal and regulatory policies, unpriced costs (indirect costs), unpriced goods and insufficient and/ or incorrect information.

Misplaced incentives are related to the principal-agent problem[17], i.e. the authority of an agent to act without taking in mind the consumer's benefit. *Distortionary fiscal and regulatory policies* include tax treatment or electricity price policies. Energy price as a market failure cause has been mentioned in

[15] Radical innovations are "discontinuous", thus requiring new lines and columns in input-output tables, in contrast to incremental innovation which are continuous improvements of existing technological systems (Freeman, The Economics of Hope, 1992).

[16] Market is defined in neoclassical terms.

[17] The implications of one technology can be distributed to different actors (maybe not involved in the original procedure or end-users).

different studies such as Bernt, Kolstad, & Lee (1993) or Popp (2006). Many researchers have linked the energy price to eco-innovation. The energy price stimulates the systems which could be interpreted as trends. One major implication is the energy efficiency trend which is more cost-efficient towards the environmental policies. End-users prefer to save energy in way to save cost (dependent on energy price) than adopt new technologies for direct pollution abatement (Bernt, Kolstad, & Lee, 1993). This energy saving attitude can become a barrier to the adoption of renewable technologies.

Unpriced costs are representing mainly social costs which are not directly asserted. These are also defined as negative externalities. One representative example is the increase of pollution gases due to the extensive use of fossil fuels. The idea of pricing these costs has not been implemented until recently by policy measures such as the European Union Emission Trading Scheme[18]. Environmental externalities concern mainly the pollution abatement. Usually, the consequences of a large-scale infrastructure, such as an energy production unit, spread out of the boundaries of the construction. Regulations are implemented to deal with this issue either by "internalising environmental costs and provoke effective decision regarding the consumption of environmental input" or by "imposing from outside a level of environmental pollution". Externalities are also discussed by Popp et al. in (Popp et al., 2009). They are a very complicated problem of innovation adoption and should be treated very carefully. Again, the policies suggest a "win-win" framework, where all firms can claim a market share and ameliorate the new technology and are provided with incentives to prevent innovation from stagnation.

In other indirect causes for market failure one can include *unpriced goods* which are public goods. Due to their nature, they tend to be under-produced as they do not yield substantial profits. Unpriced goods are also treated with public policies in way to reinforce them.

Finally, Brown defines the last cause as *insufficient and incorrect information.* The fact that information is a public good gives the right of its free use, not only by the innovator, but also by many others at low or zero cost. Innovators who wish to avoid this consequence tend to under-inform the market. Also, a technology adoption can create positive externality during the learning process.

Summing up the above, the main conclusion is that the principal mean to surpass a market failure is governmental involvement (market intervention) by adopting feasible, low-cost policies. In their article, Clinch and Healy (2000) propose different instruments in order to correct market failures in domestic energy efficiency in Ireland. Their proposed "policy mix" is set in social terms as the existing policies failed to be implemented successfully due to the ineligibility of the institutional framework of the measures. Their main instruments are information campaign and minimisation of transaction costs. In another article, Fischer and Rothkopf (1989) present their findings in response of the US energy sector to market failure. They characterize it conservative as it is designed to induce the levels of particular fuels –sometimes in particular industries. Finally, Martin and Scott (2000) emphasize in the innovation market failure: the combination of financial market failure, limited appropriability and external benefits result in under-investing innovation. The energy sector, according to their terminology belongs to complex systems which include high cost, risk and limited appropriability (particularly for infrastructure technology). Their solution is to apply measures such as R&D cooperation, subsidies and support for development of infrastructure technology. In addition, the authors highlight the need of institutional support.

[18] The trading scheme includes permits which provide with the maximum number of credits, the "cap" that defines the quantity of emissions allowed. If it is necessary to emit more the firms must pay an additional fee.

Concluding, there are different causes for market failures and instruments to confront them. In order to **avoid market failure in the adoption of the environmental innovation and establish the European Union's targets of pollution abatement and energy security, which are the policies that can be implemented for the specific cases of the innovation trends of renewable energy and energy efficiency**. This question is answered by using the findings of the empirical evidence and their policy implications for the extended system model, presented in Section 3.3. As mentioned above, the main policies stem from higher level bodies such as the European Commission or national governments.

Altman (2000) connected market failures to path dependencies. In a neoclassical approach, when there is no need to adopt superior economic regimes and displace suboptimal regimes[19], Altman supports that market failures can result (against social welfare). This creates a causal relation between path dependencies and market failures. This causality is only reinforced by introducing other externalities or increasing returns (Arthur W. B., 1994) which help maintaining the suboptimal choices. The implications of adopting a suboptimal technology instead of another one (known as "lock-in" effect) and how this choice is established, is the main subject of the next chapter.

2.4. Lock-in Effects

2.4.1. Introduction to Lock-In

Lock-in concept was first introduced by Brian Arthur in 1979 as referred in (Arthur B.W., 1994). Its formal form has not been reached until 1988 in (Arthur & al., 1988) and 1989 in (Arthur B.W., 1989). Arthur was interested in analyzing the reactions of competing technologies within a system. His main research centres on the increasing returns[20]. Within his research, one of the most important findings has been defined as the Arthur's Doctor/ Lawyer Theorem which reflects his conclusions on the dominance and the adoption of a technology within a system.

In order to facilitate the study of lock-ins, Foray (1989) reviews extensively the literature by presenting the work of, among others, Arthur and Cowan and presents the main findings. In his articles, Arthur defines that the technology diffusion is a dynamic process whose driver is the adoption rate ("self-reinforcing" mechanism). The increasing returns on adoption come from the below features: the network externalities, the economies of scale, the increasing return of learning (learning-by-doing) and the interrelations between technologies. Foray's interpretation to Arthur's model is that it represents a "dynamic outline of competition between alternative technologies, whose engine is the action itself to be adopted", where "adoption operates as a self-reinforcing mechanism in the spread of technologies". Despite the fact that Arthur's model is integrated, Foray highlights the necessity to include the study of technologies which belong to different timelines. A thorough approach to this question is pondered by Islas (1997).

The second part of the literature review about lock-ins deals with the question whether it is possible to escape from them. Arthur et al. (1988) suggests that if the improvements of the technology under adoption use the features of learning-by-using technique with its production conditions (economies of scale) and utility (technical interrelations), the lock-in effect is irreversible. On the other hand, if the

[19] The author defines that as "effort discretion"

[20] Returns in learning represent the net benefit of adopting on technology which increases as the numbers of previous adopters grows. The main sources of increasing returns of adoption are the industrial learning (or learning-by-doing), the network externalities, the information returns (imitation, aversion to risks) and the technology interdependence, directly correlated to the technology adoption (Arthur B. W., 1989).

network externalities have been the source of lock-in, then the effect can be reversible. In such case, the problem is redefined as the conversion to a new standard (Farell & Saloner, 1986) which is often followed by the “excess inertia” effect[21], thus, the absence of coordination between the firms and the importance of infrastructures which represent the transition costs of incompatibility and discourage the firms to participate in the technological change. Finally, in case the main characteristic of the technology is learning-by-using, lock-in becomes quasi-reversible. Since the specific technology does not rely on the number of users, its dominance can be considered unstable.

2.4.2. Definition of Lock-in Effects

Lock-ins as a phenomenon first appeared in the work of Brian W. Arthur. In his attempt to explain the dominance of one technology in the market and define the increasing returns, Arthur concluded to the fact that there is a possibility of the adoption of only one technology which would not leave room for others (“lock-in”) to develop and compete in the market. This idea has been demonstrated in (Arthur B. W., 1989). Arthur uses specific terms in his research: the market consumers (end-users) are called adopters since they adopt a specific technology. The technologies are competing for the adoption which represents the market share and the more they are adopted, the bigger experience and improvement they obtain, thus, the increasing returns on adoption are higher[22]. Finally, Arthur uses the term “historical small events” or “by chance events” as events that are “outside the ex-ante knowledge of the observer – beyond the resolving power of his model or abstraction of the situation”. This definition is very important in way to include the features of “unpredictability” and “flexibility” in the model. By saying “unpredictable”, a process has a strong degree of uncertainty, “flexible” when a policy measure can influence “future market choices” and “ergodic”[23] when the process is non path-dependent, thus producing the same market outcome with probability one whatever the events that have happened. These characteristics define different probabilistic models which define which technology dominates the market.

Figure 2 below depicts how the adoptions fluctuate between the regions of choice of two different technologies and the way a lock-in can be created. Initially, R-type agents prefer technology A when S-type agents prefer technology B. The dynamics of the market are changing when agents show their preference. In the beginning of the graph, technology A has a slight overtaking which means that adopters prefer to use this one instead of B. When, by “chance” the adoption of technology B is promoted, then not only agents from S-type but also agents from R-type start selecting that technology. If the total adoption number crosses a threshold, then both S-type and R-type agents choose technology B and, consequently technology B is locked-in.

[21] Coordination within the agents

[22] In a more simplistic approach, increasing returns can be defined as “the more you sell, the more you sell” by Kline **Invalid source specified.**

[23] The term “ergodic” is originally mentioned by P. A. David in (David, 1985). In fact, Arthur in (Arthur W. B., 1994) refers to his collaboration with David and the compatibility of their ideas.

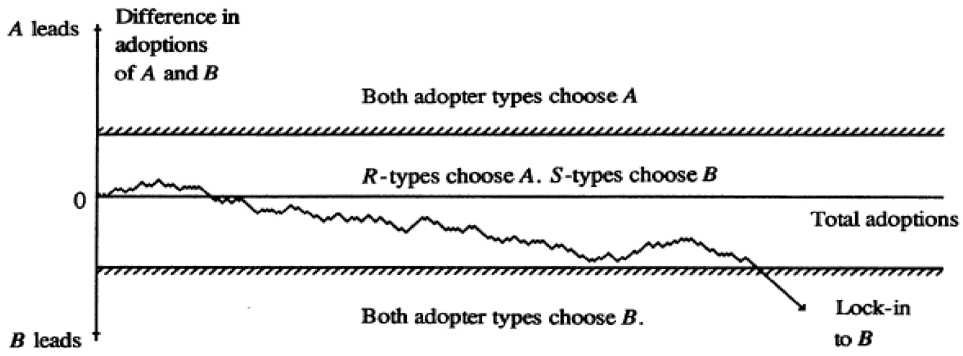

FIGURE 4 – INCREASING RETURNS ADOPTION (ARTHUR B. W., 1989)

Arthur also defines the properties of three regimes so as to characterize the choice process of the technology. Depending on the returns, whether they are constant, diminishing or increasing, the author provides four features: whether they are predictable, flexible, ergodic and necessarily path-efficient. Diminishing returns have all the above features, where constant ones have the same besides flexibility. In contrast, increasing returns are opposite to all these features. The existing energy technology has been a stable market using conventional technologies. Since 1970s, with the invasion of new technologies like nuclear, renewable etc the picture has been modified. Different energy technologies have been competing for their dominance in the market. The market has become non-predictable due to "historical events", non-flexible as policy measures have not always influenced positively the promotion of the new technology, non-ergodic and non-necessarily path-efficient as the market shows different outcomes for different paths, giving a possibility that even an inferior path could be developed.

In later work Cowan presents the concept of "lock-in" effect among technologies according to returns-in-learning (Cowan, 1991). In particular, he examines the case of two technologies, both unsponsored and supplied competitively in terms of maximising the present values of adoptions. In his theory he includes two actors, the adopters and a central authority[24] as a steering mechanism of technology promotion (by using subsidies as policy instrument). At first, when the development paths are known with certainty and the adoption function sequentially, the paper concludes to the fact that only one technology is dominant[25].

The results are more complicated in the presence of uncertainty, where every adoption is a result of a random experiment. Due to the level of randomness Cowan pleads the two-armed bandit theory, which is defined by two events with unknown probability values to occur but independent. The objective is, again, value maximisation. The author uses the Gittins index[26] (Gittings & Jones, 1974) to rank the value for each try and concludes, concerning the expected value of adoption to the following propositions: the expected present value is greater when it belongs to a controlled process (i.e. from a central authority), that the optimal policy leads to only one technology adopted and that the optimal policy leads to the inferior[27] technology will be adopted infinitely compared to the superior one, adopted only for a finite number of times (potential trade-off between immediate pay-off and knowledge).

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[24] Not necessarily a Government
[25] The Arthur's Doctor/ Lawyer Theorem
[26] Also known as the Dynamic Allocation Index
[27] Inferior is defined by the author as the one with lower probability to occur

The above serve as the explanation to lock-in effect. Based on that, the author concludes into two driving forces of this effect: the reduction of uncertainty and the increasing returns. Both forces lead to the faster growth of one technology learning curve, leaving the other behind and making the technological shift more costly. In this context, Cowan studies how efficient the level of intervention is. In earlier work, Gittins and Jones (1974) show that a central authority is reaching better the objective of value maximisation than the market itself. Besides that, the intervention is influenced by the degree of superiority of one technology towards another (as the degree increases the probability of the adoption of an inferior technology is unlike to happen), the bias of a better known technology (a new technology must be better and produce early positive results in order to confront an older secured technology), the increasing returns which can lead to rapid lock-in, e.g. the nuclear power adoption in US (Cowan, 1990) and, finally, the initial estimates of relative merits.

Concluding, Cowan presents the basic results of his research: the externality effect of no incentive to experiment on an inferior technology (which might be solved by central authority intervention), the level of intervention (moderate in order to provide incentives to investment but no leading to lock-in), the rapid lock-in in case that technologies evolve really fast and the importance of locking-in the right technology.

An early dominance can probably avert the better technology to expand and an inferior technology can dominate. As an example, one could refer to the QWERTY case, where although the keys positions produced latency in writing it still dominated the market (David, 1985). This case is very representative sample of path dependency and strong probabilities which led to the given result. In general, the path of technological dominance seems to be filled with random or not events which should be take into account and thoroughly examined in order to evaluate the highest probability rate and promote the best technology (Liebowitz & Margolis, 1995).

In other work, Islas examines in further Arthur's model relevantly to time aspect. As Foray (1997) indicates the existing model does not take into account technologies developed in different timeframes. Consequently, it cannot provide any answers to the question whether a new technology can avoid being "locked-out". Islas (1997) work revolves around this question and emphasizes in the case that the older/ dominant technology is slowing down while the new/ inferior technology accelerates. In addition to that, Arthur implies that the exit from a lock-in effect is almost impossible to occur. According to him only when learning effects are stagnated and returns in adoption increase, a technology becomes weaker and allows to others to penetrate the market (Arthur & al., 1988). Islas investigates the case of gas turbines and how they penetrated the electricity market focusing on the time of gas turbines appearance. This research is of great interest as it involves solutions to lock-ins in a market depending on technology and time[28].

Lock-in is examined specifically for the renewable energy market by Cowan and Kline (Cowan & Kline, 1996). Lock-in effects by technology are very important to policy making for the energy sector as the market has been conquered by conventional technologies driving out new ones regardless their level of efficiency. In addition to that the authors include the lock-in effect by suppliers, who dominate in a large fraction of the market by producing these technologies.

[28] In our case both models (by Arthur and Islas) are important. The first examines the relations between two parallel developing technological trends such as energy efficiency and renewable energy and the second can be proven really useful in determining ways to adopt new technologies.

Cowan and Kline focus on the importance of system dynamics and how can they be influenced by increasing returns. According to B. Arthur (1989), modern and complex technologies produce increasing returns to adoption in sense that the more they are adopted, the more experience they gain resulting to their improvement. Arthur investigates the increasing returns in static but, more importantly, dynamic environment as the returns can also evoke in conditions of “non-predictability” and “potential inefficiency”. In his paper Arthur comes to the conclusion that “random” historical events can influence the system dynamics and cause lock-in effects. This assumption is very important to the energy sector as different events (such as energy crises or environmental damage) have defined the existing market and have added up to the creation of lock-in effects.

In their paper, Cowan and Kline suggest that the market outcome stems from two major events: the lock-in effect of an existing technology and the clustering of the suppliers. The lock-in effect, as mentioned, is caused by the dominance of one technology in the market. As suggested above the increasing returns are expressing growing experience and improvement. Due to the characteristics of a new technology (immature, no defined value and further improvement possibilities) it becomes harder to penetrate the existing market. In other case, when two technologies are competing for dominance then an early lead in one of them or lower cost can lead to dominance. Lock-in effects can also be created from uncertainties for the technology’s features or network externalities where the value of technology is increased by the number of users.

The second part explains how the clustering is influencing the market dynamics. According to the writers, clustering is defined as a supplier lock-in effect. Clustering is defined as the need for specialized inputs and the importance of knowledge spillovers. Clustering has the same effects as the technological lock-in. If one specific location builds up a successful technology, it will increase returns and become more adopted, creating a self-reinforcing system.

Next, it is described to what extent all this information is applicable to the renewable energy market. The renewable technology is keen to lock-in because of its characteristics to clustering (the market is defined by a distinct number of countries (REN21, 2009), which defined the market) and the massive effect of R&D to the adoption of the renewable technology (technological lock-in). This means that if one country (generally a cluster) evolves faster than others in technological terms that will have effect on the market for the rest. Also, in case that R&D does not aim at the promotion of the specific technology, the technology will probably become inferior to another one.

2.4.3. Escaping Lock-in Effects

As mentioned above, the technological lock-in is viewed under two different timeframes. As first, using Arthur’s model, one can examine two competing technologies which have appeared in the same time frame. In our research this problem is depicted as the dominance between two energy trends which have been developed within the last thirty years, the renewable energy and energy efficiency trends. On the other hand, Islas in his research develops a model which works through time explaining the ways new technologies can penetrate an already established market. Both of these views including their strategies and instruments are explained below.

At first, the general methods based on Arthur are provided by Cowan and Hulten. Then we focus on strategies to escape from lock-in focus on the energy sector: we redefine the problem within a techno-institutional context (Unruh, 2002) and within time perspectives (Islas, 1997).

2.4.3.1. General Approach

In their article, Cowan and Hulten (Cowan & Hulten, 1996) attempt to show whether there is a possibility to escape from a technological lock-in situation, even if the dominant technology is established and has been able to increase its cognitive characteristics. The authors separate the competition of the two technologies in five phases: the first four define the technological lock-in and the last one, if it takes place represents the possible escape (or partial escape) from the technological lock-in in terms of legislation, forced introduction and large-scale production. In general, lock-in technologies show the characteristics of path dependency, meaning that the technology creates a “snowballing effect” by gaining knowledge and experience and, finally, adoption. This path dependency model implies that there is more than one competing technologies but due to specific reasons one technology has been the dominant. Technological lock-in can be triggered by a historical event (Arthur B. W., 1989) as a financial or product crisis.

The authors expand this assumption by including that technology is linked to other developments in different sectors such as economical, technical or political and that this linkage can redefine the dependency path. As an example, Cowan refers to the strong impact that military sector had in deciding the energy source in submarines and powerplants (Cowan, 1990). These linkages can affect the path to lean either to adoption or to rejection (Dosi, 1984). The linkages theory is described in the work of Dahmen’s (Dahmen, 1989) as the development blocks’ concept. The blocks connect “firms from different industries, which work in a complementary way, into one network”. Consequently, any kind of decision making or problem resolution should take into account a larger system than the one originally defined. The above reveal the interdependencies between different nodes of a network.

In order to discover the possible ways to unlock one technology, it is necessary to define the reasons why it became locked-in in the first place. In his article, David (David, 1985) numbers these features as “technical interrelatedness, economies of scale and quasi-irreversibility of investment”. The writers suggest six ideas to overcome the lock-in in the automobile market (gasoline versus electrical automobile). These ideas can be inspiring to possible resolution of the lock-in problem in other sectors as they include general frameworks which could be applied in other sectors as well. In addition, the sources of lock-in are the same for almost every sector. More specifically, for the research concerning possible lock-ins and how to overcome them in the energy sector, this article is proven to be very helpful as it frames a similar problem (also energy oriented) or it provides many examples for different technologies. The ideas the writers focus on are described below.

2. At first there is “crisis in the existing technology”. This idea is very interesting as it combines a historical event to the lock-in phenomenon. This event has already occurred in the 1970s, with the energy crises where many countries turned to alternative or nuclear energy. Both of these technologies were boosted during the 1980s but their wide adoption has been slowed down since then.

3. “Regulation concerning the competing technologies”. In our case, regulation concerning energy trends has been introduced by the European Union in the 1990s within the terms of alternative energy (e.g. biofuels directive) or energy efficiency. The effect of the regulation, which is operationalised by different policy instruments, is a very important part of the present research.

4. "Technological breakthrough" leading to a cost (real or imagined) breakthrough. If the competing technology is cost efficient then there can be a potential switch. Until now, in the energy sector new technologies have not proven to be, in general, cost efficient, besides the fluctuations of the oil and gas prices.

5. "Changes in taste", as the environmental "green" trend. Despite the fact that trends can appear imposing, the market has not leaned towards them in a satisfactory level. In the case of EU Members, most countries have not been able to reach the renewable energy targets they were supposed to and they need to make a great effort so as to engage the renewable directive (EEA, 2008).

6. "Niche markets". As the target set investing in a specific technology grows, then technology is eager to accelerate. That feature combined with the previous one ("change in taste") can create a niche market for the energy sector. Consumers who want to be more environmental friendly or countries following the Kyoto Protocol can become the set for a niche market on energy.

7. "Scientific results" for measuring the effects of an adopted technology or innovating into the sector. As an example, the implications of the pollution caused by conventional energy sources have been of great importance to turn to new energy trends.

The authors suggest that the above argumentation can cause a technology shift, bearing in mind the existing market and the measures taken to promote new trends. The research of Cowan and Hulten although made for the specific case of the electric vehicle is quite general and represents many cases of lock-ins.

2.4.3.2. Energy Lock-In defined as a Techno-Institutional Problem

In his article Unruh (2002) refers to the existing energy lock-in, specified for the carbon use, as "techno-institutional complex" (TIC), thus dependent not only on technological but also on "organizational, industrial, social and institutional co-evolution". TIC, according to the writer has both negative and positive implications. In the beginning, it can cause "stability and predictability and possibly reliability on the system". This can lead to a strong and successful market structure, which can be proven to be very effective on the technology's progress and adoption. On the other hand, the same event can cause inertia (Arthur B. W., 1989) and can lead to technological lock-in, creating a stagnant market with no intention of investing in new technologies. Besides the market implications, the technological lock-in can have other results as well. As an example, the main reason to escape this lock-in for Unruh is the resolution of the climate problem arising by the carbon emissions. In order to do so, he presents three different policy approaches which could possibly change the current system. The first one includes only emission treatment, which is the principal target, keeping the existing system unchanged. The reason to maintain the system is because of the large costs of switching to other technologies. Thus by using the same infrastructure but changing the harmful parts with "add-on technologies" the output of the system is positively altered. This is named the "end-of-pipe" (EOP) approach (Hartje & Lurie, 1984) which does not change the existing system (value not added) but, in a way, controls the release wastes (Lynn, 1989).

The above method has the benefit that there is no significant added cost, nor integrating solutions involved. The question stemming from its use is whether it is capable of reaching the target. It is a fact that energy production and consumption is not decreasing. Thus, the polluting gases are not decreasing as well. That raises the problem of non satisfactory emission treatment, which is not included in the first solution. As a result, Unruh proposes a next approach, the “continuity” one. This approach creates changes by altering the system’s components and not its core structure. The way to do so is by following the path dependencies created within the framework and changing some of its components, thus promoting an “incremental innovation or change” (Dosi,1982) in order to engage a smoother transition from one technology to another.

The last approach expresses the radical change, therefore “discontinuity” so as to adopt the new technology (Dosi, 1982). This solution defines a whole new technology using new elements. Despite the fact that this technology can be profitable, one cannot exclude the initial costs of such an operation, especially in large-scale projects such as energy technological shift.

Unruh, next, defines the guidelines for policy making within these two approaches. His advice is based into two main elements: the “level of the system” where innovation is taking place and the “performance trade-offs”. The level of the system describes which component is altered, to which degree and how does this affect the system as a whole. The performance trade-offs indicate the innovation’s features according to “efficiency, system complexity and performance”. The author concludes to the fact that following the continuity approach might have slighter transition effects since the innovation represents a path-dependent TIC. In contrast, discontinuity might offer better outcome but it involves larger financial, investment, technological, social and more kinds of risks.

More specifically in the present research, the question is what kind of policy action should be implemented in order to adopt innovation in the energy sector. All three approaches can be used as policy backbones for different innovation elements. At first, EOP can be used for energy efficiency promotion as it does not include radical innovations, it uses the existing electricity grid and, finally, it changes only few subcomponents without altering the existing system. This happens because the target outcome of the energy efficiency plan is to decrease the level of energy consumption and not to invent new ways to produce energy. In the opposite, the renewable energy plan involves changes in the backbone of the system, radical or not. Both “continuity and discontinuity” exist in the renewable energy sector. Continuity in cases where innovation is distributed through the existing network, discontinuity in case the distribution method radically changes from the current electricity grid to a new distribution system.

In the end, Unruh refers to Cowan & Hulten (1996) and their six defined features to possibly escape a technology lock-in, emphasizing to the fact that the energy system is a TIC, including many different actors who limit the possibility of innovation. In addition, the range of these actors limits the exogenous forces which can provoke changes in a large-scale system, as the energy one. The author highlights two external forces that can drive to technological shifting: the technological and the social/ institutional. The technological shift can be caused by a superior technology that can prove itself in technical and financial terms so as to be adopted i.e. increasing returns on supply and demand (Arthur B. W., 1989). Thus innovation must affect both the market and the technology.

In order to create a market share the most obvious way it by creating a niche market for the innovative product (Kemp, Schot, & Hoogma, 1998). In that way the technology can be adopted even in a more constraint market share and initiate its presence in the market. Another advantage of the niche is that it can be used even for a whole technological system. The idea is to install the new technology in a friendly environment where it can be less costly and easily adopted. After the dominance in the niche, the technology can be promoted in broader terms. Niche market seems to be a solution in promoting innovative technologies (Christensen, 1997) with only problem the time constraint. If a niche does not have enough time to evolve then it will not be effective and adopted.

A niche is considered by Unruh to be the best technological solution to a lock-in technology effect. Besides its practicability, niche cannot always be an answer due to its time inadequacy. Therefore, new solutions are proposed, not in a technological but in an institutional framework, bearing in mind that the energy lock-in has a complex nature (TIC). When the market itself is not enough, changes can be processed through policy intervention (Freeman, 1989). The disadvantage of policy intervention is also the time constraint but from a different perspective. In this case, it is not the risk that the market cannot absorb rapidly enough the new technology. Here, the problem is that the time needed to absorb an institutional change is really slow in order to create the proper environment for technological transition (Williamson, 1985). Different instruments, such as taxes or subsidies are designed in order to make this transition more proper and successful. Even though, the effects of the policy's implementation do not show immediately or do not have the same level of success.

One should take into account that an institutional shift needs to have the social approval so as to be able to be assessed. This social effect can be proven a really strong incentive for varicoloured policy making. In the energy sector, the attempt of technological shift has started early enough due to the energy crises but it has been enforced only when society has seen the consequences in the environment of the conventional energy sources' use. **Figure 5** depicts that the need for energy has only been increasing since the 1970s, including new energy sources such as renewable or nuclear. At first, these technologies have an unstable course (early stage in the market). Only after 1983, new technologies have been stabilized their presence in the market, having increasing slope. At the same time, conventional technologies show a slight degradation without losing their dominance. These tendencies coincide with two incidents: the energy crises of the 1970s and the harmful consequences of global warming in 1980s. These two effects combined (Arthur B. W., 1989) led to an institutional shifting. The European Commission worrying about the expansion of the above problems has decided to follow two different paths of innovation: the renewable energy technologies and the energy efficiency ones. In order to escape from an energy lock-in, the policy makers should take into account both technological and institutional perspectives, paying attention to the quick absorption of technology and institutional shifting before the consequences of the current energy system are irreversible in terms of climate change and energy security.

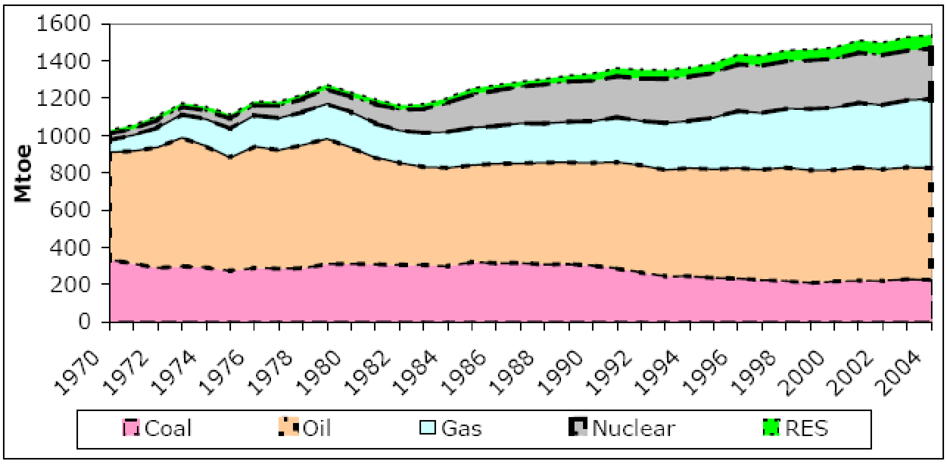

FIGURE 5 - GROSS INLAND ENERGY CONSUMPTION WITHIN THE EU-15 (KAVALOV & PETEVES, 2007)

2.4.3.3. LOCK-IN IN TIME

Islas (Islas, 1997) has defined the lock-in within the same conceptual context as Arthur. His main research question pondered around the penetration of a new technology in the market (Islas, 1997). His solution of escaping the lock-in was dependent on the “nature of increasing returns of adoption”, introducing a niche to the market strong enough to “trigger a self-reinforcing mechanism”. In his case gas turbines were trying to establish their presence in the market dominated by steam turbines. In extended context, this model can be expanded to penetration of new energy technologies in the stable market of conventional energy sources.

Again, the solution is provided through a particular production niche. By defining a successful niche (in Islas case the peak power plants) increasing returns of adoption are caused in different timeframes. The niche introduces the product to the market in a very specific way showing its technical and financial capabilities. Then, the product is adapted to different standards (electricity generating systems) and, finally, it is successfully commercialized by the firms. The main idea is to present the new technology as the dominant in very strict terms (niche). Then, increasing returns of adoption come up and due to the economies of scale; the technology can disrupt the existing lock-in.

This idea of market alteration through niche has also been suggested by Kemp et al. (1998). In order to create more sustainable technologies, Kemp suggests that by using “strategic niche management” one can “unlock” dominant technological regimes (established within a techno-institutional context) and enforce new sustainable ones. Following the same method, i.e. introducing a niche where the new technology is dominant the chances of switching to new regimes is amended.

2.4.3.4. LOCK-IN AND INNOVATION

A successful innovation definition includes both the technical and economical aspect. According to Mokyr (2002) it is the principal source of economic growth. Kemp (1994) also reinforces that opinion stating that innovation offers opportunities to increase the employment rate and the returns on environmental benefits.

As it was mentioned before lock-in has both technological and institutional aspects. Both of them indicate increasing returns of adoption, thus a positive feedback in favour of specific technologies.

These technologies can have this increased output due to historical events, due to experience in contrast to new ones or due to the fact that they are incumbent from existing technologies. Institutional lock-in also creates increasing returns of adoption (North, 1990). As expected, new institutions are harder to absorb than old ones and there is always a probational period to check whether they fit in the general institutional framework. More specifically, political institutions lead to increasing returns due to their "collective action", the "high density of institutions", the "asymmetries of power" and the "complexity and opacity of politics" (Pierson, 2000). Institutional aspect plays a very important role concerning the design and implementation of regulatory frameworks and policies to deal with lock-in effects because it includes all the actors, goals and politics within the system. Decision making in this context can be very complex thus the need of co-evolution is distinct. The definition of co-evolution is the coordination of technology and institutions together in order to control the two ways of locking-in (Foxon, 2006). This term has appeared before in the work of Unruh (Unruh, 2002) as TIC (Techno-Institutional Complex).

Decision making within TICs is influenced not only by the technological aspect but also the institutional framework. In order to promote ecological innovation in the energy sector policy makers need to come up with ideas to cause lock-in in conventional energy production methods. The main idea is to create a "socio-technical regime" which, in its context will be constituted by different levels of coordination each one with different set of instructions used by the actors involved (Rip & Kemp, 1998). Within this context, the actors and institutions are working together to promote a specific socio-technical system (in our case a sustainable one). The division of actors in different levels is to strengthen the network for robust decisions and regulating the correctness of the implementation. This idea has been also mentioned by Dosi as "technological trajectories" (Dosi, 1982).

In his article Foxon (2002) presents two methods to escape from a techno-institutional lock-in: by using existing technologies and institutional factors whose increasing returns permit the development of new technologies or to use increasing returns in new technologies with high rate of success so as to evolve rapidly and penetrate the market.

Different policy measures aid in overcoming existing deadlocks or promoting new technologies. Foxon (2002) divides these measures into three major categories. The first is the support of *public R&D* for new technologies in early stages. As an example, R&D promoting the renewable energy technologies can stimulate the producers to explore the new sources instead of remaining in conventional sources. Secondly, the author suggests the *market development policies* like "strategic niche management", (Kemp, Schot, & Hoogma, 1998) which has been described above. Public coordination could aid in creating a secure environment where firms could innovate. Another example of public policy could be the setup of obligations (mandatory measures) including the innovative technologies. This method should provide with a sufficient timeframe to implement the innovative technologies. The use of this policy can create internal lock-ins as the suppliers will prefer to support less costly technologies or more compatible to the existing ones. This fact could suppress innovation itself. Thus, this policy by itself does not lead to unblocking the existing system. Finally, the author states the *financial incentives* such as subsidies, tax credits etc. These cost reductions create positive externalities of learning-by-doing by pollution abatement and reducing prospective production costs. In our case specifically, **how can the renewable innovation energy trend escape from being locked-out by other energy trends and what are the supporting mechanisms/ policies to ensure that outcome**. This question is answered in the policy recommendations chapter.

2.2.5. CONCLUSIONS

The essence of this chapter was to introduce us to the theoretical background of the present study in order to understand the main terms included in the research, create motivation for modelling design and specification and find the relationships between the involved factors. Innovation, here, has been redefined, according to the system description. Therefore, instead of innovation, we have eco-innovation, which is not only preoccupied by the product, process or organisational differentiation, but also from the social and institutional surroundings.

Also, in this chapter we decide to follow a combination of the evolutionary and neoclassical approaches. The neoclassical approach is more suitable for the problem analysis as it is a profit-motivated tool which enables as to evaluate the different policy instruments aimed to induce R&D. This approach is very practical and can provide answers to what policies are effective concerning environmental innovation within the energy industry.

Despite the practicality of the neoclassical model, it is substantial to investigate the subject from a more environmental perspective, bearing in mind that one of the main targets of eco-innovation technologies is the pollution abatement. The evolutionary approach aims at this “win-win” situation, where tradeoffs are made between cost-efficiency and pollution abatement in order to reach a satisfactory solution. Thus, the decision making should be based on both perspectives.

Next, the causes for market failures are presented so as to prevent prospective unsuccessful policy making. All the referenced examples noted the necessity for governmental intervention and a robust institutional framework for surpassing the created failures. Finally, a connection has been made between market failures and “locked-in” technologies, which occupy the second part of the literature review.

Lock-in effect is studied from two perspectives in the next chapters. At first, through the regression analysis and the results from governmental intervention, we define to what degree the policy measures have helped in escaping the existing lock-in from conventional energy sources.

Then, we study the connection between two recent innovative energy trends, renewable energy and energy efficiency. A dependence on the results can show a possible preference towards one of the two technologies. If energy efficiency is locked-in as an easier to implement, more cost-efficient method, then the results of the empirical analysis will demonstrate stability in the innovation output of renewable energy. This potential result can create a large problem for the future as renewable energy is necessary to achieving the Commission’s targets of energy security and pollution abatement. Thus, methods in way to escape from the lock-in of energy efficiency are necessary to be implemented, as described in the previous sections.

Lock-in in energy has been a major problem for the European Union and its resolution one of the principal issues addressed in the last Framework Programs. It is safe to say that not only one of the existing policies can lead to the adoption of innovative technologies. There should be a policy mix which can reinforce the new technologies and break the existing lock-ins. More specifically, in the energy field, policy measures to promote energy sustainability have been implemented since 1990s. Until now, the countries’ policy mixes have not been up to their targets.

CHAPTER 3
MODEL CONCEPTUALISATION

3.1. INTRODUCTION

The measurement of eco-innovation and its change caused by policy measures is the main scope of this chapter. In order to design the framework we need to define all the elements related to eco-innovation. As mentioned in Chapter 2, environmental innovation is defined differently than innovation. It aims not only to technical and process change but also to social and institutional. Conventional innovation is defined as how to decrease input and, maintain the level of output. Eco-innovation has different scope. It is targeted to reduce or avoid the environmental burdens (Kemp & Arundel, 1998). Thus it has a more social character as it includes, besides the cost-effectiveness, the “consumer-oriented benefits” (Rennings & Zwick, 2002). Here, we try to incorporate both traditional and new elements of innovatory activities.

The input of the framework is constructed based on the determinants of eco-innovation, as demonstrated in the previous chapter. These have been the traditional market-pull and technology-push[29] and the new one, defined by eco-innovation, the regulation-push. Thus, the policy measures are an important part of the input. The first stage of the framework actually wants to explore the relations between these policy instruments and innovation.

For the output, the framework has one quantified variable, the patent count. This output indicator has is considered to be the most appropriate due to its detailed nature and its wide availability. One part of this chapter is dedicated to the applicability of patents as output innovation measure.

The main structure of the framework, the “black-box” refers to the innovation systems, and more specifically national innovation systems, as we study the policy implication for the Members of EU-15. This “black-box” includes the linking function of input and output. The coefficients of this function shall provide the empirical evidence on the impacts of environmental policies in eco-innovation.

In more practical terms, the leading forces behind this framework are the pollution abatement and the energy security. The European Union has defined these targets during the last decades and thrives for their implementation. This included the shift from the conventional energy sources to two new energy trends: the renewable energy and the energy efficiency. The combination of these two trends is supposed to solve the existing problems. The first question which is raised is whether there is a mistreatment between these two. As energy efficiency is easier to implement and shows direct impacts on the economy (the end-users pay less for energy) it could outcast the renewable energy, which is necessary for the way out of the existing problems. Therefore, we create a new version of the framework to investigate whether there is a possible “lock-in” of energy efficiency, which bounds the adoption of renewable energy. The research questions from the framework construction are: which is the **best-fitting model to incorporate our system**, what is the **input and output** and how is it **operationalised**, **how can we embody one more subsystem in order to correlate its function to the original framework** and **what are the implications from the frameworks**.

[29] Traditionally, innovation has been mostly driven by technology-push, i.e. financing research programs. The last years, market-pull has rebounded by using price mechanisms such as taxes to boost innovation. These mechanisms should be based on the social and institutional framework; thus, regulations are necessary to impose the market-pull incentives.

This chapter is divided as follows: first, the framework construction and the presentation of the final version. We highlight the input and the output, and we include explanations for each element we use in the framework. Then, we present the extended version so as to integrally crate the theoretical background for our main empirical research questions: how the policy measures affect innovation in the EU-15 and whether there is a "lock-in" effect created in attempt to adopt environmental technologies. This extended version of the framework provides the structure to explore the interactions of two different technologies used for the same purpose and their outcomes.

3.2. Constructing the Framework

The construction of the framework which is used in the present research stems from the combination of the general innovation framework (Manual, 1997) and the "input-output" framework (Godin, 2007). Even though the structure of the final version is input to output, the main features originate from the innovation framework.

In the next sections, we describe the frameworks on which our framework is based on, the final version of the framework for our research (for measuring the appropriateness of the existing policy measures) and, finally, the extended version of the framework, so as to include the main hypothesis, which is the links between the energy trends of renewable energy technologies and energy efficiency technologies.

3.2.1. General Innovation Frameworks

The innovation framework is depicted in **Figure 6**. There are four main terms to describe: the framework conditions (general conditions and institutions), the transfer factors (learning by human, social and cultural factors), the innovation dynamo (including the factors which shape innovation in firms) and the science and engineering base. The broad innovation indicators are the educational level, the communications infrastructure, the financial institutions, the legislative and macro-economic settings, the market accessibility and the industry structure. All these factors are proven to be important in order to set up this analysis' framework for innovation.

This general model provides the cornerstone of the framework adapted in the environmental context. In the next section this model is converted in a more practical version, where elements are presented as input and output so as to define the correlation functions. Analyzing the links from both economical and environmental perspectives (Peterson, 2000) leads to a complex system (socially and naturally attributed) which should be carefully examined (Starik & Rangs, 1995). Thus, system analysis on those terms becomes really complicated. The solution is defining system boundaries to simplify and organize the system (Boons & Wagner, 2009). Boons and Wagner divide the system economically and ecologically. Indicators for the systems' performance are based on different definitions. For ecological performance is *what societies consider to be problematic ecological impacts*. Economic indicators are also *social constructions of standardized efforts to establish a firm's performance in measures such as Return on Investment (ROI)*. As mentioned above, the framework should include these multiple-level perspectives.

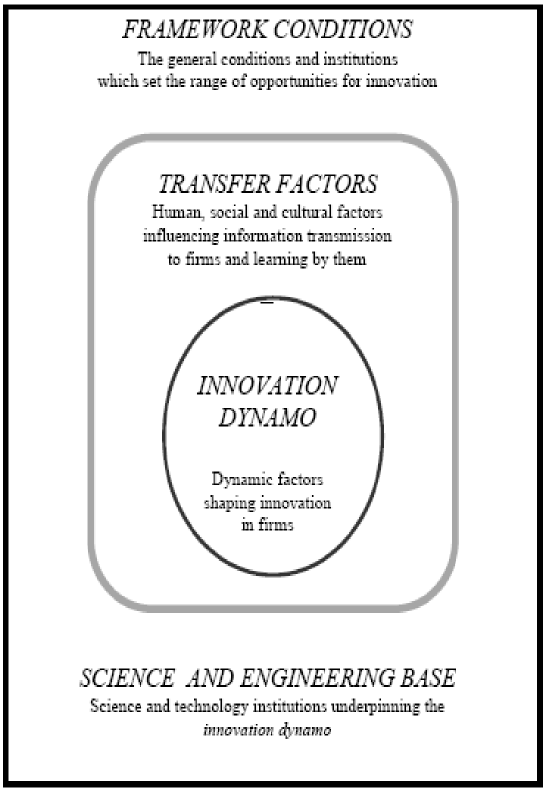

FIGURE 6 - THE INNOVATION POLICY TERRAIN – SOURCE (MANUAL, 1997)

3.2.2. CREATING THE FRAMEWORK

The most appropriate model to simulate our system belongs to the "input-output" model category (Godin, 2007). It analyses multiple indicators, such as innovation indicators and frame them in way to explain the data under question. In this case, our under investigation input are the policies used and the output is the innovation as patent counts. Their relation, in the article mentioned as "research activities", is influenced partially from the EU settings such as legislation, the technological progress itself, the policy framework followed and the methodology used to analyse the data (**Figure 7**). This box represents an innovation system (in the next steps, it is either renrewable enrgy or energy efficiency innovation system).

FIGURE 7 - GENERAL INNOVATION FRAMEWORK

The meaning of the box is setting the boundaries of the innovation system. The input to the system can be multi-attributed but one should keep in mind that the research is conducted to inspect the policy implications (economical, social and institutional). The rest of the variables are a stable input to the model and function as additive information in order to simulate better the system function.

In consequence to the general framework, a new one has been created so as to include all the aspects of the present research (the REIS[30] framework depicted in **Figure 8**). In order to do so, most of the concepts of the general framework have been operationalised, not only because of a clearer depiction of the actual system, but also because of the values needed to define and, eventually, optimise the system. Due to the complexity of the system, boundaries have been defined in the analytical model specifications. As an example, it is considered that technological progress within the "black box" is given. This happens because measuring the technological progress or defining its relation to the market does not belong to the aims of the research.

Our main aim is to define the relation of the input and the output, policies and technological change, considering the current market status (whether the market is liberalized or the oil/ gas price) and the influence by different energy trends (such as energy efficiency measures).

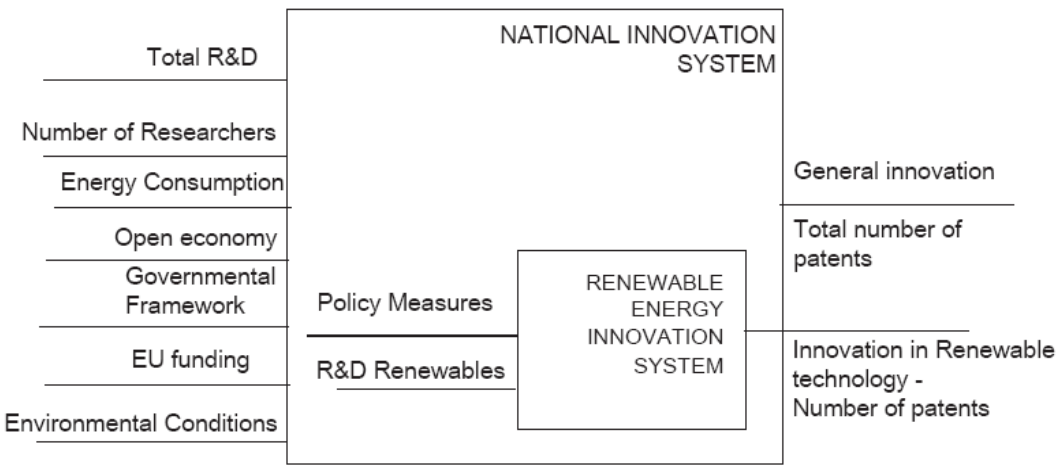

FIGURE 8 - THE REIS FRAMEWORK

The main input variables depicted in **Figure 8** are described in the next section.

The main system under examination is, originally, the renewable energy innovation system. The results of the analysis of this "input-output" model will give further insight to the relation of innovation and policy instruments in renewable technologies. In the next section, the framework is adapted to include one more energy trend, the energy efficiency innovation system.

3.2.3. UPDATING THE FRAMEWORK

The original framework is redefined to re-examine the empirical analysis results, in case some of the input variables are not highly correlated to the output or there is new evidence which influences the final output, such as possible "lock-in" effects[31]. Figure 9 shows the updated model. Lock-in effects are important to this stage's definition of the system as they can possibly explain the output results. More specifically, the case whether the recent solution of energy efficiency creates a lock-in effect so that

[30] REIS is the abbreviation for Renewable Energy Innovation Framework

[31] Lock-in effects are extensively described from their concept perspective to their leading mechanisms in the previous chapter.

innovation in renewable technologies is actually paused, as it is proven at the time being more cost efficient as well. Energy savings as a concept cannot by itself solve the current energy demand issue. From the statistical analysis in the next chapter, according to our findings there is a clear correlation of RETs to energy efficiency. More specifically, as shown in the extended framework figure, a part of the REIS output is actually used for the energy efficiency innovation system (EEIS) as well. According to our output measure almost one third of the patent classified as renewable also belongs to the energy savings. Thus, a lock-in effect is easier to be created due to the existing dependence of the framework's outputs.

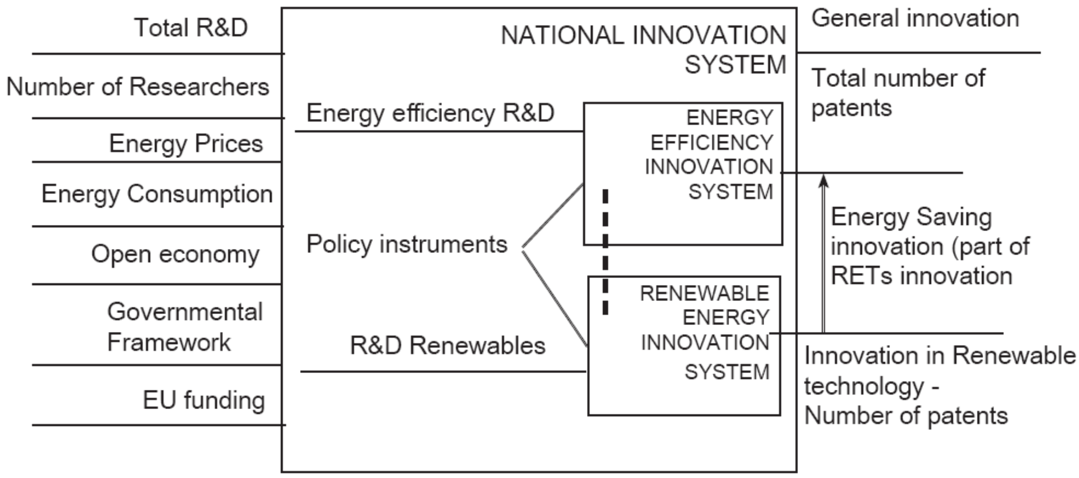

FIGURE 9 – LOCK-IN FRAMEWORK

In this system, energy efficiency is included. Energy efficiency has the same input such as renewable energy[32]. One possible explanation of their correlation is also depicted in the number of patents in Renewables. The hypothesis is **when energy efficiency R&D is increased, then one should probably remark stability or even decrease in the number of patents as output for renewable innovation.** Thus, there should be an investigation on how these two energy trends are related to each other.

3.3. INPUT AND OUTPUT VARIABLES

The EU settings are named "directives" which the EU Member States are supposed to follow. Concerning the Renewables, the directives have not strictly defined the instruments or the methods that should be used in order to achieve the 20% of renewable energy used by the year 2020[33]. The EU has given the initiative to Member States to decide how to proceed in terms of policies or financial costs. The policy framework is defined in terms of a national innovation system. According to (Anne Held, 2006), the policy instruments are categorised in two ways, whether they are voluntary or obligatory and whether they are direct (price or quantity driven) or indirect. From these, our interest is focused on feed in tariffs, investment and tax incentives from the direct, price driven regulatory instruments, the tendering and quota obligations from the quantity regulatory and, finally, the voluntary agreements from the voluntary section. These measures define the set of policies which will be used as one of the inputs of

[32] Data on energy efficiency are easily provided through the IEA or Mure (MURE) database. Chapter 4 is occupied with the analytical explanation of these data.

[33] Besides the directive about the Biofuels which has been highly criticised and not integrally implemented yet.

our model for both renewable energy and energy efficiency systems. It is of great interest that the same policies are used for both systems, because this fact makes them comparable.

The framework[34] can be characterized as a new technological system combined with a radical innovation, according to (Archibugi, 1988). Radical due to its sudden appearance and the possible shifting from one technological group to another and new technological as it concerns different sectors of economy with a common technological basis. This multi-functional approach demands that the input to the framework is divided into separate aspects.

In order to understand the correlations between the variables, dependent and independent, of the framework we need to clearly define the nature of the variables, their units and how they contribute in the framework. The choice of the variables and their operationalisation is one of the main targets of this research. That is why their choice has been careful and thoroughly justified. These variables are our means to shape the economic processes that take place and cast light on the correlation function, thus the "black-box" of the framework. Griliches (1990) states that "we would like to measure both the inputs and the outputs of such processes, to understand what determines the allocation of resources to such *technology changing* activities, and also what is happening and why to the efficiency with which they are pursued in different times and in different places". That statement depicts the general idea of our framework as it includes both spatial and time aspects, besides of the processes themselves.

The relationship between the variables is based, originally, on a Cobb-Douglas production function to explain the countries' output (knowlegde patent stock) through a set of input variables (Heshmati, 2006). The production function includes as general input labour, capital, energy etc. we decided to use a generalised function to explain variations within countries (such as population, size or economic growth). The same basis use Zoltan et al. (2000) in order to measure refional production of new knowledge. Griliches (1979) models, based on the production function, including the time trend, emphasizing on the importance of R&D expenditures in the input.

In the next sections, the input and ouput of the framework will be analytically described, including the corrections which come up gradially due to redefinement of the features of the original framework.

3.3.1. INPUT

The governmental framework towards innovation is the action plan which a country designs and implements within a specific time interval. The national action plans are concerning different aspects of energy (energy efficiency, renewable energy etc.) and are reviewed by a European level committee. More specifically, the National Renewable Energy Action Plans should include the targets of renewable energy in final energy consumption (transport, electricity, heating and cooling) by 2020, the national policies on biomass resources and biofuels sustainability schemes bearing in mind policy measures concerning energy efficiency and other administrative procedures and general schemes (TechKnowledge, 2009). It seems from the plans' design that the Committee does not want to divide renewable energy from energy efficiency, although the mean focus leans on renewable energy.

Main input variables to this framework, i.e. the operationalisation of the policy aspect, are the total R&D expenditures, meaning which part of the total budget is going to R&D and the number of researchers (in the public sector). Both of these variables are concerning purely innovation.

[34] Innovation and its variables' definition are analyzed in the previous section

Another variable is whether the economy is liberated (Prospects for the internal gas and electricity market, 2007). In case of a liberated economy, competition can influence the market trends. The liberated market is a very important aspect for the energy sector as well, especially within the EU. The EU has tried to impose the energy market liberalisation from the 1990s, first in the industry and then the households sector, in order to introduce competition to the field. Despite the fact that the directive has been implemented, the market still retains the characteristics of the older centralised system, with dominating companies, usually national, which control the electricity price.

The energy consumption, so as the energy prices are included in the model since they represent changes in possible trends concerning energy. These changes are usually positive: increase in energy prices or consumption is assumed to lead to technological changes for both ecological and economical reasons.

The output of the original framework is as mentioned above the total number of patents as an operationalisation of innovation concept. In this research, a more specific part of this framework is examined, the one concerning the renewable energy innovation sector. In **Figure 9**, the most important tool concerning the input is depicted: the *policy measures* are complex variable[35] which include *governmental intervention* that defines when a measure starts, the budget devoted to it, its duration, i.e. the planning and implementation following the EU directives for the defined *policy instruments* such as taxes, subsidies or voluntary agreements, that reflect the actions of the country and they include the level of their importance and the environmental conditions which represent the geographical aspect.

Finally, the *R&D budget* spent on renewable technologies, a part of the original budget measured in million of Euros. As expected, the output of this part of the framework is, also the number of patents, but retrieved only for renewable energy technologies, and in detail, wind, solar, geothermal, ocean (wave/ tide), biomass and waste renewable energies. The R&D budget is redefined in the “Lock-In Framework”, which includes besides the Renewable R&D, the energy efficiency R&D so as to re-interpret the output results and suggest a new policy framework.

3.3.2. OUTPUT

The output of the framework needed to be a robust representative of the changes occurring in the input. Thus, it should not just represent in the clearest possible way the relations of input and output, but also, it should be sensitive to probable alterations of the input variables or the function that associates input to output. Within different innovation indicators such as R&D expenditure or scientific personnel, patents have been shown to be the most effective. In the next sections we describe why patents are an appropriate innovation measure in general and the exact form and attributes which is used in the present research.

3.3.2.1. PATENTS AS INNOVATION OUTPUT INDICATOR

According to Griliches (1990), patents reflect the innovative performance of an industry as it “represents the minimum quantum of invention which has passed both the scrutiny of the patent office as to its novelty and the test of the investment of effort and resources by the inventor and his organisation into the development of this product or idea, indicating thereby the presence of a non-negligible expectation

[35] That is why a thicker line is used in the framework definition.

as to its ultimate utility and marketability". Griliches, here, seconds that a patent is a measure which expresses both technical utility and financial profitability.

In addition to the above definition patents, by nature, have very appealing characteristics prone to research. First of all they are discrete elements, fact which makes their modelling easier, and available through databases, which makes their retrieval feasible and integrated (without element loss) and minimises the simulation error (N.Johnstone, January 2008). Johnstone in his article refers to the work of Lanjouw and Mody (1996) or Popp (2003). Also, Johnstone mentions that there are few inventions with large commerciality which have not been patented according to (Dernis & Guellec, 2001).

Kleinknecht et al. (2002) discuss the *strengths and weaknesses* of different innovation indicators including patent applications. Within the advantages, the article refers to their availability, in time series terms and their detailed description. It also includes the *regional disaggregation* which is feasible but complicated due to large international firms etc. The stability and divisibility are the strongest features of patent applications. On the other hand, the article sums up the weaknesses of this output measure. The authors refer to the fact that there are many inventions/ innovation not patented or there are patents which have not been commercialised[36]. Also, the degree of commercialisation might not be reflected through the citations' use. Finally, it is important to distinguish whether the industry has a propensity to patent[37] and, thereafter whether the countries involved also tend to patent as well. **Figure 10** depicts the tendencies in patenting for some OECD countries in environmental technologies for the time period of 1983 to 2002. In general, most of the countries show either increasing or constant propensity to this patenting field.

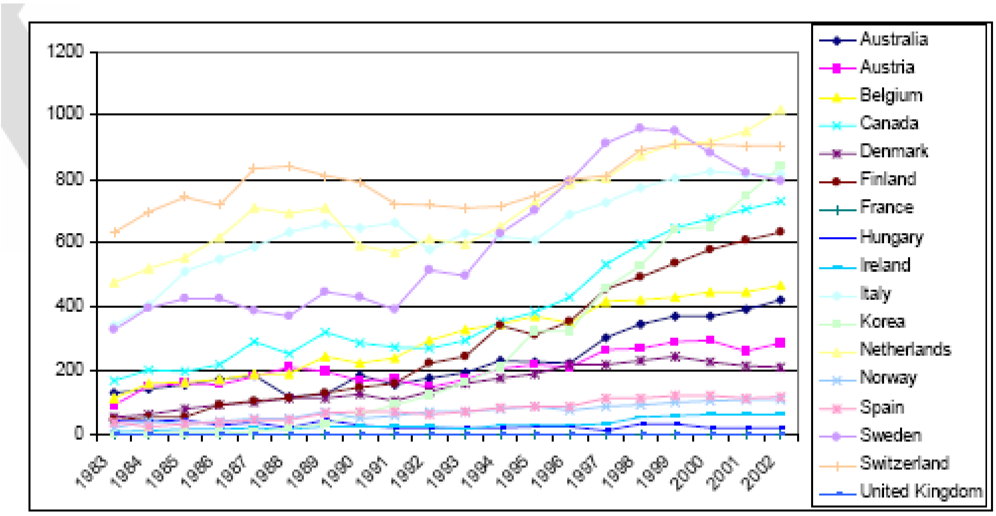

FIGURE 10 – PATENTS FOR ENVIRONMENTAL TECHNOLOGIES – STI SCHMOOCH DEFINITION (SOURCE: OECD)

An extended review of literature about the efficacy of patents as an innovation measure is presented by Basberg (Basberg, 1987). The author stands positively in using the patents as a measure, although he suggests cautious use bearing possible *trade-offs* in the research process. As trade-off the author

[36] This may occur due to the *firm's strategic behaviour to prevent the competitors from using the invention/ innovation*

[37] The industry where the patent belongs is very important. As an example one could refer to pharmaceutical industry which always ends to patenting. In the energy field, the patenting curves show a slight increase according to WIPO (WIPO, 2008) due to *pressures on energy resources*.

defines the *limitations of data* versus the *lack of adequate technology indicators*, especially when studying the time aspect. Archibugi and Planta in (Archibugi & Planta, 1996) also support patents as innovation measures, especially when the research is conducted for a specific time frame. Finally Albert Link in (Link, 1995) defines criteria according to which the appropriateness of the output indicator is chosen. He divides the cases' nature in either technology-based evaluation standards or cost-effective evaluation standards. Patents relatively to the above taxonomy are applicable to both standards but when it comes to the evaluation of private or public activities patents are not useful (Kleinklecht & Bain, 1993).

Concluding, the use of patents as innovation output measure is the most appropriate kind of variable type. Besides the fact that patents are par excellence output measure, discrete and available, in our case it is also defined accurately for a long time frame, it includes the spatial aspect and, finally, due to the international classification it is easier to define innovation in specific sectors, such as the renewable energy sector. In spite of the usefulness of the patents, one should not omit that there are few drawbacks, such as the propensity level of the industry or the region, the fact that not all patents are commercialised and the fact that there are innovations/ inventions unpatented for strategic reasons.

3.3.3. THE ATTRIBUTES OF THE OUTPUT

As mentioned in the previous section, patents are an appropriate innovation output indicator due to their attributes. More specifically for our research, patents are able to divide "environmental innovation" into different sectors due to the detailed classification.

The dataset was obtained from the EPO patent database (EPO). The classification set was retrieved by previous research of Johnstone et al. for OECD (N.Johnstone, 2008). The main fields of renewable energy technologies are: wind, solar, wave/ tide, waste and biomass. Each one of these includes specific classes. The table of classification is presented in Appendix A (Table 2).

For each one of these classes and subclasses we recover the patent counts according to the priority number and the publication date. Publication date refers to the year of patenting and the priority number includes in the first two letters the country of the patent submission. An example could be as following:

Title	Publication number	Publication date
Self suspended solar chimney SELF-SUSPENDED SOLAR CHIMNEY	GR1004334 (B1)	11/09/2003
FLOATING SYSTEM FOR SUPPORTING WIND-POWERED GENERATORS	GR1005225 (B2)	14/06/2006
WALL CONSTRUCTION FOR FLOATING SOLAR CHIMNEYS (FSC)	GR1004837 (B1)	02/03/2005
WIND AMPLIFIED ROTOR PLATFORM SYSTEMS	GR3036835 (T3)	31/01/2002
WIND TURBINE	GR3036127 (T3)	28/09/2001
Gearbox-generator combination for wind turbine	GR3034046 (T3)	30/11/2000
Wind turbine	GR3034045 (T3)	30/11/2000

TABLE 3 – EXAMPLE OF SEARCH RESULTS FROM THE EPO DATABASE

Detailed results and statistics from the EPO Database are presented in Chapter 5. The EPO database was chosen, besides the practical reasons, therefore, detailed search form, availability and export of data to convenient format, because it includes 36 member states, which are representing a large sample from patenting activity, and because it includes data since 1977 (depending on when the country became a member).

3.4. CONCLUSIONS

This chapter is dedicated to the creation of the framework so as to model the system for afterwards simulation. The basic model has derived from a combination of the innovation model specified in the Oslo Manual and the “input-output” one.

Due to the complexity of the system, we have set boundaries to fragment the input and output of the framework, always maintaining its twofold character: the economical and the ecological one. From the boundaries’ set two frameworks have been extracted. The first is used to describe the correlation of the policies measures on renewable energies innovation and the second connects the renewable energy innovation system to the energy efficiency innovation system, which is implemented at the same time.

Finally, we analyse the choice of variables and dedicate a whole section to attributing the output innovation indicator, i.e. the patent counts, in general and in relevance to the model.

CHAPTER 4
MODEL SPECIFICATION

4.1. INTRODUCTION

The model operationalisation described in this chapter routes the transformation from the theoretical framework of the previous chapters to the model simulation according to the limitations of the system. The chapter is divided as follows:

At first, we set the instruments of governmental intervention for the RES and energy efficiency. Policy instruments are considered as a specific part of the empirical analysis chapter as their definition and analysis constitute one of the milestones of the present research, keeping in mind that one of the main research questions is how different policy instruments influence the RES and energy efficiency energy trends within the EU-15. Thus, the model specification part answers the following research questions:

- What are the driving forces behind the design and implementation of policy instruments for RES?
- Which are the policy instruments available for RES? How are those categorised?
- What are the main characteristics of each policy instrument?
- Are the policy instruments for RES similar to the ones of energy efficiency? Are they based on the same drivers? What are the similarities and what are the differences?
- Which policy instruments are used in the present research and why?

Then, we operationalise the rest of the variables as presented in the conceptualisation phase. Until now, the literature review set the ground terms so as to understand the main concepts of the research, design the framework in order to depict the system and its boundaries and reveal relations between the involved factors. All these elements have been combined to create a representative simulation of REIS and Lock-in frameworks. The empirical model, created for that purpose is based on the literature review of induced innovation (explained in chapter 5). The questions that are answered in this part of the chapter are the following:

- In which context are the system limitations defined and what are boundaries which frame our system (so as to be modelled satisfactory)?
- According to the bounding settings, which are the system variables, how are they categorised and which are their units?
- How is the dataset, stemming from the variables, characterised. What are its main features and how are they reflected in the model simulation?
- Which is the methodology used in order to treat the data in the most effective way? How is the dataset treated to provide the best possible results?
- What are the results of the empirical analysis and which is the degree of their robustness?

The structure of the chapter is the below: at first, we present the data of the model. This part is generally divided into the policy instruments analysis and, then, the variables definition. Then, we include the data treatment and the methods used to extract our results. The last parts describe the regressions analyses and testing so as to define the formulas connecting the input to output and the verification of their validity.

4.2. Data

4.2.1. Policy Instruments

This part, at first, analyses the driving forces which point to the policy measures designed specifically for the RES. Based on the findings, we present the different policy instruments according to various classification methods, each one focusing on different characteristics of them.

4.2.1.1. Driving Forces of Policy Instruments

In the introductory part, we mentioned the necessity of governmental intervention for the adoption of renewable energy within the EU-15. The reasons that governments pay attention in empowering the RES can be divided into three main categories according to (van Dijk, et al., 2003): the economic drivers, the social drivers and the environmental drivers. The main drives and their aspects are depicted in the picture below (figure 5). The terms that are part of our framework are highlighted in bold letters.

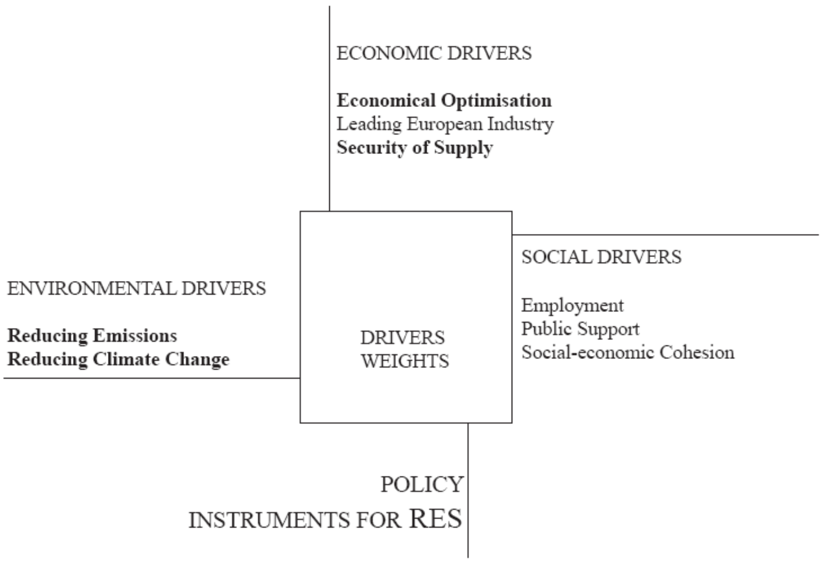

Figure 10 – Driving Forces for RES Policy Instruments (van Dijk, et al., 2003)

The economic drivers include the economical optimisation which is the main motive of production and distribution in firms. In some cases, renewable energy can be proven most appropriate solution in financial terms, compared to the use of conventional methods[38]. Secondly, the security of supply is one of the most important reasons for RES deployment. Due to the large energy consumption of the indigenous energy sources and the growing dependency on external ones, the security of supply has become one of the major issues in the European Commission's agenda. This situation is reinforced by the fluctuation of energy prices[39] and the uncertainty of political relations between the exchanging

[38] In (van Dijk, et al., 2003), the authors use the example of decentralised energy supply. They suggest that the function of a small off-grid plant of renewable energy is a more cost-efficient solution than the expansion of an existing grid using conventional energy sources.

[39] The energy price has effects on both social welfare and economic stability.

countries[40]. Finally, the Leading European Industry is an attempt to increase the influence of the EU internationally concerning the RETs. From all the economic drivers, the ones that affect our model the most are the energy security and, secondary, the economical optimisation.

One more driving force is the environmental preservation. The consequences of conventional fuels utilisation can be alleviated through the use of RES. For energy sources such as wind, solar or tidal energy the implications for the environment in terms of polluting emissions or climate change are smaller compared to those of conventional energy sources. Only the cases of biomass and waste sources have effects on the environment which are already covered by legislation. In addition to that, the CO2 emissions are significantly lower than the ones of fossil fuels, and can be released in more environmentally “friendly” ways. The environment is a major driving force for the design of our model.

Finally, the social drivers include increase of the employment rate, the consciousness of the public concerning the effects of conventional energy sources and the socio-economic cohesion, which represents the possibility of RETs to spread geographically, creating new opportunities in areas that were not utilised until now. This last driving force is not part of this research, although it is significant for deploying the RETs. The social impacts of innovative activities, such as RETs, are not counted as a factor of our framework.

Weighting our factors of creating the policy instruments is a matter of current necessities, priorities and trends. In our model, the social factors are not a signpost of a successful policy measure. The instruments more related to financial and environmental factors are those mostly taken into account.

4.2.1.1.1. Classification of Policy Instruments in the EU

There are different methods of distinguishing the RES policy instruments. Here, we use the top-down approach (figure 11) to introduce all existing policy instruments. This approach is described by (Pfaffenberger, Jahn, & Djourdjin, 2006). Then, we categorise the policy instruments in terms of attributes according to (van Dijk, et al., 2003) and (Anne Held, 2006).

In their research, (Pfaffenberger, Jahn, & Djourdjin, 2006) have classified the policy instruments concerning the RES into five main categories (depicted in figure 6). We refer to this classification scheme only to define all policy measures.

The first category includes the establishment of institutional tools in order to define a suitable framework for the promotion of RES in multiple sectors. These tools create the institutional scheme (laws, policy programs, organisations etc) for the success and appropriateness of policy instruments. They act as the theoretical research and analysis in order to design the best outcome policies. The other four categories concern more practical features.

At first, regulation of prices includes fiscal and non-fiscal instruments. The fiscal instruments represent the public revenues, such as energy taxes. This form of public investment provides with a strong incentive the firms to innovate. Non-fiscal instruments are mainly control of prices and investment and feed-in-tariffs. Feed-in-tariffs is one of the main instruments used for the promotion of RETs. The government regulates the tariff, a fixed amount paid for RES electricity production or an additional

[40] As a recent example, we could refer to the conflict between Russia and Ukraine over natural gas distribution. The consequence of this conflict was the shut-down of the gas-pipe which effected many more European countries.

premium on the current electricity price to the RES producers. The most important feature of this instrument is its duration which allows high investments on new technologies. The possibility of cutting back the innovation activity due to the time safeguard can be prevented with dynamically decreasing tariffs.

Also in prices regulation, one important category is the governmental expenses, such as subsidies, grants, soft loans etc. These instruments focus on providing financial aid to create incentives for the promotion of RES. One significant sort of subsidy used in RES is the promotion schemes (grants for investment/ operation, credits at reduced rate, tax reliefs or bonuses) which are defined in time and budget terms and are usually evaluated by state committees.

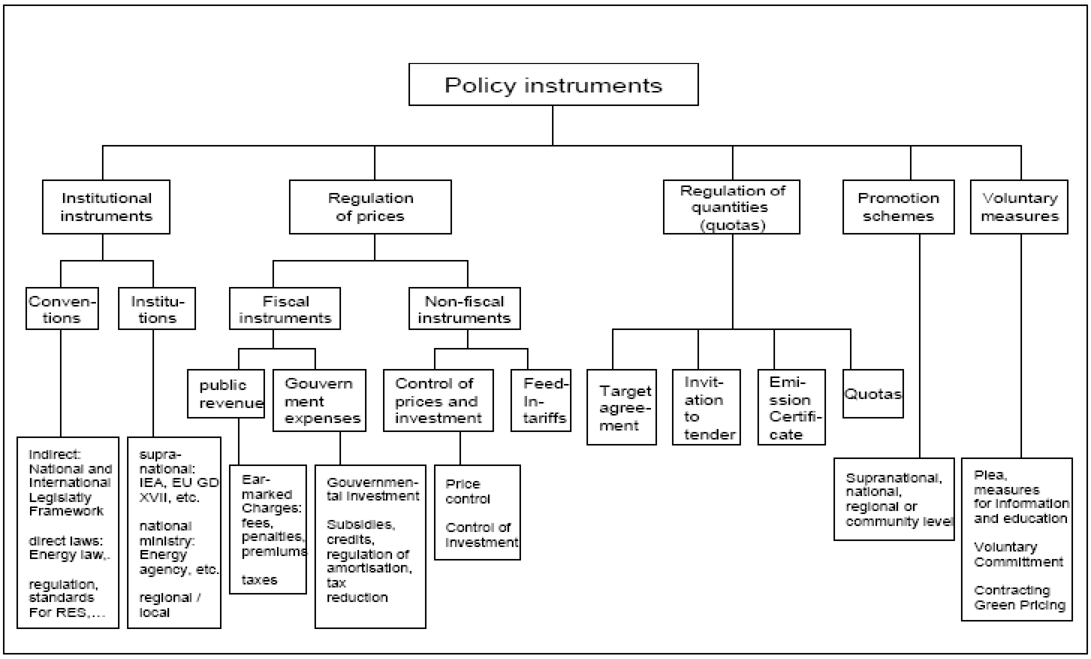

FIGURE 11 – CLASSIFICATION OF POLICY INSTRUMENTS FOR THE PROMOTION OF RES ACCORDING TO (ESPEY, 2001

The next type is the quantity regulated measures concerning production capacity or quantity of RES energy produced. These are divided into target agreements, which set the objective value of RES energy production[41], the tendering procedures for investing in renewable energy infrastructure, the emission certificates for reducing the polluting emissions and the quotas, for a minimum level of RES production. Certificates represent a "cap" for harmful emissions. Firms can either sell or buy certificates (selling when emissions are lower than the amount allocated to the firm, and buying when emissions exceed the allocated amount). Depending on the certificate price, the measure creates a strong incentive for both energy saving or renewable energy techniques. The quotas, regulating the RES production, combined with certificates create a powerful market incentive to promote the above-mentioned energy trends. The certificate defines that the set quota has been reached by the firm and can be traded by its owners. Firms can treat quotas as their targets, and gradually lose interest in new investments. This effect can be corrected by creating multiple quotas under the main quota which can be fulfilled in different time periods.

[41] Target agreement is the European Commission's Directives on the percentage of renewable energy consumed or the Energy Saving (or Energy Efficiency) Targets for each member state.

Finally, the last measure presented is the voluntary agreements. The importance of this measure depends on the willingness of every actor (from energy producers to end-users) to adopt renewable or energy saving technologies. This measure is called "soft" as its implementation is not mandatory. The most important policy instruments are information and education. These two features inform about the real costs, possibilities and consequences coming from the use of energy saving techniques or renewable energy. Especially for the energy saving, the European Commission has promoted labelling for every domestic product in order for the consumer to know how much energy he consumes and how much is the environmental benefit (if any). Voluntary obligations are contracts between the state and energy producers so as to decrease emissions or achieve an RES energy goal without undergoing through the expenses of official regulations. This option has not been effective as the legal bond has not restrained the firms concerning their commitment. The last type is "green" electricity products which have prices competitive to conventional energy products. This type is not appropriate as a market instrument; although it offers "green" products in lower than usual RES products' prices. Appendix B includes a table which sums up the results from different criteria on evaluating the different policy instruments.

A different classification perspective from van Dijk et al. (2003) focuses on a more economical perspective. Their system acts as a quarterly-divided field where instruments are categorised in terms of supply and demand, price and quantity. If the measure stimulates the supply by price regulation it is mainly a tariff, if it stimulates the supply by quantity regulation it is a tendering. In that order for the demand it is accordingly price support of demand and quota-obligation for consumers/ suppliers. The figure below also depicts the countries involved in each measure.

	price	quantity
supply	*Feed-in tariff* Germany, Austria, Spain, France, Greece, Portugal, Finland	*Competitive Bidding* Ireland *Obligation for producers* Italy
demand	*Price support of the demand* Netherlands	*Quota-Obligation for consumers or suppliers* UK, Austria (small hydro), Belgium

FIGURE 12 – FUNCTIONALITY OF THE RENEWABLE ENERGY MARKET ACCORDING TO (VAN DIJK, ET AL., 2003)

The mechanisms are also divided into direct and indirect, compulsory and voluntary (Haas, et al., 2001). According to the following scheme all the presented mechanisms can either be regulatory[42] or voluntary. Also, quantity is phrased as capacity. What is introduced in the classification below is the nature of acting: direct or indirect. Direct measures aims at the straightaway promotion of a specific RET, where indirect act at a second level, as their primary target is not the promotion of RETs[43]. In addition, both regulatory and voluntary are divided into investment focused or generation based. Investment focused means to provide incentive for investment, and generation based is to achieve the target value of energy generation.

[42] Regulatory is another expression of mandatory or compulsory.
[43] One possible target is the pollution abatement.

		Direct		Indirect
		Price-driven	Capacity-driven	
Regulatory	Investment focussed	• Rebates • Tax incentives	• Quotas (RPS) / TGC • Bidding	• Environmental taxes
	Generation based	• Feed-in tariffs • Rate-based incentives		
Voluntary	Investment focussed	• Shareholder programmes • Contribution programmes		• Voluntary agreements
	Generation based	• Green tariffs		

FIGURE 13 – THE POLICY INSTRUMENTS MECHANISMS (HAAS, ET AL., 2001)

The next section presents the policy instruments for energy saving technology. Most of them have already been presented in this section as the two technologies act simultaneously, thus the policies for their adoption are quite similar. All these different measures fall in the classification we use in the present study. Our general planning is based on figure 11, which includes all kinds of instruments. The other classifications emphasise on the characteristics of the instruments: the economical perspective on figure 12 and the instruments' nature in figure 13.

4.2.1.2. ENERGY SAVING POLICY MEASURES

Energy saving policy measures have been retrieved from the MURE2 (Mesures d' Utilisation Rationelle de l' Energie or Measures of rational utilisation of energy) Database. This database divides the measures depending on the sector they are implemented (and more specifically, households, industry, transport, tertiary and cross-cutting) and by attribute. The main categories, for all sectors[44], are:

- Legislative/ Normative
- Legislative/ Informative
- Financial (Grants, Subsidies)
- Fiscal and Tariffs (price regulation)
- Information/ Education (Voluntary)
- Cooperative Measures (Voluntary agreements) and,
- Cross-cutting with sector-specific characteristics (energy taxes)
- New market-based instruments (only for industries – emission trading schemes)

According to the number of measures for each sector (see Appendix B) the measures which are shown to be most important are for the industry financial and voluntary and for households legislative, financial and voluntary. Thus, subsidies, legislation and voluntary agreements appear intensively in the energy saving measures. In contrast, price based incentives, such as fiscal and tariffs are less utilised, compared to the renewable energy policies.

Even though all policies exist in both energy trends, the rate of their presence is different. Taken that in mind, the next section concludes this chapter by reporting the policy measures which are used in the model implementation of the present research.

4.2.1.3. SYSTEM SPECIFICATION ACCORDING TO POLICY INSTRUMENTS

[44] A detailed description of all measures for households and industries is enlisted in Appendix B.

This chapter is devoted to the presentation of policy instruments used by the European Union's governments, in order to promote the energy trends of renewable energy and energy savings. During the literature survey, different attributes of the measures[45] have been labelled. At first, these measures are divided according to different features (the type of instrument) in separate groups. This feature of "clustering" has facilitated the instruments' analysis and modelling. Afterwards, each measure is characterised by attributes such as the country it is implemented, its duration, its level of impact etc. In our system, it is not possible for all aspects to be examined due to lack of information and time. This section indicates the instruments which are subject to testing in the model and what led to their choice. The first part enlists all the policy attributes and the second the selected measures.

4.2.1.3.1. Attributes of the Policy Measures

According to the policy scheme referred in section 4.2, the measures are screened into different categories according to their attributes. Most classifications divide them by the criteria of price or quantity regulations and obligation or voluntarism. These sets include a range of measures. Due to simplicity reasons, lack of information and the incentives (mentioned in part 4.1) for innovation, not all measure types are used in the model. The simplicity concept is used as not all measures have the same effect on innovation trends. As an example the institutional measures have an indirect effect on innovation designing creative policy schemes based on the necessities of the European Union. Lack of information prevented us from finding robust data on voluntary measures for renewable energy sources. Finally, social aspects such as raise of employment are not part of the incentives which lead to innovative energy trends in this research[46].

Besides the type of the measure, there are other attributes which contribute to the model. These are: the country that the measure takes place, the time period that it is on effect, the sector that they belong, its evaluated impact (when existing), the actors involved (including both implementing and target actors) and its applications. From the above aspects, the ones necessary in the model are the country of application, the duration, the sector and the impact of the measures. The actors which set up the instruments are central governments (which can act on their own will or following the directives from the European Commission). The implementers are usually energy industries and the targets are second order industries (manufacturers, retailers) and eventually the general public[47]. The applications of the measures are not important for the present research as they do not contribute to its research questions directly or indirectly.

4.2.1.3.2. Selected Instruments

Due to the model's extension, clustering has been necessary in order to measure the instruments efficiency. Therefore, there are four types of variables taken into account: the price based instruments, including fiscal and non fiscal measures, the quantity based, including quotas, certificates, tender procedures and normative/ informative legislation, the voluntary measures and the financial ones,

[45] By referring simply as measures and instruments, we mean policy measures and policy instruments.

[46] This research examines the innovation trends influenced by the energy security problem and the attempt to pollution abatement within the EU15.

[47] These data are retrieved in detail from the MURE2 Database in participation to the Odyssee project (ODYSSEE is a project between ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie – Agency for the Environment and the Energy Measurement), the EIE programme (Europe Intelligent Energy program) of the European Commission/DGTREN (Directorate General Transport and Energy) and energy efficiency agencies, or their representative, in the 27 countries in Europe plus Norway and Croatia (ODYSSEE project, 2008).

including grants, loans and subsidies. The exception to these general types comprises the tax measurements, which are separately referred in the model.

The duration of model's simulation is the time period from 1990 to 2006. The period was selected to include the effects from the two examined trends (energy saving and renewable energy) simultaneously, as the implementation of the second has started during the 1990s[48]. Data for the measures have been selected by the MURE2 Database for the energy efficiency and the OPTRES report (Ragwitz, et al., 2007) for the renewable energy.

MURE2 assesses the impact from each measure in a semi-quantitative way (low, medium, high). The evaluating methods can differ: from the ecological effectiveness and energy savings to annual sales revenues. For renewable energy the OPTRES assessment declares whether the measure has been implemented or not for the 1997-2006 time frame. In (Pfaffenberger, Jahn, & Djourdjin, 2006) a table of comparison was introduced between the instruments for different criteria including their performance rate on objectives concerning RES production and cost and environmental goals[49]. Also, (Burgers, van Ommen, & Verheij, 2009) have developed an evaluation method[50] for specific measures (the main representatives from each cluster) which denotes whether they are suitable for specific market features, such as market maturity, market compatibility etc. Their measurements are also semi-quantitative. Besides these general instruments' evaluation, the (Haas et al., 2007) report specifies in, again, semi-quantitative way the instruments' impact implemented for a specific country[51]. Their rating of impact is quantified according to the RES produced quantities related to capita. Their results are used in the system's modelling.

Concluding, due to the system's restrictions (information and time constraints), the latest findings of this chapter are summarised in the table below:

Type of measure	Representatives for RES	Representatives for Energy Savings	Unit
Quantity based (legislative)	Quotas, Certificates, tender procedures	Legislative informative/ normative (Standards, Certificates)	Semi-quantitative (Low, Medium, High)
Price based	Tariffs, Taxes	Non fiscal, Tariffs, Taxes	Semi-quantitative (Low, Medium, High) Taxes are measures in USD (PPP) for RES and USD (PPP) per GW per year for energy savings
Financial	Subsidies	Grants, Loans, Subsidies	Semi-quantitative (Low, Medium, High)
Voluntary		Cooperative measures, Voluntary agreements	Semi-quantitative (Low, Medium, High)

TABLE 4 – SUMMARY OF POLICY INSTRUMENTS USED IN THE STUDY

[48] Renewable energy is an older trend deriving from the energy crises of the 1970s as a independent trend from specific countries (such as Germany). Its embodiment in the European Commission's directives, though, was not official until the 1990s.
[49] The table is included in the Appendix B.
[50] Their impact table is included in the Appendix B.
[51] The table is included in the Appendix.

The selected policy instruments for both energy trends are examined thoroughly in model simulation. The next chapter works on the detailed modelling of the system concerning the system boundaries and system variables in total. The above table constitutes the input variables for the policy measures in both “REIS” and “Lock-in” frameworks.

4.3. Model Variables

According to the findings of the previous sections, the framework is now operationalised into variables. The framework variables belong to three main categories. At first, we list the variables which define the time duration and the geographical extension of the model. Then, we describe the explanatory variables, i.e. the variables which act as our general regressor in the model. These are divided into the complex variables (e.g. R&D personnel) which are produced by the combination of more than one variable, and the simple variables (e.g. energy consumption). The complex variables are explanatory variables, which are normalised by auxiliary variables (R&D personnel is a product of the division of R&D personnel to the total population) or other simple variables. All the variables are enlisted in Appendix B.

4.3.1. Spatial – Temporal Variables

The first constraint of the model is its definition in terms of **space** and **time**. The first is defined as the countries belonging to the EU-15[52]. The choice of this state in the European Union is based on two concepts. The first is to include the countries which had an established presence in the European Union in terms of time. The EU-15 Member States have been the oldest members of the Union, providing the clearest insight concerning the effects of the policy measures published by the European Commission. Secondly, the policy measures referring to the energy trends examined have been implemented in the 1990s, thus, the Member States more involved into their implementation are the EU-15 ones.

More specifically, the policy measures designed for renewable energy have not officially started until 1997[53]. At the same time, another energy trend, the energy efficiency one has been proposed by the European Commission. This fact has defined the timeframe of our research. The under examination period should involve the years of design the measures, and the maximum possible years of their implementation. To that extent, the timeframe was defined from 1990 to 2006. This period expresses the major changes in the energy trends within the EU-15 and possibly the effects of their application.

4.3.2. Explanatory Variables

The second part describes the explanatory variables which were taken into account in order to get a clearer perspective of the innovation trends for renewable energy and energy efficiency. Patenting activity is further more than a result of adoption of policy measures. There are more determinants to drive innovation. Following the system boundaries, we decided to operationalise the national innovation capacities and openness, the prices of energy and the energy consumption in the input, so as the total national patenting activity in the output.

Before describing the variables used in the regression analyses, we denote with the basic variables, the field of innovation activities in the EU15.

[52] The EU-15 is compounded by Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom. These countries have been the only EU Member States until 2004. All of these were present in 1990 except from Austria, Sweden and Finland which joined the Union in 1995.

[53] Due to the energy crises many countries have shown a tendency to innovate concerning the RETs during the 1980s in their own initiative.

4.3.2.1. BASIC VARIABLES

At first, according to the national innovation determinants, we included the total R&D expenditures and the percentage of governmental expenditures given to R&D. These two elements represent the degree to which each government is preoccupied with research during the given timeframe. The total R&D expenditures were retrieved from the EUROSTAT database (EUROSTAT, 2009)[54]. R&D expenditures include all expenditures for R&D performed within the business enterprise sector (BERD) on the national territory during a given period, regardless of the source of funds. The unit of this variable is million PPS, where PPS defines the Purchasing Power Standard. PPS is the unit, expressed in US dollars which equalises the purchasing power of two currencies considering the cost of living and the inflation rates. Despite the fact that the research is conducted within the European Union, PPS was considered to be a fairer measurement unit as it does not involve the conversion of national currencies to euro[55].

Then, in order to measure in general, the tendency of a government to spend in innovation, we use a comparative measure of total government budget appropriations or outlays on R&D (GBAORD) as a percentage of **total general government expenditure**. GBAORD measures government support for R&D using data collected from budgets, expressed as a percentage of GDP (EUROSTAT, 2009). The below figure shows that in general the percentage of governmental spending to R&D is not more than 2.76% in the best cases, with mean value at 1.36%. Figure 14 also shows that highly investing countries (such as France, Germany or United Kingdom) have lowered their investing rate, while lower investing countries (such as Greece or Ireland) have shifted to higher levels of R&D expenditures. This measure is not used in the regression model. It only highlights the fact that R&D expenditures are a small part of the total governmental spending, which by the years, has not changed significantly for most EU15 countries[56].

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[54] *Eurostat is the Statistical Office of the European Communities situated in Luxembourg. Its task is to provide the European Union with statistics at European level that enable comparisons between countries and regions. Eurostat offers a whole range of important and interesting data that governments, businesses, the education sector, journalists and the public can use for their work and daily life* (EUROSTAT, 2009).

[55] From now on, all variables which are expressed through currency unit (such as prices or R&D expenditures) use always the USD (PPP) unit.

[56] There are exceptions such as France, which decreased its investing rate from 2.76% to 1.53% or Ireland, which increased its investing rate from 0.65% to 1.31%.

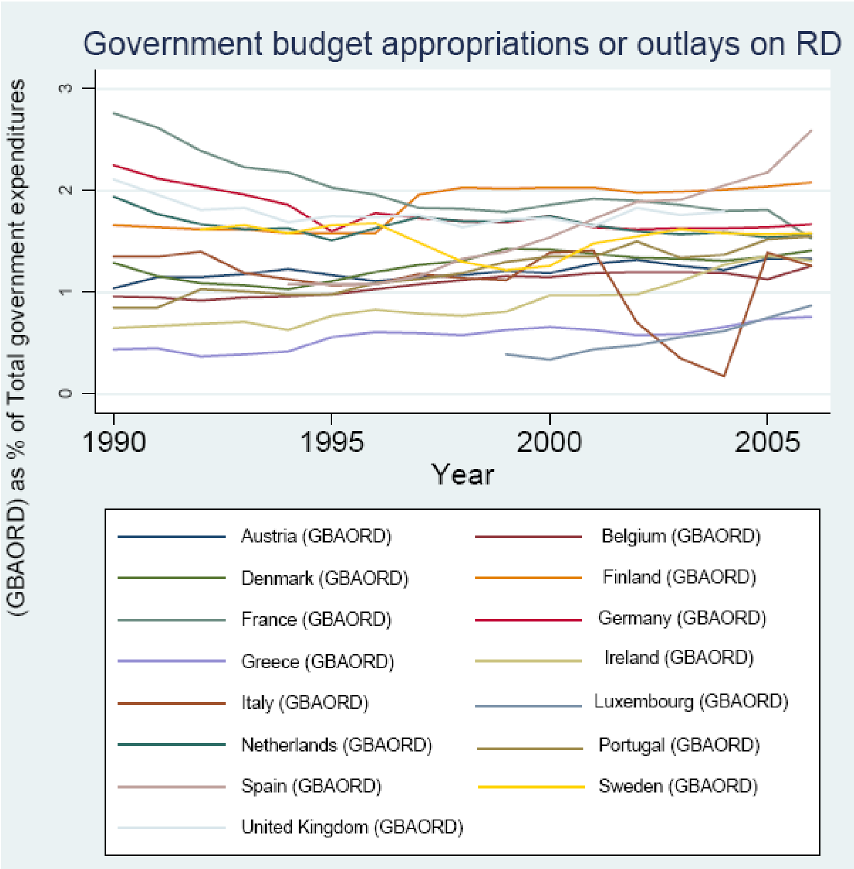

FIGURE 14 – GBAORD FOR THE EU15 (SOURCE: EUROSTAT)

As an additional R&D measure, the **Energy R&D** (in million USD) has been defined as the R&D for all energy related activities, such as renewable, fossil fuels, nuclear, energy efficiency etc. The source of that measure was the IEA Database[57] (IEA, 2008). Energy R&D shows the inclination of a country to invest on energy research. It reaches the maximum of 995.7 while the mean is 177.1 million USD (in the EU15). This measure also is not included in the main regression analysis. One interesting point though is its positive relation to the output (total number of patent counts. That shows that investment to energy in general leads to innovation for RETs.

[57] IEA is the abbreviation term for International Energy Agency. *The International Energy Agency (IEA) is an intergovernmental organization which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens. Founded during the oil crisis of 1973-74, the IEA's initial role was to co-ordinate measures in times of oil supply emergencies*. The IEA includes statistical data for energy related subjects, such as R&D energy statistics.

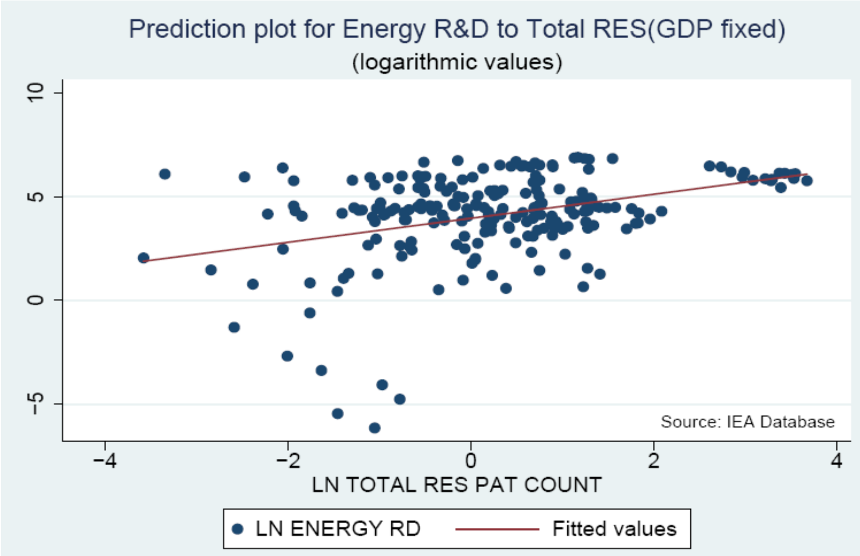

FIGURE 15 – PREDICTION PLOT FOR ENERGY R&D TO TOTAL PATENT COUNTS

4.3.2.2. SIMPLE VARIABLES

This model uses only two simple variables. By simple, we denote that the variable has not been treated in further and was used as obtained. The first one is **openness** to international trade and investment. This measure shows the general tendency of a country to invest and trade. The data were retrieved from Penn World Tables[58] (PENN, 2007). Penn World Tables define openness as exports plus imports divided by GDP (total trade as a percentage of GDP). The export and import figures are in national currencies from the World Bank and United Nations data archives. Openness can be an ambiguous measure as it expresses the tendency of a country to investment, but, at the same time, it fosters the possibility of negative spillovers. Openness is expected to have a positive sign.

At next, the **energy consumption**, in thousand tonnes of oil equivalent (TOE), retrieved from the EUROSTAT database, reflects the energy necessary to satisfy inland consumption within the limits of national territory. This measure is very important as it also reflects the energy trends through consumption. As consumption increases, the market in order to ensure that it can cover the required amount of energy may turn to other energy trends (such as renewable energy or energy efficiency). The sign of this variable is expected to be positive for both renewable energy and energy efficiency models (innovation output is expected to grow as energy consumption grows).

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Openness	255	84.10965	54.69365	27.62135	296.5986
Energy consumption	255	49056.42	66444.14	39	277576

TABLE 5 – SIMPLE VARIABLES DESCRIPTIVES

4.3.2.3. AUXILIARY VARIABLES

Auxiliary are the variables whose use is only to modify basic variables. This procedure of normalisation is necessary to ensure data integrity. For our normalisations, it was necessary to retrieve the **overall**

[58] *The Penn World Table (PWT) displays a set of national accounts economic time series covering many countries. Its expenditure entries are denominated in a common set of prices in a common currency so that real quantity comparisons can be made, both between countries and over time. It also provides information about relative prices within and between countries, as well as demographic data and capital stock estimates* (PENN, 2007).

patenting activity, **national populations**, the **Gross Domestic Product per capita** (GDP per capita) and the **Purchasing Power Parities** (PPP).

The overall patenting activity (measures in EPO patent applications per year) was considered, at first, as an indicative measure to normalise the output of the framework. Another variable of the input is the **overall number of patent applications** per country measured in million patents. . Data for this measure were retrieved from the OECD database[59] (OECD, 2008). The patents were selected by country/ applicant, priority date (from 1990 to 2006) and only for the European Patent Office. This variable, also set by Johnstone et al (2008), shows the propensity of the countries to patent. This measure is quite efficient as all the included applicants are from the European Union. Thus, it is more likely for them to patent in the EPO instead of another organisation. Unfortunately, the results of the normalisation were far from optimal as they provided unclear results.

From the OECD database we extracted data about the total population for each country in the period of 1990 to 2006 so as to normalise the R&D personnel from Penn World Tables. The variable comes from the World Bank World Development Indicators 2001 and United Nations Development Centre sources prior to 1960, and is measured in million persons.

The GDP and PPP values for all countries were, also, extracted from the Penn World Tables. According to (PENN, 2007), Real Gross Domestic Product per capita and components for 1996 are obtained from an aggregation using price parities and domestic currency expenditures for consumption, investment and government of August 2001 vintage. For countries that were not in the 1996 benchmark study, the price parities are estimated using either a short-cut method or extrapolated from previous benchmarks. GDP is by definition a very interesting variable as it is a measure reflecting the environmental stringency (Vries & Withagen, 2005). Vries & Withagen used in their model, in order to connect environmental innovation and strict environmental policy, GPD as an economy-sided SO2 emission substitute. They claimed that SO2 emissions lead to more environmental stringency and, consequently to higher environmental innovation. Specifically for GDP, they claim that: o*n one hand a higher national income would lead to more emissions. On the other hand, environmental policy could be negatively related to national income*. Therefore, Vries and Withagen made no speculations about the GDP variable sign. Their results though have shown a positive sign. GDP besides energy consumption reflects, as a model variable, on the pollution abatement targets of the European Commission.

Then, PPP is the number of currency units required to buy goods equivalent to what can be bought with one unit of the base country. PPP was calculated over GDP over GDP. The measure unit is US dollars (given price in 1996) as mentioned above. The auxiliary variables statistics are found in the table below:

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
GDP	255	27727.83	9500.494	15064.61	74366.13
Total patent applications	255	2614.583	4360.026	4.5	22723.31
Population	255	25132.39	25929.89	382.966	82431.39
PPP	255	2.023936	2.993766	.3610401	10.36007

[59] *For more than 40 years, OECD has been one of the world's largest and most reliable sources of comparable statistics and economic and social data. As well as collecting data, OECD monitors trends, analyses and forecasts economic developments and researches social changes or evolving patterns in trade, environment, agriculture, technology, taxation and more.* (OECD, 2008)

TABLE 6 – AUXILIARY VARIABLES DESCRIPTIVES

4.3.2.4. COMPLEX VARIABLES

The complex variables are those that are product of more than one variable either by combination with another simple variable (e.g. R&D intensity) or an auxiliary variable (e.g. R&D personnel).

The **patent counts** variable is defined for two main energy trends output, renewable energy and energy efficiency. For renewable energy the data were extracted from the European Patent Office (EPO) database (ESPACENET, 2009). Datasets were retrieved according to the OECD definition of International Patent Classification (IPC) classes (OECD, 2008a). The renewable energy fields for which the patent applications have been counted were: wind, solar, geothermal, ocean (wave/ tide), biomass and waste. According to the IPC classes, the publication date and the country, the datasets were created for all EU-15 members for the time period of 1990 to 2006. The data were, then, normalised according to real GDP per capita values (in millions of USD). The real GDP per capita expresses the standard of living for each country during time. Consequently, this measure shows the wealth of each country during time (affecting all sectors of production, including the energy sector) and, as mentioned above, the level of pollution and energy consumption. It is expected that a country with high GDP per capita consumes more energy and, at the same time, increase the pollution levels, but also, has higher levels of production and enforces technological change. These remarks are captured in the model's output by the accorded normalisation and that is the reason we decided to use it in the present study. GDP per capita includes also the population perspective which is really important. Even though most of the countries included have high GDP, the population differences are great in the dataset. Therefore, by using this variable we can observe each country's behaviour taking account both its wealth and population features.

Below, the graph for the countries with the largest and smallest output respectively. Germany is the leader country in innovative output with quite a strong difference from the others. The results show small fluctuations for the examined period of time. In the cases of Netherlands, Greece, Ireland, Italy and Luxembourg, the output has a negative slope.

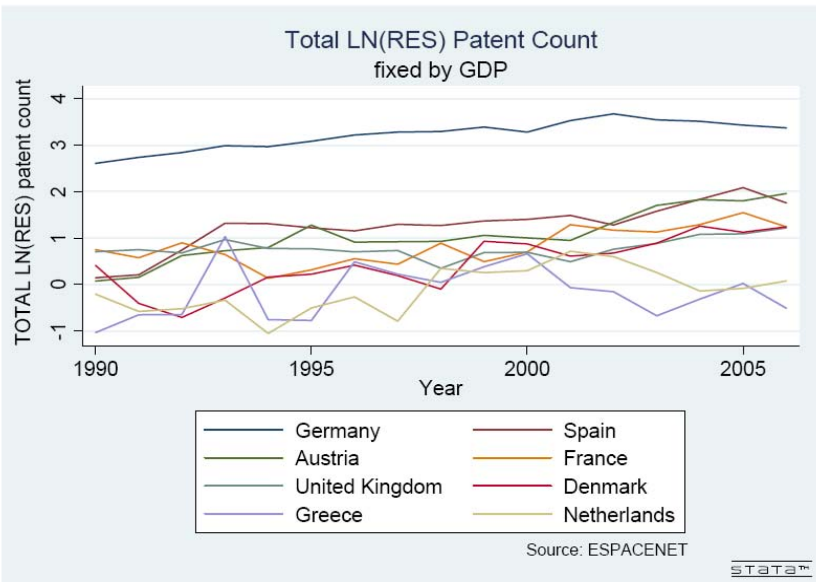

FIGURE 16 - COUNTRIES WITH LARGEST OUTPUT

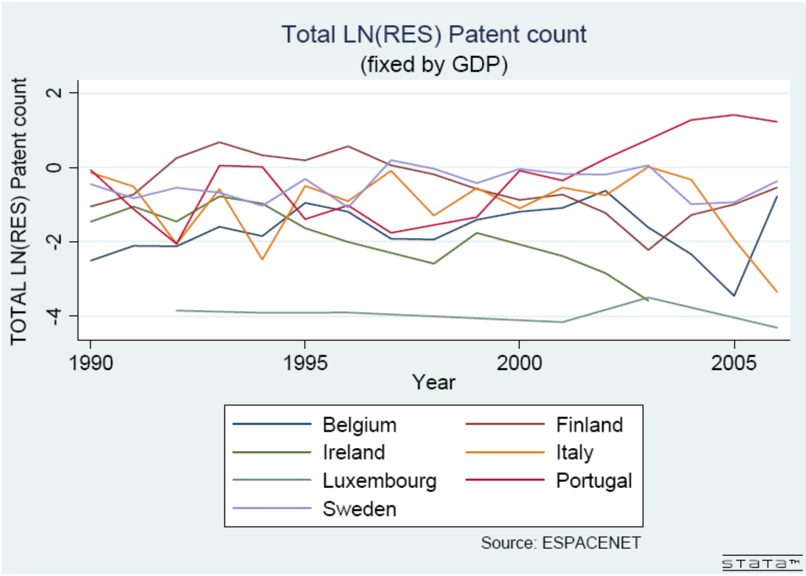

FIGURE 17 – COUNTRIES WITH SMALLEST OUTPUT

In addition to renewable energy, we have counted the patents belonging to the IPC classes which were common for both energy efficiency and renewable energy[60]. This correlation derived from the IPC classes for energy efficiency from Ecofys[61]. For the specific areas of wind and waste, according to the Ecofys report, the IPC classes for renewable energy and energy efficiency were the same. This relation should be taken into consideration while evaluating the impact of energy efficiency in the RETs innovation activity. The results for patent data are mentioned in the table below (also for natural logarithmic transformation, used in the empirical model):

Variable (in Patent Counts)	Observations	Mean	Standard deviation	Minimum	Maximum
Wind	255	23.4	56.37757	0	377
Solar	255	30.76471	78.53631	0	395
Geothermal	255	3.027451	7.113481	0	51
Ocean	255	4.670588	7.493391	0	47
Biomass	255	6.631373	11.2224	0	66
Waste	255	13.96863	34.79726	0	242
RES total	255	82.46275	188.3172	0	1141
ENEF	255	29.24706	76.86207	0	564

TABLE 7 – NON NORMALISED OUTPUT DESCRIPTIVES

Variable (logarithmic)	Observations	Mean	Standard deviation	Minimum	Maximum
Wind	255	.8441581	1.944393	0	12.98128
Solar	255	1.129036	2.7952	0	13.93061
Geothermal	255	.1124428	.2533913	0	1.840876
Ocean	255	.1769945	.2670685	0	1.604685
Biomass	255	.2491338	.4017696	0	2.251564
Waste	255	.5081633	1.202617	0	8.332808
RES total	255	3.019928	6.585366	0	39.28816

[60] During the research for energy efficiency classes, the work of Joëlle Noailly, Svetlana Batrakova and Ruslan Lukach, for the CPB Netherlands Bureau for Economic Policy Analysis (September 2008), was brought up. Their study focuses on the impact of environmental policy on energy-efficient innovation in buildings. In their research, they used the IPC classification for energy efficiency from Ecofys.

[61] Ecofys is a consultancy company with several areas of expertise concerning the energy sector, such as RETs, energy in the built environment, innovation in energy systems etc.

ENEF	255	1.047422	2.641172	0	19.42026

TABLE 8 – NORMALISED OUTPUT DESCRIPTIVES

One main finding from the standard deviation of the above tables is that data are overdispersed. Concerning the different RETs, one can observe that most patent counts are measured for solar, wind and waste. This observation can be proven really helpful as the patent applications extracted for energy efficiency belong in wind and waste sectors. This shows that energy efficiency and RETs trends are highly correlated[62].

Another variable is the **R&D expenditures** for different renewable energy technologies and energy efficiency, extracted from the IEA database (IEA, 2008) measured in US dollars (PPP). these data combined with total R&D expenditures created a new measure to depict the intensity rate of R&D expenditures. For the total of RES and energy savings R&D budget, we calculated the intensity rates dividing them by the total governmental R&D expenditures. In spite of the fact that the maximum value of RES R&D intensity is relatively greater than the energy efficiency one, the mean value is the opposite. This means that the average R&D intensity of energy efficiency is greater than the one of RES (EU15 spends on average more on energy efficiency than on RES). RES intensity rate is supposed to have a positive connection to the output, while the energy efficiency rate should have a negative one, as it represents a different technology trend.

Variable (logarithmic)	Observations	Mean	Standard deviation	Minimum	Maximum
Wind	255	.8441581	1.944393	0	12.98128
Solar	255	1.129036	2.7952	0	13.93061
Geothermal	255	.1124428	.2533913	0	1.840876
Ocean	255	.1769945	.2670685	0	1.604685
Biomass	255	.2491338	.4017696	0	2.251564
Waste	255	.5081633	1.202617	0	8.332808
RES total	255	3.019928	6.585366	0	39.28816
ENEF	255	1.047422	2.641172	0	19.42026
RES R&D intensity	245	3.656943	3.016223	0	18.79403
ENEF R&D intensity	245	3.745516	3.847274	0	18.13427

TABLE 9 – R&D FINDINGS DESCRIPTIVES

One more measure of R&D activity refers to the total number of **R&D personnel**, also retrieved from EUROSTAT. The original unit is Full Time Equivalent (FTE). Full-time equivalent (FTE) is a way to measure a worker's involvement in a project, or a student's enrolment at an educational institution[63]. It includes the researchers, the technicians and more supporting staff. These data were normalised to each country’s population, so as to express the percentage of personnel occupied with R&D. Their relation to the output is expected to be positive. The sign of this variable is expected to be positive reflecting that the innovation output is reinforced by the increase of the R&D personnel.

[62] In fact, the ratio of energy efficiency to RETs is almost one third.

[63] An FTE means that the person is equivalent to a full-time worker; while an FTE of 0.5 signals that the worker is only half-time (WIKIPEDIA, 2009). The direct unit is number of persons.

Finally we include the **electricity price**, which has an important effect on the promotion of new energy trends[64]. This variable's data have been divided into two elements: the electricity price for households, the electricity price for industries. Concerning this dataset, instead of using the raw data, that express the electricity price induced innovation, we decided to modify it and use the fraction of energy price in households (electricity) to the energy price in industries (electricity). Thus, instead of price induced, we examine subsidy induced innovation. In households the energy consumption is less than the energy consumption in industry. The price, on the contrary, follows the opposite direction. The proxy representing the ratio is, therefore, a useful instrument for subsidisation. Instead of measuring the effect of each category's price to the output (number of patents) we use a more independent measure which is not affected by currencies, as long as we use the same source, and provides with more eligible data (the fluctuations of prices are smoothened. Data were retrieved from Eurostat database, only for medium size households and industries[65], and defined as the average national price in Euro per kWh without taxes applicable for the first semester of each year. The Eurostat database included prices only from 1998 to 2007. The values were transformed into USD according to PPP values. The definition of this variable is not quite representative. It would be better to have prices for all the examined time period and from large-scale industries and households.

If the electricity ratio augments that means that either the household prices increased or the industry prices decreased. As the households' prices increase innovation output should be increased as well. On the other hand, when industry prices fall innovation output is decreased. Also, we should bear in mind that the sector which mainly influences innovation concerning RES is industry. That means that if the electricity ratio increases that would not necessarily lead to a positive correlation to the output. In the case of renewables, if this ratio increases, either the household price increased, which does not influence the output strongly, either the industry price has fallen which could lead to a negative sign. As shown in scatterplot 13 and 14 (Appendix C), the RES output is negatively connected to the electricity ratio. This explains why the electricity ratio is expected to give a negative sign in the RES regression. This is not the case for the energy efficiency model, where most innovations have been implemented for the household sector (also illustrated in table B.5 (Appendix B)). The sign here is expected to be positive as when the household price increases this suggests a positive effect on the innovation output and when the industry prices fall this could have less effect on the output. The electricity ratio is a very interesting variable as it also defines the sectors of application of the innovation output: the industries for the renewables and the households for the energy efficiency.

The general statistics for the variables above are presented in the following table:

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
R&D personnel	255	2.907949	1.939958	.189571	7.700042
Electricity price ratio	150	1.53933	.287101	.7470199	2.430341

TABLE 10 – THE REST OF COMPLEX VARIABLES STATISTICS

[64] Historically this is shown during the energy crises of the 1970s or the oil price recession during the 1980s.

[65] These data were the only available at that time data for the electricity prices. Medium size industries defined by Eurostat: Consumption band Ic with annual consumption between 500 and 2000MWh. Medium size households defined by Eurostat: Consumption band Dc with annual consumption between 2500 and 5000kWh.

The strong deviations in general variables are expected due to the variance of the EU15 country Members in features such as population.

4.3.3. Policy instruments

The **policy instruments** for both trends have been thoroughly described in the previous chapter. Here, we mention that the unit of measures' evaluation is semi-quantitative, therefore, expressed by the values of {1, 2, 3} depending on the impact of the measure {low, medium, high}. The table below summarises our findings on the policy measures:

Policy Measures	Observations	Mean	Standard deviation	Minimum	Maximum
RES					
Price based	150	1.226667	1.204837	0	3
Financial	150	.1733333	.3798033	0	1
Legislative	150	.34	.6220771	0	3
ENEF					
Price based	255	1.062745	1.533094	0	7
Financial	255	5.113725	5.242806	0	25
Legislative	255	7.823529	5.37604	0	26
Voluntary	255	4.294118	5.216925	0	25

Table 11 – Policy Measures Statistics

The next two tables indicate the evolution of policy measures according to their cumulative impact (added values for each year for all the EU15 countries) through the time period of 1990 to 2006.

As one can observe in figure 18, the measures for RES start only from 1997 and on. Besides the fact that the legislative measures seem to be the ones that have the greatest impact, compared to the other two, there is no clear tendency to increase the effect of the RES policy measures for the examined time period. There seems to be a slight negative slope from 2003 for legislative and financial measures. The price based measures fluctuate between 16 and 20. Here, we should remind that the policy instruments are measured on a semi-quantitative scale {1, 2, 3} relatively to their effect {low, medium, high} and added up when they belong in the same year.

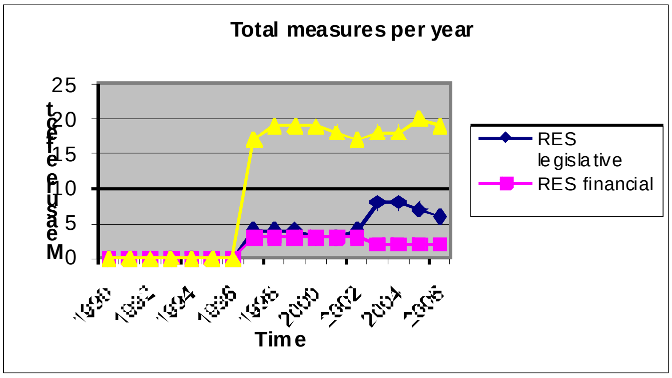

Figure 18 – RES Policy Measures

Data are more refined for energy efficiency due to the integrated database (MURE, 2000). Here, the cumulative prices are higher in their total effect. All four clusters show an upward slope. What is shown from figure 19 is that the cluster most promoted in energy efficiency (legislative) is the least promoted in renewables. The next chapter will confirm whether these relations are interpreted as shown in these figures in the performed regressions.

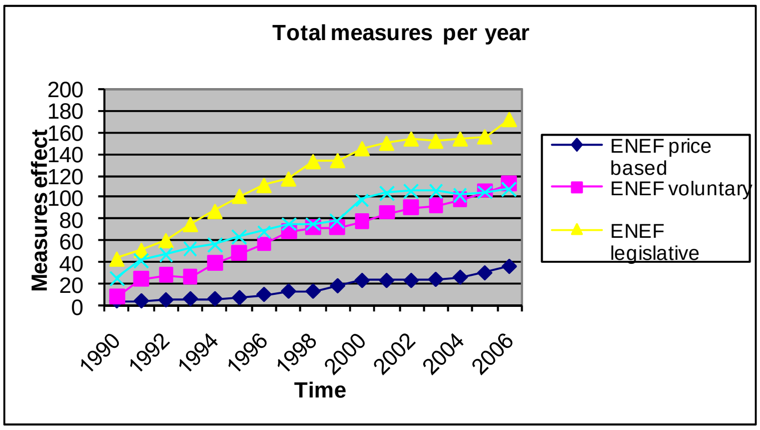

FIGURE 19 – ENEF POLICY MEASURES

4.4. COUNTRIES' PROFILES

This section includes some general information about the countries' tendencies deriving from the dataset.

4.4.1. OUTPUT INDICATIONS

From the following graph, we can observe that, in general, patent counts (normalised by GDP) are higher for solar, wind and waste energy sources. We include the total amount of patent count for RES only to compare it with the share of energy efficiency patent counts. As mentioned before, their ratio is almost three to one.

Each country specialises in different renewable energy sources. That occurs due to the natural conditions and to the fact that the European Commission does not impose specific energy sources as its target (only the percentage of energy stemming from RES)[66]. As we have seen in section 3.3 the countries with the biggest innovative output are Germany, Spain, United Kingdom, France, Denmark and Austria. In this section, we present the sectoral out, i.e. which energy technologies appear to be the most important within each country of EU15. These observations derive from the Stata tables referenced in Appendix D.

[66] One small objection to that is the directive for the promotion of biofuels and other renewable fuels in 2003 in the transportation sector, where 5.75% of the fossil fuels used in the transportation should be replaced by biofuels (by 2010).

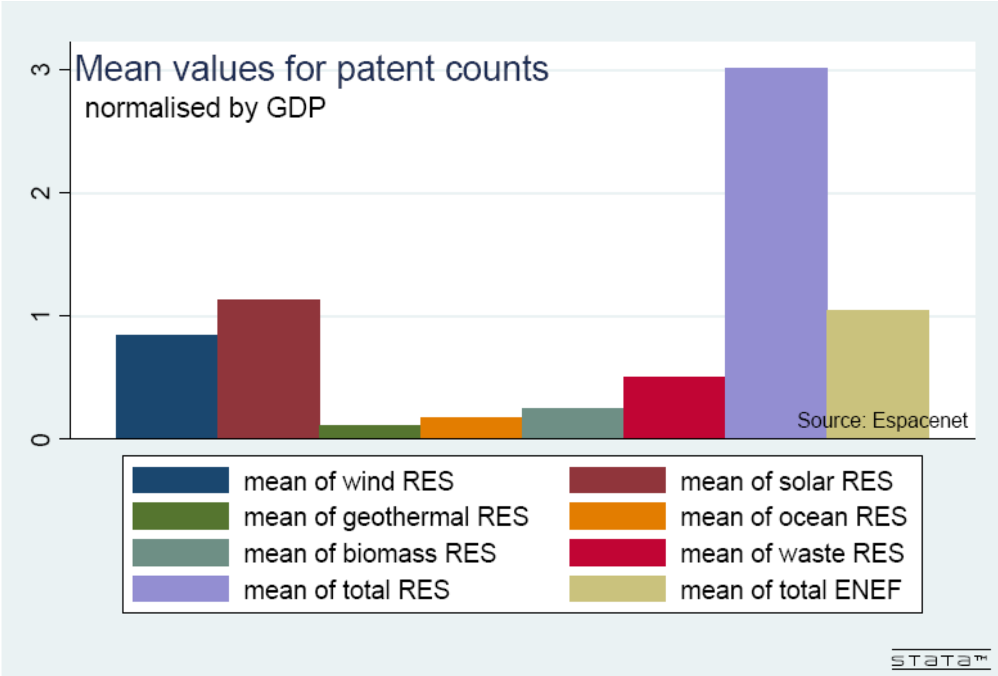

FIGURE 20 – MEAN VALUES FOR PATENT COUNTS

Countries with strong innovation output tend to follow the above graph. This means that all fifteen countries have relatively[67] (to their total) high output results in solar energy, thirteen in wind and seven in waste. Consequently, for the remaining technologies, we have five in biomass, four in ocean and one in geothermal. The table below summarises our findings:

Energy Type per Country															
Solar	AU1	BE2	DK3	FI3	FR1	GE1	GR1	IE3	IT1	LU2	NL1	PT2	SP1	SE1	UK2
Wind	AU2	BE1	DK1	FI2	FR3	GE2	GR2		IT3		NL2	PT1	SP2	SE2	UK1
Ocean							GR3	IE2				PT3			UK3
Waste		BE3	DK2			GE3		IE1	IT2	LU1	NL3				
Biomass	AU3			FI1	FR2					LU3			SP3		
Geothermal														SE3	

TABLE 12 – ENERGY TYPE PER COUNTRY

The table highlights the position of energy type for each country. As an example, Italy's highest output is respectively in solar, waste and wind energy. This conclusion is important for two reasons. At first, we observe which is the most successful (for the period under examination) energy type. Secondly, we notice a tendency to innovate in specific technologies more than others.

4.4.2. POLICY MEASURES

The table below includes the mean values of all semi-quantitative measures (cumulative impact) for both RES and energy efficiency (for the households and industry sectors). From a first glance, one can observe that the values for energy efficiency are far more explicit than those of renewable energy. This happens mainly because the source of information is different and, secondly, because the observations

[67] This assumption derived from the first three numerically innovation output for each country.

for renewable measures do not start until 1995. On the contrary, MURE database for energy efficiency measures offers much more extended load of data.

Besides the differences in the dataset, there are many conclusions to be extracted. For renewable measures, we observed that most measures are of price-based nature mostly implemented in Germany, Denmark, Portugal and Spain. The legislative measures are following, in a much lower level of implementation, with peak countries Sweden, United Kingdom, Ireland and France. Finally, the financial measures seem to be less common as we verify their presence in only three countries (Finland, Netherlands and Sweden). From all countries, only the Netherlands implement all three types of measures. The countries with the largest total impact values are Germany, Denmark, Portugal and Spain. The following figure depicts the difference between the implementation of price based measures, compared to legislative and financial.

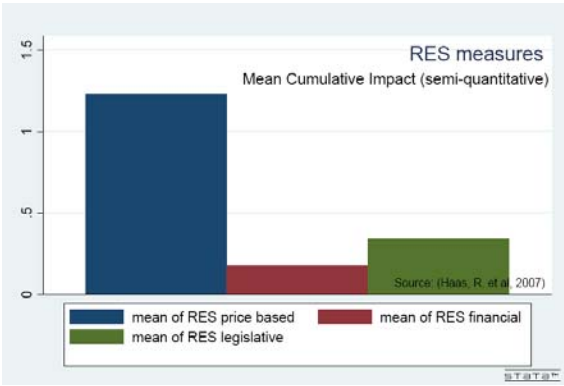

FIGURE 21 – RES MEAN VALUES

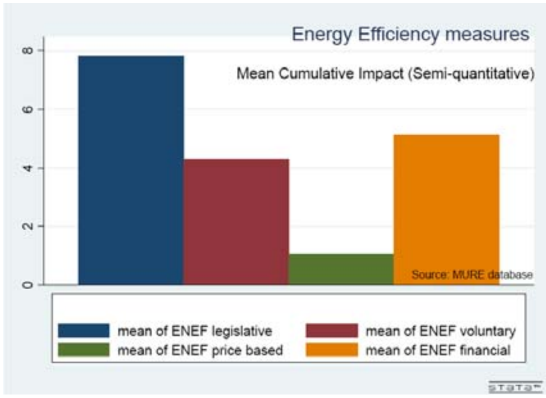

FIGURE 22 – ENERGY EFFICIENCY MEAN VALUES

For energy efficiency we had a larger range of data, as it appears in figure 20. Here most countries implement all types of measures with the exception of Denmark (without price based), Greece (without financial), Ireland (without price based) and Luxembourg (without price based and voluntary). The largest values come from legislative measures, followed by financial, voluntary and, lastly, price based (as shown in the table below).

For legislative, higher observations come from Greece, Germany, Portugal and Spain. For financial measures it is Spain, Germany and Austria. For voluntary measures, it is the Netherlands (with great difference from the others), Finland and Germany. Finally, the strongest results for price based are counted for the Netherlands, France and Austria. The countries demonstrating the stronger impact rate are: Austria, Germany, Netherlands and Spain.

What is the most impressive finding from this comparison is that different energy trends use different policy instruments so as to be promoted. For RES the price based measures have the highest rating. On the contrary, for energy efficiency, price based measures have the smallest rating. The opposite happens for legislative measures. This observation is quite important as it could lead to the promotion of one energy trend towards another. If more price based measures were to be designed, with parallel decrease of other types of measures, then it could be possible that renewable energy could be adopted more easily. Of course, in order to establish that kind of remark we should study in further not only the presence of measures but also their relationship to the innovation output. This step takes place in the regression analysis phase.

4.4.3. OTHER COUNTRIES' INDICATORS

Energy Consumption: most countries have shown a stable consumption rate for the period of 1990 to 2006. The ones that increased their energy consumption are Denmark, Finland, Sweden and France (from the high consuming countries[68]). On the other hand, countries that decreased their consumption are Spain, Ireland and from the high consumers Germany and United Kingdom. Especially for the United Kingdom, we should notice that the consumption curve is negatively parabolic.

Electricity ratio: as mentioned before, this ratio serves as an energy price subsidy and is expressed as the ratio of electricity price in households to electricity price in industry. In the graph, as shown below, this ratio is defined from 1997 to 2006 and has, in general, either a constant or descending slope. Only few countries show a minor increase of the ratio (Ireland, Denmark, Luxembourg and France). This subsidisation focuses on the effect of industry electricity prices on the residential ones. That occurs due to the fact that industries consume a larger share of electricity and "define" the energy market trends. Also, it is well known that the energy prices for industry are, in most cases, significantly smaller than those of households. Only for the case of Belgium and Greece the ratios have been close to one, equalising the prices of households and industries. For most countries the ratio fluctuates between 1.2 and 1.8. Finally, for the cases of Italy and Sweden, the ratio reaches its highest level (more than 2) which indicates the different policies followed for the two sectors. Even for these cases, the prices tend to fall within the limits of the rest of the countries. This difference shows that policies implemented in the industry sector tend to have a greater effect on the quantity and the type of energy used, influencing both energy security and pollution abatement issues. Therefore, industries play a strong role in the definition and implementation of energy trends, which creates a paradox, as most policies, until now, have been designed for the residential sector.

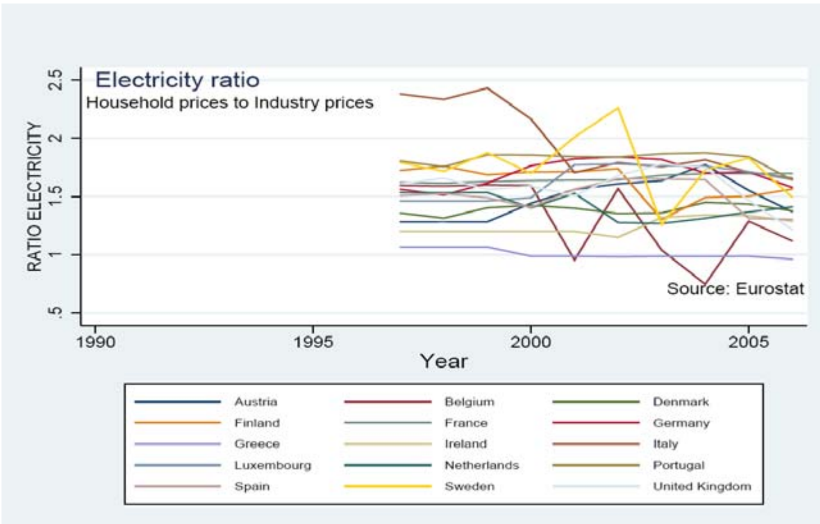

FIGURE 23 – ELECTRICITY RATIO

68 For reasons of clearer results depiction, we divided the countries into those that consume more than 5000 TOE and less. The ones with higher consumption are named high consuming countries.

Openness: as mentioned before, openness indicates the international trade and investment tendency. All country curves have upward slopes. Most countries fluctuate between 50 and 100, with the exception of Luxembourg (with values between 200 and 300), Belgium, Ireland and the Netherlands (with values more than 100). As the measure expresses the exports and imports, it acts as a substitute for private R&D funding. The upward slope indicates that these values constantly increase, thus, the investment increases as well. This measure may produce conflicting results in the empirical analysis as it might not lead to positive innovation output due to the fact that it represents the private funding. Private funding is not necessarily established by a patent application for each innovative activity. Instead, due to reasons such as secrecy (explained in Chapter 2), private firms tend to use other methods of intellectual property protection rather than patenting their products. This conclusion does not affect the present research, which bases its input on public generated variables.

R&D personnel: R&D personnel variable is measured by full time equivalent (for scientists and engineers in all sectors) expressing the labour resources for innovation. As it is depicted in figure S (Appendix R) the Nordic countries have the greatest values and slopes, surpassing 4 FTE, where Mediterranean countries have the smallest values and slopes (from 0 to 1 FTE). The rest of the countries vary between 1 and 3 FTE. In the case of Luxembourg, the result is so extreme due to the normalisation of the variable per country's population.

After presenting the general tendencies of the variables, we proceed with the empirical analysis of the dataset. The next section describes the methods we use in order to evaluate the data and come up to conclusions about the connection of input to output variables.

CHAPTER 5
EMPIRICAL ANALYSIS

5.1. INTRODUCTION

The empirical analysis of the model is necessary in order to define original correlation and proceed, if necessary, to data treatment in order to come up to more representative results. Different kinds of set regressions were performed for that case. We divided the testing sets into three categories:

- Correlations, where the correlations between the output and the general variables are examined, overall, per energy trend.
- Regressions for the policy measures, where the relations between the renewable energy policy clusters and the energy technologies are examined, overall, per technology.
- Then, the effect of energy efficiency on renewable energy is examined through regression analysis with all policy measures involved overall and per renewable energy technology.

The model is modified so as to provide the best possible results. Logarithmic transformation is one of the variables modifications in order to smooth the dataset and still maintain the data characteristics. The chapter is divided in the same order of data treatment. First, we refer to all data changes necessary to run the regression models. The next step is to choose an appropriate regression method. Then, we present the correlation results for the variables and their explanation. Finally, we perform several tests in order to show the robustness of the model.

The aim of this chapter is to provide the coefficients that influence the output innovation, thus, the patent counts for RES and energy efficiency, and their degree of significance.

5.2. NORMALISATION

As mentioned in the previous section, data were not used exactly in the form they were retrieved. The first step was data normalisation according to auxiliary variables such as real GDP per capita or total number of R&D expenditures. Instead of using the exact count of patent applications, we decided to normalise it according to GDP so as to get better-fitting measurements. In that way, we include each country's economic performance and population in the output. Other ways of normalisation such as overall number of patent counts or population have been rejected as they did not accurately depict the relation between the innovation output and the country[69].

The second step was the logarithmic transformation for some variables explained in the next section. As expected, data were not uniformly distributed. In fact, the dispersion rates were quite large. For that reason, we decided to proceed with a logarithmic transformation in order to flatten the differences between data values. This change was made on natural logarithmic basis. The transformation results and the relation of the main variables to the output are presented in Appendix C (Part II).

5.3. METHOD OF ANALYSIS

[69] As an example we could mention that the output has reached high levels for countries, such as Ireland, with small innovation activity because in the normalisation process their data were boosted. Another example is that countries, such as Germany, because of increased innovation activity in all sectors, were degraded due to unsuccessful normalisation.

All datasets mentioned in the previous section were collected in excel files, where they were treated in terms of normalisation. Data analysis though was performed in Stata, a program specialised in regression analysis. The aim of the regression analysis is to model the dependent variable Y (in our case the patent counts) as the estimate of the outcome of explanatory variables Xj, where j is the number of input variables, j =1, ..., n.

At first, we have to analyse the data taking into account their specific nature (count data). Then, we define the method of regression and perform different kinds of tests for different sets of variables. According to these preliminary results, data are, in further, treated so as to depict better the relations between the variables. The results of the regression analysis are explained in the next section.

5.3.1. Data nature

The variables set up a multi-dimensional dataset as it describes the trends for specific countries in a specific time period. The output could be generally expressed as:

$$y(i,t) = \beta_1 x_1(i,t) + \beta_2 x_2(i,t) + ... + \beta_N x_N(i,t) + a(i) + \varepsilon(i,t) \quad \text{(Equation 5.1)}$$

Where $i, i = 1,...,15$ represents the cross-sectional unit, i.e. the country (the fifteen members of the European Union) and $t, t = 1990,...,2006$, represents the timeframe of the model's simulation. β Values reflect the correlation factors of the regression analysis (for given i, t) where x are the model variables (such as policy measures or energy prices) for given i, t. Finally, two more factors are included: the fixed effects (for heterogeneity capture) $a(i)$ and the residual variation $\varepsilon(i,t)$.

From this equation, it becomes obvious that we work with cross-sectional data over time series. This kind of representation is called "panel data". In our case, panel data are also balanced as they are retrieved for the exact time period of [1990, 2006]. Before proceeding in further analysis, we enlist some characteristics of panel data, their benefits and their limitations.

The main characteristics of panel data are that they analyse a large number of elements for a usually small period of time. Data are often not independent due to common features of the variables and the effects of strong elements to others during time. Benefits and limitations were recovered from (Baltagi, 2005). In benefits, Baltagi lists the ability to control heterogeneity, the fact that the data are more informative with more variability and less collinearity, more degrees of freedom and more efficiency in studying the dynamics of a system, the feature of identification of effects not detectable in other types of analyses, and in general, testing of more complicated systems. Finally, biases resulting from aggregation may be reduced or eliminated. In limitations, Baltagi reports some design and data collection problems, which we have faced due to incomplete sample of data in some cases, distortion of measurements and selectivity problems, which refer to faulty hypotheses, short time-series, which do not cover the system trends in a satisfactory way and, finally, possible cross-country dependencies. In our case, we should also include that the output variable is numeric, and in the form of counts and over-dispersed, meaning that the variance of the variables is quite large.

In view of the above features, we create specific regression analysis model paying attention to the residuals and heterogeneity effects. The next section presents the basis for regression analysis of the present model.

5.3.2. Regression analysis of Data

The particularity of the dataset obtained for this research is that it is in form of cross-sectional count data, as mentioned above. This actually means that the dependent variable (y) is non-negative count analysed with a set of independent variables (covariates x). Cross-section data usually use the Poisson distribution function for regression. Poisson regression has the limitation that is often too restrictive often because the distribution is parameterised in terms of the singe parameter μ[70] implying that all values of the dependent variable are a function of μ (since the distribution mean is equal to the deviation, equal to μ). Also, in case of overdispersion[71], the Poisson regression is too limited to analyse the dataset.

To sum up, the Poisson distribution has been disqualified because of its inability to specify correctly the rate parameter (due to unobserved heterogeneity) or because of failure of the assumption that events are independent (Cameron & Trivedi, 1999).

Due to the dataset's nature, we decided to proceed by applying three different methods. The first is by changing the base of data and transforming them into their natural logarithmic values. This transformation is used so that the characteristics of data remain the same, but in the same time they are smoothened. Following this method the kind of regression remains the same: linear where the optimal function is retrieved by ordinary least squares (OLS) method.

The second approach is by using general least squares method (GLS) for panel data. This method takes into account the particularity of the dataset by redefining them according to the country and year values. Here, we use the logarithmically transformed dataset, as in the OLS method. The GLS method is an extension of the previous OLS technique and, because of its general form it is used to handle possible heteroscedasticity or correlation effects. Also, the GLS method is used to take advantage of the structure of the dataset (panel data). Both methods estimate the parameters using the least squares method (for the residuals).

During the statistical analysis there were mainly two problems that came by: the multicollinearity and the heteroscedasticity. Multicollinearity is used to describe the condition when a linear approach fails to approximate reliably the regression estimates (Verbreek, 2004). The multicollinearity aspect is captured in the $\varepsilon(i,t)$ term of equation 5.1. Heteroscedasticity is the condition when the variance of the error produced in the regression depends on the regressors (variance is not constant). In order to avoid heteroscedasticity, we use the logarithmic form of the dependent variable.

5.4. Correlations

After defining our datasets, we need to investigate the correlations between the variables. The correlations show the measures the degree of association between two variables. If there is a strong dependency (positive or negative) the correlation coefficient tends to be closer to +/- 1. The correlation results show small correlation between the variables (Appendix E).

For general variables, the output (RES patent counts fixed) is mostly correlated positively to energy consumption (with correlation coefficient equal to 0.5065) and negatively to intensity of energy efficiency R&D rate (with correlation coefficient equal to -0.4459). In the negative correlations we encounter the

[70] The variable μ declares the intensity or rate parameter of the Poisson probability distribution.
[71] Overdispersion means that the variance var(Y) > μ (instead of equality called as equidispersion in Poisson models).

gas ratio (with value equal to -0.0222), openness (with value -0.3385) and intensity of RES R&D rate (with value -0.0267). Positively correlated are the electricity ratio (with value -0.0550), total R&D (with value 0.3385) and total R&D personnel (with value 0.1087). Due to its negative correlation to the output the gas ratio was dropped from the independent variable set.

For the policy measures, the output is highly correlated to energy efficiency financial measures (with value 0.6703) and RES price based measures (with value 0.5489). We observe a weak negative correlation for RES financial (including taxes separately) and legislative measures. This can be explained due to partial lack of observations. Even though the values are very small, the tendency to decrease innovation by using financial or legislative measures is clear. The correlations to energy efficiency measures are all positive, and in most cases weak (except the one mentioned above). This fact is explained through the high correlation of RES and energy efficiency trends. As a large part of the output for RES belongs also to the output of energy efficiency, it would be inevitable to have a positive relationship, unless the measures had a negative effect on both technologies (like the taxation for RES).

5.5. Regression results

This section is divided as follows: at first we perform regressions and create a comparative table concluding in the validity of our variables for OLS (Ordinal least squares) and GLS (General least squares) for renewables (we perform the same models for energy efficiency in the third part). We also perform sectoral analysis and an exploration of the Lock-in effect.

5.5.1. OLS and GLS results

The first regressions are calculated with the OLS and GLS methods. At first, we present the general results and then, the results for each energy trend. The general equation 5.1 is transformed in order to capture the results:

$$\begin{aligned} &\ln a(PatentCountsENEF/GDP)_{i,t} = \\ &\beta_{1(i,t)}\ln(ENEF\,intensity) + \beta_{2(i,t)}\ln(openness) + \\ &+\beta_{3(i,t)}\ln(RatioElectricity) + \beta_{4(i,t)}\ln(R\&Dpersonnel) + \\ &+\beta_{5(i,t)}\ln(GDP) + \beta_{6(i,t)}\ln(EnergyConsumption) + \\ &+\beta_{7(i,t)}\ln(EPOpatents) + \sum_{j=1}^{4}\beta_{j(i,t)}PolicyCluster_j + ConstantCoeff \end{aligned}$$

(Equation 5.2a)

, where $\beta_{(i,t)}$ are the coefficients from the OLS regression analysis. The equation is modified for specific energy types, such as wind, solar, biomass etc. The formula calculates the natural logarithm of patent counts for RES per GDP multiplied by a coefficient a. This coefficient in our case is one thousand and indicates the number of thousand patents per GDP[72]. The same treatment was performed for RES intensity variable. The RES intensity is actually given by the formula: $RES\,intensity = a(R\&D\,expendituresRES / OverallR\&D\,expenditures)$, where a is also one thousand and denotes the R&D intensity for RES per thousand (million) USD. One more treatment happened for the R&D personnel, which was normalised per population, thus, providing the

[72] When we use GDP in the regressions, it is always assumed as Real GDP per capita

formula $R\&Dpersonnel = a(FTE / population)$. Here, we include a again, as the population in measured in millions. We also include the constant coefficient (corrective term) of the regression function. The equation, in its final form is as follows:

$$
\begin{aligned}
&\ln a(PatentCountsRES / GDP)_{i,t} = \\
&\beta_{1(i,t)} \ln(RES\,intensity) + \beta_{2(i,t)} \ln(openness) + \\
&+\beta_{3(i,t)} \ln(RatioElectricity) + \beta_{4(i,t)} \ln(R\&Dpersonnel) + \\
&+\beta_{5(i,t)} \ln(GDP) + \beta_{6(i,t)} \ln(EnergyConsumption) + \\
&+\beta_{7(i,t)} \ln(EPOpatents) + \sum_{j=1}^{3} \beta_{j(i,t)} PolicyCluster_j + ConstantCoeff + 3\ln 10(\beta_{1(i,t)} + \beta_{4(i,t)} - 1)
\end{aligned}
$$

Equation 5.2b

In the case of energy efficiency, the equation switches to ENEF intensity and ENEF Policy measures as shown below:

$$
\begin{aligned}
&\ln(PatentCountsENEF / GDP)_{i,t} = \\
&+\beta_{1(i,t)} \ln(ENEF\,intensity) + \beta_{2(i,t)} \ln(openness) + \\
&+\beta_{3(i,t)} \ln(RatioElectricity) + \beta_{4(i,t)} \ln(R\&Dpersonnel) + \\
&+\beta_{5(i,t)} \ln(GDP) + \beta_{6(i,t)} \ln(EnergyConsumption) + \\
&+\beta_{7(i,t)} \ln(EPOpatents) + \sum_{j=1}^{4} \beta_{j(i,t)} PolicyCluster_j + ConstantCoeff + 3\ln 10(\beta_{1(i,t)} + \beta_{4(i,t)} - 1)
\end{aligned}
$$

(Equation 5.3)

The normalisation coefficients are the same as the ones in renewables giving the extra term. One should notice that the sum of policy clusters is increased by one more term, as the clusters in the energy efficiency case are four instead of three in the renewables. We present the regression coefficients for these two methods together in order to compare the results. The two methods use the same estimation method, which makes feasible their comparison.

A. Total RES results

Here, we use logarithmic values of all variables but the policy measures. The dependent variable is the natural logarithm of patent counts, normalised per real GDP per capita. The input variables are, the energy intensity, openness, energy consumption, electricity ratio, R&D personnel (all logarithmic), and from the policy measures: the price-based, financial and legislative for RES. The following table summarises[73] the results (coefficients and standard errors) of the stepwise regression analysis:

Dependent variable: (LN patent counts/ GDP)	**Dependent variable: LN RES patent counts/ GDP)**
Number of Observations: 137	**Number of Observations**: (119/ 208)

[73] The complete regression tables are found in the Appendix E. The significance of coefficients for the tables (like the above) as represented by stars as follows: *** for p-value <.05
** for p-value <.01 and
* for p-value <.001

Independent variables	Regression (coeff/ sterror)	Stepwise regression (coeff/ sterror)
LN intensity RES	0.087 (0.09)	
LN openness	-0.519 (0.29)	
LN energy consumption	0.606*** (0.07)	0.696*** (0.04)
LN ratio electricity	-0.246 (0.42)	
LN R&D personnel	0.312 (0.21)	
RES price based	0.656*** (0.10)	0.677*** (0.06)
RES financial	-0.207 (0.38)	
RES legislative	-0.284 (0.17)	-0.279* (0.13)
Constant	2.360 (6.19)	-7.563*** (0.39)
R2	0.737	0.722

TABLE 13 – OLS RESULTS FOR RES

Independent variables	Regression (coeff/ st error)	Stepwise regression (coeff/ st error)
LN intensity RES	1.075*** (0.017)	1.028*** (0.014)
LN openness	0.851*** (0.106)	0.825*** (0.053)
LN energy consumption	0.488*** (0.069)	0.306*** (0.045)
LN ratio electricity	-0.189* (0.089)	
LN R&D personnel	0.602*** (0.053)	0.631*** (0.038)
RES price based	0.035 (0.029)	
RES financial	0.081 (0.109)	
RES legislative	0.022 (0.032)	
Constant	-7.448*** (0.828)	-5.587*** (0.515)
N	119	208
Wald chi2	4573.461	6148.360
Prob> chi2	0.0000	0.0000

TABLE 14 – GSL RESULTS FOR RES

The second column of each table (13 and 14) presents the results from the first regression and the third, the results from the stepwise regression (with p <.05). We estimate also for the OLS and GLS regressions to define the most significant regressors. We should notice that for OLS we use robust standard errors (in order to avoid heteroscedasticity) and for the GLS regression we use fixed effects (to eliminate omitted variable bias from time-invariant unobservable factors).

From the first regression, we observe that the most significant contributors to the model are the energy consumption and the RES price based measures (with p<.001). The results of the stepwise regression are quite similar. The only difference is that instead of R&D personnel the significant regressor becomes the RES legislative measures. Although the model is not strongly explained (with R2 = 0.737), its results seem quite robust, as they also follow the correlation results. What is really interesting is the positive effect of price based measures on the output and the negative effects of both financial (minor) and legislative measures.

The model considers the R&D intensity, electricity ratio and openness to be non-significant variables. That is one reason why we investigate the model with GLS analysis as well. Therefore, the model does not provide with significant results on the general variables, but it gives a clear picture about the effects of the policy clusters. Compared to the results of Johnstone et al. (2008), as an indication, the results relate as follows. Johnstone et al. indicate three policy clusters, using binary variables. The first cluster includes the price based measures, the second the voluntary and the third the legislative ones. Their study indicates that legislative and price based measures are within 1% statistical significance and they both have a positive effect on the output. On the contrary the results indicate poor performance for the voluntary measures. For the remaining model, Johnstone et al. use the variables of electricity price, R&D expenditures, electricity consumption and total EPO filings.

Due to the different clusters and variables definitions used in their model, the comparison is done only for explanatory and similarity reasons. We should emphasize on the differences in order to show that the comparison is not exact. On the contrary, we use these measurements as simple indicators, without influencing our model's conclusions. Therefore, Johnstone's et al. research takes into account also United States and Japan omitting countries such as Ireland, Luxembourg etc. Also, the time period examined is 1978 to 2003. Finally, the defined variables are not the same (their model uses a smaller number of variables and variables such as R&D expenditures are accounted differently in our model). Nevertheless, their method and basic elements are quite similar to the ones used in the present study. Thus, we use their results only as a reference point to our study.

The main difference in the policy measures between (Johnstone et al., 2008) and here is that all policy clusters have positive effect on the output of the model. Here, on the contrary only price based are positively connected to the output. Both legislative and financial have a negative effect.

Table 13 enlists the results for the GLS regression (general and stepwise). GLS results are more robust than OLS results as they take into account that the dataset is designed for panel data. This method works impressively for the general variables but it degrades the policy coefficients. This method fails to explain the policy measures affiliation to the output.

As the table denotes the most important variables are the RES intensity, the electricity consumption, the openness to international trade and the R&D personnel. It is impressive how the R&D intensity affects the model. Also, we should note the great difference for the openness variable compared to the correlation matrix, which constitutes it a non valid parameter, as its effect is major in this model. As expected, the signs of the variables function accordingly to our description in the previous chapter. Both our R&D measures (R&D intensity and R&D personnel) have a strong positive effect on the model (in the case of R&D intensity the effect is more than one unit of output). This means that R&D is a successful mean in RES promotion. In Johnstone et al. (2008), their result for R&D expenditures is relatively the same. Openness seems to have also a great influence on the patenting activity. This shows that international trade and investment induce innovation as well. The energy consumption is one more factor to affect positively the output as expected (almost half a unit of output increase). Finally, the electricity ratio behaved as described in the previous chapter. The sign of this variable is negative. This means that the more the price ratio raises the less output is produced or vice versa.

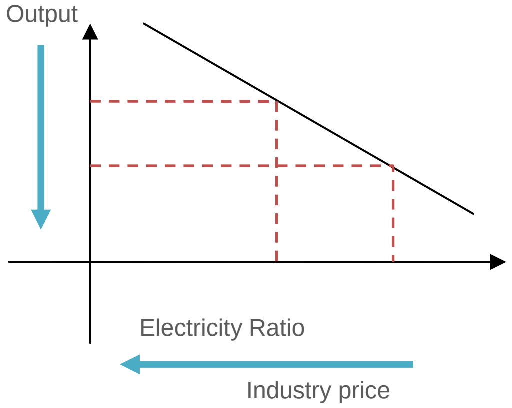

FIGURE 24 – ELECTRICITY RATIO REGRESSOR

If the industry electricity price increases, the electricity ratio decreases, which leads to an increase of output. The industry will focus on innovation. On the contrary, if the household price increases, the ratio increases, thus the output decreases. This can be explained as households could turn to more energy saving techniques using existing technologies, instead of promoting RETs.

The effect is similarly explained if the industry price decreases. Then, the ratio increases and the innovation output decreases (as expected).

The complete regression tables can be found in Appendix E.

B. SECTORAL REGRESSIONS

By the term sectoral regression, we refer to all regression performed per different renewable energy source. The table below includes the coefficient and t-statistics of all the regressions performed for each renewable type.

Dependent variable: LN patent counts(RES type) / GDP)						
Number of Observations:						
Independent variables	**Solar (coeff/ t)**	**Wind (coeff/ t)**	**Biomass (coeff/ t)**	**Waste (coeff/ t)**	**Ocean (coeff/ t)**	**Geothermal (coeff/ t)**
LN R&D RES	0.164* (2.19)	-0.053 (-0.51)	0.220* (2.52)	0.061* (2.47)	0.084 (0.61)	-0.073 (-0.70)
LN energy consumption	0.506*** (4.18)	0.686*** (5.53)	0.116 (1.34)	0.381*** (3.93)	0.747 (1.73)	0.587 (2.00)
LN ratio electricity	-0.481 (-0.58)	0.318 (0.38)	-0.057 (-0.08)	0.021 (0.04)	0.059 (0.06)	-0.957 (-0.71)
LN openness	0.245 (0.58)	0.135 (0.28)	-1.531*** (-5.35)	-0.121 (-0.36)	1.487 (0.81)	0.769 (0.84)
LN R&D personnel	0.134 (0.78)	0.304* (2.14)	0.472** (2.96)	0.305* (2.13)	-0.937 (-1.51)	1.135* (2.39)
RES price based	0.520*** (3.75)	0.839*** (5.85)	0.274 (2.44)	0.479*** (4.84)	0.238 (1.13)	0.490 (1.87)
RES financial	-0.436 (-1.08)	0.249 (0.58)	-1.393*** (-3.95)	-0.759* (-2.44)	-1.346 (-1.45)	-0.606 (-0.79)
RES legislative	-0.503* (-2.55)	0.044 (0.23)	-0.774*** (-5.37)	-0.458** (-2.79)	-0.287 (-1.33)	-0.523 (-1.93)
Constant	-7.622 (-2.89)	-9.969*** (-3.74)	2.972 (1.49)	-5.671** (-2.77)	-15.207 (-1.27)	-12.650 (-1.97)
R2	0.591	0.680	0.658	0.670	0.511	0.730

TABLE 15 – OLS REGRESSIONS PER RENEWABLE ENERGY TYPE

As far as table 13 shows, the results for each renewable type separately are not that robust (the coefficient of determination is not very high[74], especially for solar and ocean types). In spite of that fact, we can still observe some features, concerning the policy measures and the general variables. Similarly to the general OLS model, the energy consumption and the price based measures are the most significant coefficients (for solar, wind and waste[75]). Besides these two variables, the R&D personnel variable also produces some robust results, positive in all cases but the ocean. More specifically for the policy instruments, the financial and legislative are negative, as expected from the correlation table, for all cases but the wind. Ambiguous results are produced for some general variables (such as openness and electricity ratio). This fact affirms the uncertainty of the regression. Finally, the R&D expenditures for each sector provide different results: in most types of energy, the results are positive and quite robust (like solar and waste). Only for the cases of wind and geothermal, the R&D expenditures come up with a negative, but minor, coefficient.

From table 15, one can observe that the variables do not share the same level of significance for all renewable energy types. As an example of minor correlation, we can demonstrate the results for ocean and geothermal types, which also, as shown in table 11, show a minor significance for each country's innovation output. Thus, this result was expected. What is impressive is the relation of variables to biomass and waste types. These two trends are connected to most of the examined variables (with the exception of electricity ratio). Concerning the policy measures, the different types show a relatively uniform behaviour: the price based are everywhere positive and the financial and legislative are almost everywhere negative (except from the wind type) showing accordance to the general model.

Due to the weakness of the sectoral regressions, the stepwise regression analyses have not produced any further explanatory data. That is why we decided to omit its presentation, as all possible information could be driven from the general OLS regression.

C. ENERGY EFFICIENCY REGRESSIONS

Differently to the above regressions, energy efficiency model has two interesting characteristics: the output, which is a part defined from the RES output set and the different policy measures, extracted from the MURE database. From the equation 5.3, we get the coefficients for this regression, as shown in the table below:

[74] The R-squared value increases by the use of an additional "dummy" variable for each energy type defined as Energy_type_dummy = (LN(Energy_type_patent_counts)/LN(Overall_patent_counts))* LN(R&D_intensity). The variables which have a strong impact are the same as in the above model, and their values do not differentiate significantly.

[75] The observations for waste R&D expenditures were not sufficient. Thus, we used an alternative measure. From the patent observations, we created the ratio of patent counts (waste) to patent counts (overall). Then, we multiplied that ratio with the total R&D expenditures for RES and came up with the R&D expenditures for waste. This measure is considered to be temporary and has been used only for this type of regression.

Dependent variable: LN patent counts(Energy efficiency) / GDP) Number of Observations: 137		
Independent variables	**Regression (coeff/ sterror)**	**Regression Stepwise (coeff/ sterror)**
LN R&D intensity ENEF	-0.105 (0.058)	-0.164** (0.049)
LN energy consumption	0.164 (0.091)	
LN ratio electricity	1.140** (0.362)	1.216*** (0.348)
LN openness	0.125 (0.287)	
LN R&D personnel	0.637*** (0.142)	0.668*** (0.117)
ENEF legislative	0.171*** (0.019)	0.164*** (0.019)
ENEF voluntary	-0.002 (0.014)	
ENEF price based	-0.061 (0.047)	
ENEF financial	0.138*** (0.013)	0.140*** (0.013)
Constant	-6.433** (1.951)	-4.369*** (0.331)
R2	0.788	0.779

TABLE 6 – ENEF OLS REGRESSIONS

Dependent variable: LN ENEF patent counts per GDP		
Independent variables	**Regression (coeff/ st error)**	**Stepwise regression (coeff/ st error)**
LN intensity ENEF	0.024 (0.080)	
LN energy consumption	0.523** (0.191)	0.402*** (0.091)
LN ratio electricity	0.627 (0.505)	
LN openness	0.525 (0.553)	
LN R&D personnel	0.573* (0.238)	0.336** (0.124)
ENEF legislative	0.193*** (0.031)	0.092*** (0.015)
ENEF voluntary	-0.007 (0.025)	
ENEF price based	-0.066 (0.065)	
ENEF financial	0.078** (0.025)	0.070*** (0.017)
Constant	-11.422** (3.669)	-6.487*** (0.898)
N	126	211
Wald chi2	104.20	161.69
Prob> chi2	0.0000	0.0000

TABLE 7 – GLS ENEF GENERAL RESULTS

An interesting finding, occurring from this regression analysis, is the calculated coefficients' values. The electricity ratio becomes an important variable, which is highly expected, as the energy efficiency trend is directly correlated to the energy price. Also the sign, here, is positive. This difference in the results with RETs leads to a very interesting conclusion. The energy trends are oppositely affected by the electricity ratio, following the expectation of the previous chapter. Indeed, in energy efficiency, if household prices increase, increasing the ratio, households turn to energy saving techniques in order to minimise their electricity cost. On the other hand, as the industry price increases, the energy efficiency innovation output decreases. An explanation to that could be that industries do not use extensively energy saving techniques. This can be illustrated also by the great difference between the policy instruments for energy efficiency implemented for households to industries. Therefore, the electricity ratio variable shows that different energy trends could affect different sectors. Energy efficiency seems to focus on households, while renewable energy to industry.

R&D personnel, also, has a positive impact on the model, as expected. On the contrary R&D intensity seems to play a minor part in the model. This could be interpreted as a possible weakness of energy efficiency trend to absorb efficiently the budget which corresponds to it. Openness seems to be a minor part of the model. As expected, energy consumption had, once again a positive sign.

The most important finding is the policy measures evaluation. Policy instruments seem to work opposite to the ones of renewable energy. There, price based instruments were the most indicative ones. Here, price based with voluntary measures have a minor impact. The policy instruments adopted by energy efficiency seem to be the legislative and financial ones.. Since the sources of data acquisition for RES and ENEF measures have not been the same, we should not jump into the conclusion that a shifting from one technology to another can be provoked by changing the policy instruments. Despite that fact, the intense differences in policy preferences could be indicative to the policy design for promotion of RETs. In the case of energy efficiency, the two models seem to give similar results, with the exception of R&D intensity. Also, the electricity ratio turns from a very significant variable to a less important one.

5.5.2. Lock-in exploration

According to the updated framework definition, there is a clear connection of the two trends we examine (as demonstrated in the output). In order to test that idea, and whether it is valid, we decided to use all the policy instruments and check the output of the model. We already know, from figures 16 and 17 that the innovation output is not as great as it should be taking into consideration all the R&D activities and policy measures in action. Most countries show a negative slope of progress, including most innovative ones, such as Germany.

The idea tested is whether the energy efficiency trend influences the output of the REIS model. For that and taking in mind that the output includes both energy efficiency and RES, we create a new variable which is the subtraction of LN RES patent counts per GDP and ENEF patent counts per GDP whose attributes are shown in the table below:

Variable	Observations	Mean	Standard deviation
varlockin	211	1.233544	.5453796

Table 8 – New output: varlockin

The idea of testing comes as follows. Since there is a percentage of a patent count shared for the two energy trends, we should investigate the following cases: the cases that all shared patent counts belong to the RETs and the case they all belong to energy savings. In that way, we fragment the shared set. The table below includes the results for these regression analyses for an OLS and a GLS run. This model is also interesting because it combines the policy clusters for both trends. What is expected from the model is that for the first regression, the RES policy clusters have positive values, where the ENEf clusters

Dependent variable: LN RES patent counts per GDP			Dependent variable: varlockin	
	OLS regression	GLS regression	OLS regression	GLS regression
Variables	Coefficient/ standard	Coefficient/ standard error	Coefficient/ standard	Coefficient/ standard error

	error		error	
ENEF legislative	0.078** (0.025)	0.078** (0.025)	-0.022 (0.014)	-0.022 (0.014)
ENEF voluntary	-0.002 (0.019)	-0.002 (0.019)	-0.012 (0.011)	-0.012 (0.011)
ENEF price based	0.065 (0.050)	0.065 (0.050)	0.082** (0.025)	0.082** (0.025)
ENEF financial	0.094*** (0.020)	0.094*** (0.020)	-0.004 (0.010)	-0.004 (0.010)
RES price based	0.182 (0.110)	0.182 (0.110)	-0.107 (0.057)	-0.107 (0.057)
RES financial	-0.337 (0.316)	-0.337 (0.316)	-0.271 (0.194)	-0.271 (0.194)
RES legislative	-0.438** (0.141)	-0.438** (0.141)	-0.248** (0.074)	-0.248** (0.074)
LN R&D intensity RES	0.072 (0.113)	0.072 (0.113)	-0.107* (0.050)	-0.107* (0.050)
LN R&D intensity ENEF	-0.075 (0.085)	-0.075 (0.085)	0.164*** (0.036)	0.164*** (0.036)
LN energy consumption	0.248** (0.094)	0.248** (0.094)	-0.017 (0.049)	-0.017 (0.049)
LN ratio electricity	0.433 (0.402)	0.433 (0.402)	-0.426 (0.284)	-0.426 (0.284)
LN openness	-0.791** (0.288)	-0.791** (0.288)	-0.925*** (0.166)	-0.925*** (0.166)
LN R&D personnel	0.563*** (0.149)	0.563*** (0.149)	0.014 (0.074)	0.014 (0.074)
Constant	-1.079 (1.950)	-1.079 (1.950)	5.891*** (1.060)	5.891*** (1.060)
R-squared	0.7843	0.7843	0.4377	0.4377

TABLE 20 – LOCK-IN TEST

The first remark is that there is no explanatory power for the model in case we use valrockin instead of LN RES patent counts per GDP. Thus, in case all shared patent counts belong to energy efficiency, we cannot give clear conclusions of the input-output relation. In case all patent counts go to the renewable energy the model is clearly more robust (R-squared is equal to 0.7843). What we expect from the energy efficiency measures is not to affect the output at all (or in a minor way) as they do not belong to the elements of input influencing the output. The same goes for LN R&D intensity of energy efficiency. The model output is different though.

Thus, we decided that this model is not capable of interpreting possible lock-ins between different energy trends. In the next chapter we propose some possible solutions which could ameliorate the model.

5.6. TESTING AND VALIDATION

This section is occupied with the robustness of the results, performing a post regression analysis of the models. The post-regression analysis is defined through four different tests: the normality of residuals, model specification, multicollinearity verification and heteroscedasticity test for each model.

I. Normality of the residuals is a test calculating the residuals for a standardised normal distribution and comparing the quantiles of the output (LN patent counts per GDP) to the quantiles of the normal plot.

II. Model specification test is performed for single equation models, in Stata and it shows whether there are additional independent variables significant to the model.

III. Multicollinearity effects take place when the variables are nearly an exact product of each other, jeopardising the accuracy of the model by producing unstable coefficients (which can be shown through a stepwise regression analysis) and highly inflated standard errors (UCLA, 2007).

IV. Finally, heteroscedasticity test is performed to check the residuals variance of the regression models.

5.6.1. General Model Testing

Normality of residuals test: the results of the tests show a minor deviation from the normal distribution as depicted in figures 23 and 24. Thus the residuals approximate the normal distribution.

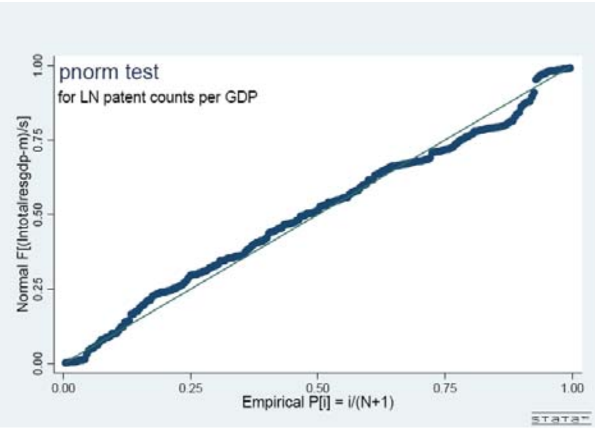

FIGURE 25 – PNORM FOR RES

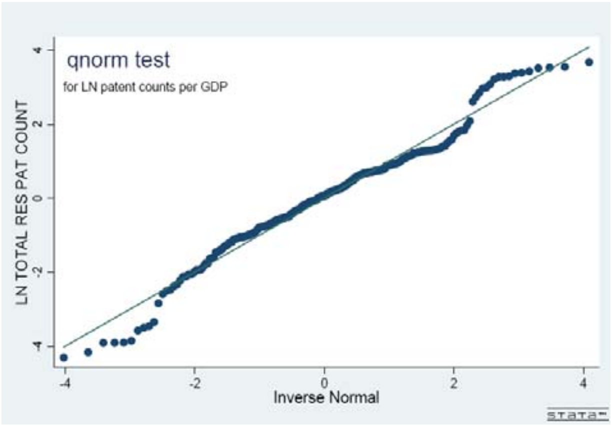

FIGURE 26 - QNORM FOR RES

Model specification test: Stata produces two new variables for the model: _hat (variable of prediction) and _hatsq (variable of squared prediction). In order to have robust results, _hatsq power should be minor and its coefficient should not be significant. The results of the model are depicted in the following table:

LN RES patent count per GDP	Coefficient	Std. Error	t	P> t
_hat	1.000436	.0517103	19.35	0.000
_hatsq	.0071491	.023654	0.30	0.763
_cons	-.0137014	.0845108	-0.16	0.871

TABLE 9 – LINKTEST RESULTS FOR LN RES PATENT COUNTS PER GDP

The results show that _hatsq is equal to .007 and its probability P>t is equal to 0.763, thus the specification for the model is correct.

Multicollinearity test: using the vif command he export the following table:

Variable	VIF	1/VIF
lnepopatents	7.03	0.142302
lnenergyconsumption	6.68	0.149706
lnopenness	3.25	0.307947
lnrdpersonnel	2.85	0.350939
resfinancial	2.83	0.353574
respricebased	2.59	0.386577
lnratioelectricity	2.02	0.493909
reslegislative	2.01	0.498744
lnintensinsityresrd	1.50	0.666837
Mean VIF	3.42	

TABLE 10 – VIF RESULTS

Since the VIF values are less than ten (following the rule of thumb), then there are no obvious multicollinearity issues. Also, the tolerance values (1/VIF) are greater than 0.1, reinforcing our argument.

For heteroscedasticity check we first plotted the residuals and then performed the Breusch-Pagan test. The plot below, which shows the distribution of the residuals with the fitted values of the model (from the dependent variable), has shown no obvious heteroscedasticity.

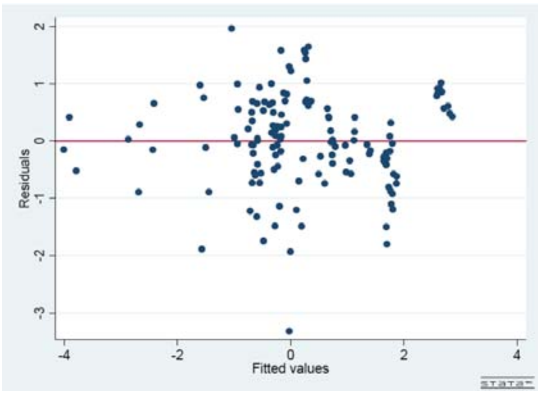

FIGURE 27 – HETEROSCEDASTICITY PLOT RES

The Breusch-Pagan test checks the null hypothesis for constant variance of the residuals (produced in the regression model); therefore the hypothesis there is homoscedasticity in the model. For the RES model, the null hypothesis was not rejected with value of squared chi equal to 0.08 and probability of value greater of chi squared equal to 0.7752. This model shows no evidence of heteroscedasticity.

5.6.2. ENERGY EFFICIENCY MODEL TESTING

The same tests are also performed for the model of energy efficiency. Their results are stated below.

Normality of residuals test:

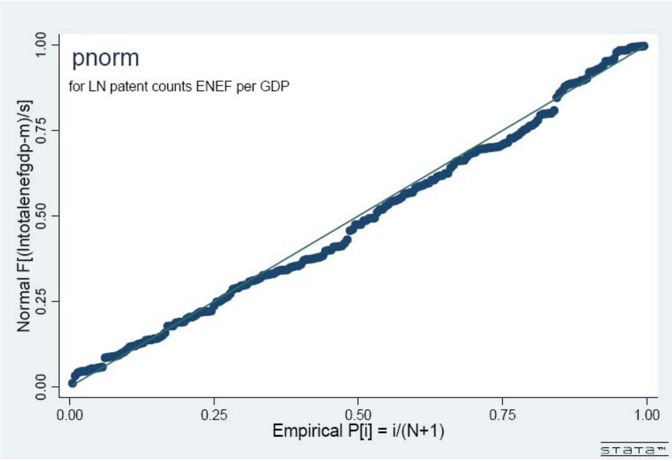

FIGURE 28 - PNORM FOR ENEF MODEL

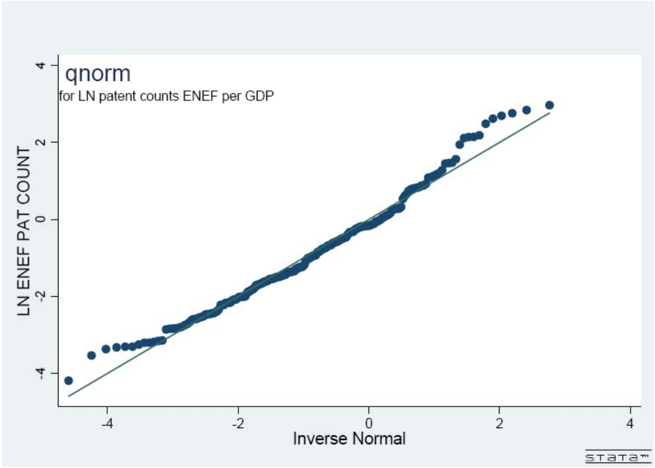

FIGURE 29 - QNORM FOR ENEF MODEL

Both test show the normality of the residuals compared to normal distribution.

Model specification test:

LN RES patent count per GDP	Coefficient	Std. Error	t	P> t
_hat	.9971986	.0470231	21.21	0.000
_hatsq	-.0172602	.0263986	-0.65	0.514
_cons	.0336787	.0845456	0.40	0.691

TABLE 11 – LINKTEST RESULTS FOR LN ENEF PATENT COUNTS PER GDP

The results show that _hatsq is equal to.-0.017 and P>t is equal to 0.514, thus the specification for the model is correct.

Multicollinearity test: using the **vif** command he export the following table:

Variable	VIF	1/VIF
lnenergyconsumption	3.16	0.316184
lnopenness	2.91	0.343293
lnrdpersonnel	2.73	0.366152
eneflegislative	2.24	0.446511
enefpricebased	1.72	0.582229
lnintensinsityenefrd	1.66	0.603570
eneffinancial	1.54	0.649901
lnratioelectricity	1.24	0.803362
Mean VIF	2.15	

TABLE 12 – VIF RESULTS

According to the rule of thumb, the results are again, satisfactory, as all VIF values are less than then and, at the same time, the tolerance values are greater than 0.1.

The second model revealed heteroscedasticity problem. As the figure below depicts, the shape of the scatterplot shows probable heteroscedasticity. This result was confirmed by the Breusch-Pagan test.

Testing the null hypothesis (homoscedasticity) had the following results: the chi squared value was 3.93 with probability of 95% of significance (equal to 0.0473).

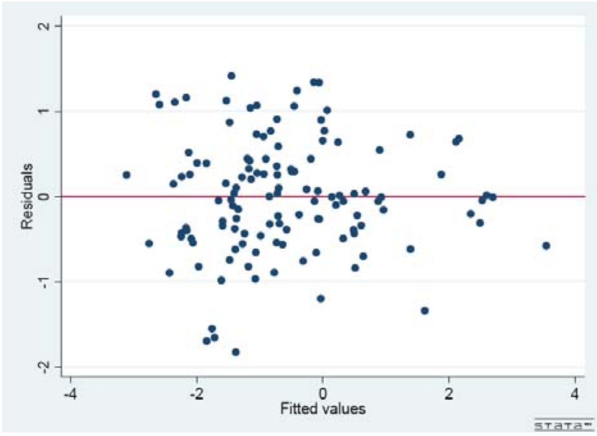

FIGURE 30 – HETEROSCEDASTICITY CHECK ENEF

Heteroscedasticity's main problem is that the variance of the dependent variable (in our case the LN of patent counts for ENEF) is only explained well in a small area. Thus, the model is not significant everywhere. OLS regression is therefore not capable of explain in to an important degree the ENEF model. The remedy for heteroscedasticity implemented in this study was at first using robust standard errors for OLS. The results of our regression analyses for both RES and energy efficiency are calculated with robust standard errors allowing the residual to interact with the regressors. Robust standard errors provide robust-statistics and t-statistics but do not affect the regression estimators or the R squared value.

CHAPTER 6

POLICY RECOMMENDATIONS– FURTHER RESEARCH

This chapter aims to affiliate the recent findings from the regression to the countries of the EU15 to previous research. This study's model originates from the work of Johnstone et al. (2008) conducted for the OECD and results to the design of the REIS framework. Therefore, the regression results are compared to the ones of their study. Before proceeding with the comparisons, we should mention that their research has been conducted for a different set of countries and for a different time period. Besides, this comparison, we compare our results to other studies, conducted for researches similar to this one

In addition, we present an analysis based only on the policy instruments, which constitutes the core of this study, for the EU15 and their connection to the output. In this part we explain the relation of energy efficiency and renewable energy to the policy measures and examine the trends' behaviour. Then, we analyse the model approach to the general variables defined in chapter 4, according to the OLS and GLS regression analyses.

During our findings presentation, we refer to the inadequacies of the model and the possible ameliorations which could drive to better, more robust results.

6.1. Comparison to previous research

6.1.1. Comparison to Johnstone's Model

At first, for explanatory reasons we include the results of the Johnstone's model. Johnstone et al. (2008) studied the relationship between the environmental innovation and the renewable energy policies based on the evidence of patent counts. For that, they include seven different policy instruments, which are later, redefined into policy clusters and a set of explanatory variables (electricity price, R&D expenditures, electricity consumption and total EPO filings). Their results come from a cross-country regression analysis (using the negative binomial method) for the time period of 1978 to 2003. The results of their study are measured for five different RETs (wind, solar, wave-tide, biomass and waste) and their total. We should, finally, report that the number of observations is significantly larger in their dataset (for overall RES is 463 observations compared to just 137 of this study's model).Their model for the total RETs shows that only the R&D expenditures, the total EPO filings and from the policy clusters, the price based and the legislative have a strong effect on the output. The electricity price plays a minor role. Also, the energy consumption is negatively connected to the output. The main issue of their study were the multicollinearity problems among the policy dummies and possible interaction effects. We decided to deal with this problem by defining policy clusters with specific characteristics, so as to separate as far as possible, the communal bonds of the policy instruments.

Compared to these results, our model has significant differences concerning the explanatory variables. The energy consumption is both important and is positively connected to the output. This result is as expected. As the energy consumption increases, the need to turn to other energy sources, and if possible not depletable, for energy security reasons increases as well. Johnstone's model shows a slight positive impact of the electricity price. In our case, the electricity price was modified and examined as electricity ratio of households to industries. The results of this variable were negative as expected denoting the increased impact of the industrial sector. In case of R&D expenditures, the results are quite similar. Johnstone et al. find there is a strong positive connection of R&D expenditures and the output. In our model, we come to the same findings using two representative variables of R&D, to represent capital and labour, the R&D intensity and the R&D personnel. Finally, we did not include the total EPO filings in the output so that we would not use a part of the same data for both input and output. Instead, we used the openness to investment and trade of the EU15 countries. This variable gave conflicting results for the two simulations. In OLS it gave negative results (also found in the correlation scatterplot) while in GLS it gave strong positive results.

Johnstone's model shows interesting results concerning the policy clusters. Legislative measures have the greatest impact, followed by price-based (both positively connected to the output). Their study also includes voluntary measures (the third cluster), which has almost no effect on the output. Our results differ from the ones just mentioned. One possible explanation is because their definition is quite different. In this study, we tried to simulate the policy clusters not as binary variables, but as semi-quantitative ones, including their overall impact. The results of this research show that price-based measures have a strong positive impact while legislative and financial have minor and negative impacts. This means that within the EU15, the Members have supported measures such as taxes and tariffs. On the contrary, quotas or subsidies have not been successfully promoted.

6.1.2. Introduction of an energy efficiency model

Based again on Johnstone's model, we have designed a similar model for energy efficiency trend. For that, we had to expand our original framework in order to cover the new trend (the "Lock-in" framework). The output data were retrieved from the common data of RETs and energy efficiency according to Ecofys. We included the energy saving R&D expenditures for the IES database and the overall impact of policy measures from the MURE database. Thus, we created a model to simulate energy efficiency for the EU15. One main difference from the previous model is the existence of four policy clusters, the previous three including voluntary measures. Before proceeding with the results, we should mention that this model confronted heteroscedasticity issues which were dealt with the use of robust standard errors in the model run.

The results of this model were quite interesting, especially when compared to those of RETs. For the explanatory variables, the most important finding was the sign of electricity ratio. As expected, electricity ratio had a positive sign, following the premise that energy saving techniques are mostly designed and implemented for the households. This result is important for one further reason. It shows that innovation in energy savings takes place in different sectors than those of renewable energies. This finding, combined with the results on policy clusters shows a high differentiation in governance the two energy trends. The policy clusters which affect most energy efficiency innovation are the legislative and financial, which simultaneously are not that effective on renewables. This sectoral diversion could be perceived as a "lock-in" of different energy trends in specific areas of application. A hint coming from the models is the adoption of different technologies which are also promoted by different policy instruments. This conclusion comes from the interpretation of the electricity ratio and policy cluster results.

6.1.3. Comparison to previous research

A. Patent counts

Patent counts have not been extensively used as environmental innovation output for the environmental policies. Johnstone et al. (2008) used in their model the patent counts in their cross-sectional analysis. The present research modified the patent counts as output for two main reasons. At first, the patents were weighted per real GDP per capita in order to include the population and wealth aspects in the sample. Then, the output was logarithmically transformed in order to deal with correlation and heteroscedasticity issues which came up in the regression analyses. Besides their drawbacks, the patents had two important characteristics which indicated their use in this study: their availability and their extensive information (priority date, application number etc.) for chronological and spatial setup.

B. Policy measures

In other studies, variables used in the model were part of different models, which had as their main issue environmental innovation. For instance, Popp (2004) tried to link environmental innovation, and more specific SO_2 and NO_x abatement technologies to the regulatory system and found that the domestic environmental regulations influenced strongly the innovation output. Also, Vries and Withagen (2005) linked environmental innovation to stringency policies for the specific case of SO_2. According to their model, stringency policies led to increased innovation output. Also, as mentioned above, Johnstone et al. (2008) showed that different policy instruments could affect different types of renewable energy. This study also shows the importance of policy measures (price based, legislative and financial) on environmental innovation, and, in further, defines the level of significance of different policies on different energy trends. The voluntary measures seem to have a minor impact on the model. The fact that the two energy trends use different policy clusters could be very helpful for promoting new policies. This means that, if legislative or financial measures are better adopted that could lead to the conclusion that maybe it should be wise to switch to a policy mix oriented more to these clusters also for the renewables, instead of keeping up with policies that do not offer substantial changes.

A further step to the research could be the redefinition of the RES policy measures, divided into residential and industrial. The study could have more broad results if we could separate the analysis of the measures like the energy saving measures (as raw data). Instead, due to the fact that we could not separate the two sectors, we had to unify the energy efficiency measures as well. In reality, we did not have equally enough information for both energy trends. Due to the integrity of the MURE database we were able to define far more explicitly the policy measures for the energy efficiency sector. Also, a better representation of the RETs policy measures could provide clearer results for the model. The limited data on RETs policy measures possibly restrained the results of the regression models.

C. Electricity ratio

The electricity price has been studied by Popp (2001) for the US. Popp uses the citations of granted patents in order to measure the productivity of knowledge for energy saving technology. His model showed strong positive impact of the energy prices on innovation. We have produced also positive results, using the electricity ratio for energy efficiency. Our variable's justification was that energy saving techniques are mostly implemented for households, thus an increase in electricity price could lead to the use of energy saving techniques. Instead, the industrial sector prefers to turn to other innovation trends as the energy price does not really affect the consumption. Therefore, industry seems not to induce energy saving innovation. One main reason we used the electricity ratio was the fact that we did not differentiate the analysis in sectors. The electricity ratio helped in interpreting the effect of the price, taking into account both industries and households.

In order to have better results, the prices used should be measured for a longer duration and not only for medium-scale sectors (as in the present study).

D. R&D input

The R&D input is defined for both capital and labour by setting two variables: the R&D intensity (for RES and energy efficiency) and R&D personnel. The R&D personnel had a strong positive effect for all models. The R&D intensity represents the ratio of R&D for the specific sector to the overall R&D. The returns to R&D have been usually estimated by patent counts. Jaffe (2000) mentions that *negative results confirm that the patents are not central to appropriating the returns to R&D in most industries*. This study has given contradictory results concerning this measure. For most regressions the measure has given minor effects (except from the RES GLS regression, where the measure gave a more than one impact coefficient). In the case of energy efficiency, it also depicts the negative returns on investment. This measure should be reconsidered taking in mind the firms' perception to patenting. Here, we confront the issue of marketability and investment returns. Consequently, the patent counts might not be directly related to R&D expenditures, and if so, it still should be reviewed with attention.

E. Openness

The openness variable was acting problematically switching from OLS to GLS method. Correlated to the output openness has been negative as expected. As wider the international trade becomes it is easier to have negative spillovers (the knowledge exchange between different countries could have harmful effects). Also trade is mostly perceived as a private R&D measure. Since the model is highly governmental oriented, this variable cannot stand correctly within the model as it is not enough to represent the private sector for innovation activities. As further research, more variables, private sector oriented could enter in the framework and give a more integral perspective. Since we develop a model for the national innovation system, it was not considered necessary to explore this dimension.

6.2. Renewable energy types

Even though the model results for sectoral regressions are not that robust, it is still interesting to explore this model as well. Concerning the energy type, the technologies with the most influential factors (more than 10 percent of significance) are biomass and waste. This could be interpreted as the energy types whose input is most keen to environmental innovation are these two. It seems as biomass and waste are the two sectors where there has been the most effort to innovate.

Relevantly to the explanatory variables, we have different results for different types. As an example energy consumption mainly affects solar, wind and waste while R&D personnel variable mostly affects biomass and waste output. Therefore, these results show different determinants of innovation. Biomass and waste seem to be knowledge induced, while solar and wind seem to be price induced. This is also an indicator of the determinants of environmental innovation. The older technologies (wind and solar) are demand-pull while the newer ones (biomass and waste) are technology-driven. By imposing an appropriate regulatory framework, we could achieve equilibrium so that all technologies are sufficiently promoted, so that there will not be created internal/ within technology lock-in effects (adopting one renewable type instead of another, due to original underinvestment).

The policy clusters also show some differences. It is very interesting to observe that for waste and biomass there is a strong negative effect from financial measures. This could be interpreted as possible failure of the measure. Thus, instead of a growing output, grants and subsidies contribute negatively to the output. The same effect comes from legislative measures. This result depicts the inadequacy of these measures to promote environmental innovation for the biomass and waste sectors specifically. Strong negative effect is also obtained for the wind sector for the legislative measures. On the contrary, price based measures have shown impressive effects on environmental innovation for most renewable sectors (apart from biomass, where the effect is still positive). The results of ocean and geothermal types were not taken into account due to the lack of robustness.

Johnstone et al. (2008) also performed regression analysis for the sectoral renewables. Actually, their model is quite more robust for these regressions instead of the overall RES regression. Their results are quite different. At first, electricity consumption has a strong negative effect. The R&D expenditures are positive (except from biomass) with large coefficients for wind and ocean. In our case, the coefficients of R&D intensity were rather small and insignificant. Concerning the policy clusters, their model gives strong results for price based measures (like the present model). the model differs in the case of legislative measures, where it shows positive results (significant only for the case of wind). This could be due to the difference of the country set. The measures implemented in the EU15 are not the same with the ones implemented in US or Japan. Since the Johnstone model includes these countries as well, there are expected some deviations between the results.

6.3. Governmental intervention

The main question of the research has been to what extend the governmental intervention has been successful concerning the RETs and how could that be ameliorated. It has been clear that the results of the current energy policies have not been most effective. This was proven by the inability of the Member countries to fulfil their renewable energy targets by now. The framework tried to depict the existing innovation systems and, through the empirical analysis to spot the factors which were most influential, in increasing the output.

Governmental intervention should be set up according to the European Commission’s targets. These targets are reflected by the evolutionary approach. According to that, regulation should be imposed in order to encourage innovation (Porter hypothesis). Besides from price-induced, innovation should be occurring in order to make the products more sustainable[76] (instead of less costly). Environmental regulation is responsible to compensate for the innovation costs and induce technological change. In their turn, governments are responsible to design and implement these policies to support technologies which could help in achieving the Commission’s goals.

Governmental intervention can work in two different ways according to the regression analyses. The first one is to boost the factors that have been proven to be most efficient. What we have seen in sectoral models is different innovation determinants. There are those that are market-driven and those that are knowledge-driven. These two kinds of determinants serve the induced innovation hypothesis, where, innovation comes as an attempt to reduce the costs of production. Regulation is necessary in order to avoid possible drop of a technology not market-driven (and probably having negative returns on

[76] The use of sustainable here represents the environmental implications (pollution abatement), the economical implication (cost reduction) and the long –term implications (security of supply).

investment). The way to do so is by enforcing price based measures in already adopted technologies and applying financial incentives to new presented ones.

Comparing the renewable to energy efficiency, governmental has a wide range of intervention possibilities. We should denote that it is most favourable for both trends to succeed. According to the model's results, this is feasible, as the two trends are implemented for different sectors of application. Possible lock-in is considered in terms of application field. More specifically, there could be a tendency to lock the energy saving technology in the household sector. Also, the same effect could happen for renewable technologies and the industries. In a market level, the government could design policy instruments to favour innovation for a specific technology. According to chapter 2, the most preferable way to escape from a lock-in in innovation areas is by creating niche markets, which can promote the products and establish the trends. This strategy could be used to promote renewable energies as well. Designing measures which could protect the niche markets could be also a solution to the problem.

The second approach of governmental intervention is by creating a more flexible policy framework towards renewables. Since the existing policies have proven to be inadequate, there should be changes in the current approach. This could be implemented in two ways. The first is to occupy strictly with the renewables policy measures and create a more successful policy mix. Fiscal measures and tariffs have been the most widespread measures by now. Their orientation is mandatory and punishing. Instead, legislative measures (quotas) or financial (grants, subsidies) have been less promoted, even though the act in a rewarding way.

On the other hand, the policy measures for energy efficiency have the exact opposite character. That is partially due to the circumstances of the development of these trends. The renewables have followed an energy crisis which warned the governments that energy cannot be taken for granted. Even now, this argument is still valid taking in mind the energy dependency of some EU members to the energy imports. The governments considered it would be better to impose renewable energy so as to have better results and energy production (followed by energy security). On the contrary, energy efficiency started as a "green" trend, where energy consumption should be decreased. The orientation of this trend could be defined as voluntary. Only the last few years, the European Commission tried to create some directives on the promotion of energy efficiency (and mostly for the residential sector).

Therefore, a good policy suggestion would be to treat both trends simultaneously. Instead of each trend to work in a different way, a combination of both in the same regulations could have better results. Even though there is no certain connection between the trends, it is obvious that they do not cooperate. Governmental intervention could create some common ground for their success.

6.5. FURTHER SUGGESTIONS

In case of obtaining more information, it could be possible to study the EU15 Members individually. In our case, the sample included only 17 observations for each country in total, which were diminished due to the absence of values in electricity prices and RES policy measures information. For complete time-series of more than twenty years, the study of each country's effects, using country dummies, could be feasible and reliable.

One last further suggestion to the framework is to expand it in geographical terms. Many researchers have indicated the need to include the natural dimension in the national framework such as Vollebergh (Vollebergh, 2007) or Popp (Popp D. , 2005). Geographical features such as days of sunlight, precipitation, and wind speed could become valuable determinants for environmental innovation and provide a new perspective in this research area. One example could be the positive knowledge spillovers and their innovation rate between regions that are geographically similar.

CHAPTER 7
CONCLUSIONS

The energy sector has been traditionally manipulated from the governments, before and after market liberalisation. In his article, (Simon, 2007) refers to energy as a marketable public good: "in a modernizing society, electricity served a necessary function without which a large-scale modern citizenry could not easily exist". For a "more urbanised model of living" Simon argues that "decisions about energy policy were made at a fairly low level and market-based economic forces of rivalry or excludability played almost no role in energy generation or use decisions" (Simon C. A., 2007) . Energy itself might not be a public good following the exact definition[77], but many aspects connected directly or indirectly to it are characterised as public goods. As an example, the right to a proper living standard includes electricity in a modern society or clear environment. Governments, in that sense, have treated energy as a utility good.

The renewable energy sector has become a field demanding for governmental intervention. Renewable energy's benefits have failed to be captured in the market price and tended to be under-produced. That happens because negative externalities, such as air pollution have failed to be included in energy prices for conventional energy sources, such as fossil fuels. At the same time, markets fail to value the benefits from the RES causing underinvestment. In addition to that, RES cannot act that fast so as to mitigate the negative effects and create a motive to their adoption[78]. The demand for governmental intervention has increased in order to include the new energy market trends and balance the effects caused by existing policies. More specifically, the European Commission defined as the goals of governmental intervention the establishment of a certain percentage for each country, of renewable energy use, in order to secure the energy supply and at the same time, abate the pollution caused by its consumption.

In the beginning of our research we reviewed analytically the drivers of eco-innovation and the economical theories behind it. We have concluded to use a twofold approach for this case. Induced innovation theory was used to define the system and its specifications. For the policy recommendation part, we decided to include also the evolutionary theory which represented better our perspective, as mentioned above and create "win-win" situations for our actors' network. Our study included the possibility of market failures associated with environmental innovation, as the technological advance in influenced by market and regulatory incentives (Jaffe et al., 2005). Environmental oriented policies, as suggested by the Porter hypothesis are necessary to the development of environmental technologies. Jaffe et al., (2005) suggest a long-term strategy of experimentation with policy approaches and evaluation of their success.

For that reason we have developed an input-output framework originating from the work of Johnstone (N.Johnstone, 2008) and Popp et al. in (Popp, Newell, & Jaffe, 2009). The framework defined at first the national innovation system, specified for the renewable energies (REIS framework) and then, it was extended including the energy efficiency trend as well (Lock-in framework).

[77] Public goods are defined as non-rival and non-excludable. Non-rivalry feature means that the products are available unlimitedly and non- excludability means that no one is excluded from their consumption. Examples of public goods are education, military defence, environmental standards (clear air, water, soil) etc.

[78] That happens if we assume that renewable energies start as "niches". Their rate of adoption is very important. If it is fast enough it may lead to increasing returns and, consequently additional investment. If not established quickly enough it may lead to a failure of adoption.

The core of this study was to relate the innovation output to the implemented policy measures for the EU15, from 1990 to 2006.

The evaluation of the policy measures was our main goal. Here, we should mention that policy instruments have been mainly designed based on the price-induced innovation theory. Policy instruments have been gathered as semi-quantitative cumulative (according to their impact) variables divided into four clusters. We included the impact factor in order to evaluate more representatively the extension of their effect. From these clusters the renewables use only three (price based, legislative and financial). In Appendix F, we include the policy measures clusters for each EU15 country. Our empirical study ran the different models with two types of regression: OLS and GLS. Both methods had their weak and strong points.

In general, for the renewables, one can observe a tendency for price based measures. On the contrary, the measures promoted for energy efficiency were the legislative and the financial. Also, on a country level, few countries demonstrate the use of combination of more than one policy clusters[79]. This observation shows the rigidness of the design and implementation of policy measures in the EU15. The conclusions of the regressions are summarised as follows. Our main finding, concerning the policy clusters created to check the governmental intervention on the innovation output, was the difference of policy design for the two energy trends (renewables and energy efficiency) and the difference of policy design within the different types of renewable technologies.

The model highlighted the importance of two more factors, the energy consumption and the R&D personnel. Finally, by using the electricity price subsidy, we were able to observe the difference between the industry and residential sectors as far as the promoted energy trend. For the industry sector that was the renewables, while for the household sector that was the energy savings technology.

To sum up, this model was able to demonstrate results which could adopt governmental intervention and potentially improve the current system, as defined in Chapter 3, so as to reach the demanded target values of renewable energy as set by the European Union.

[79] These are Belgium (which switched from price based to legislative in 2002), France (using a combination of price based and legislative), Ireland (which switched from legislative to price based in 2004), Italy (using a combination of price based and legislative), Netherlands (using all three RES policy clusters) and Sweden (switching from financial to legislative). Only Finland uses clearly financial measures.

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APPENDIX A – THEORY

A. National overall targets

	Share of energy from renewable sources in final consumption of energy, 2005 (S_{2005})	Target for share of energy from renewable sources in final consumption of energy, 2020 (S_{2020})
Belgium	2.2%	13%
Bulgaria	9.4%	16%
The Czech Republic	6.1%	13%
Denmark	17.0%	30%
Germany	5.8%	18%
Estonia	18.0%	25%
Ireland	3.1%	16%
Greece	6.9%	18%
Spain	8.7%	20%
France	10.3%	23%
Italy	5.2%	17%
Cyprus	2.9%	13%
Latvia	34.9%	42%
Lithuania	15.0%	23%
Luxembourg	0.9%	11%
Hungary	4.3%	13%
Malta	0.0%	10%
The Netherlands	2.4%	14%
Austria	23.3%	34%
Poland	7.2%	15%
Portugal	20.5%	31%
Romania	17.8%	24%
Slovenia	16.0%	25%
The Slovak Republic	6.7%	14%
Finland	28.5%	38%
Sweden	39.8%	49%
United Kingdom	1.3%	15%

TABLE A. 1 - TARGETS TABLE FROM THE EU (COMMISSION, 2008)

WIND		
Wind motors with rotation axis substantially in wind direction	F03D	1/00-06
Wind motors with rotation axis substantially at right angle to wind direction	F03D	3/00-06
Other wind motors	F03D	5/00-06
Controlling wind motors	F03D	7/00-06
Adaptations of wind motors for special use;	F03D	9/00-02
Details, component parts, or accessories not provided for in, or of interest apart from, the other groups of this subclass	F03D	11/00-04
Electric propulsion with power supply from force of nature, *e.g.* sun, wind	B60L	8/00
Effecting propulsion by wind motors driving water-engaging propulsive elements	B63H	13/00
SOLAR		
Devices for producing mechanical power from solar energy	F03G	6/00 – 08
Use of solar heat, *e.g.* solar heat collectors	F24J	2/00 – 54
Machine plant or systems using particular sources of energy – sun	F25B	27/00B
Drying solid materials or objects by processes involving the application of heat by radiation – *e.g.* sun	F26B	3/28
Semiconductor devices sensitive to infra-red radiation – including a panel or array of photoelectric cells, *e.g.* solar cells	H01L	31/042
Generators in which light radiation is directly converted into electrical energy	H02N	6/00
Aspects of roofing for the collection of energy – *i.e.* Solar panels	E04D	13/18
Electric propulsion with power supply from force of nature, *e.g.* sun, wind	B60L	8/00
GEOTHERMAL		
Other production or use of heat, not derived from combustion – using natural or geothermal heat	F24J	3/00 – 08
Devices for producing mechanical power from geothermal energy	F03G	4/00-06
Electric motors using thermal effects	H02N	10/00
WAVE/TIDE		
Adaptations of machines or engines for special use – characterised by using wave or tide energy	F03B	13/12-24
Mechanical-power producing mechanisms – ocean thermal energy conversion	F03G	7/05
Mechanical-power producing mechanisms – using pressure differentials or thermal differences	F03G	7/04
Water wheels	F03B	7/00
BIOMASS		
Solid fuels based on materials of non-mineral origin – animal or vegetable	C10L	5/42-44
Engines operating on gaseous fuels from solid fuel – *e.g.* wood	F02B	43/08
Liquid carbonaceous fuels – organic compounds	C10L	1/14
Anion exchange – use of materials, cellulose or wood	B01J	41/16
WASTE		
Solid fuels based on materials of non-material origin – refuse or waste	C10L	5/46-48
Machine plant or systems using particular sources of energy – waste	F25B	27/02
Hot gas or combustion – Profiting from waste heat of exhaust gases	F02G	5/00-04
Incineration of waste – recuperation of heat	F23G	5/46
Plants or engines characterised by use of industrial or other waste gases	F012K	25/14
Prod. of combustible gases – combined with waste heat boilers	C10J	3.86
Incinerators or other apparatus consuming waste – field organic waste	F23G	7/10
Manufacture of fuel cells – combined with treatment of residues	H01M	8/06

TABLE A. 2 - IPC CLASSIFICATIONS FOR RENEWABLE ENERGY - SOURCE: (OECD, ENVIRONMENTAL POLICY, TECHNOLOGICAL INNOVATION AND PATENTS, 2008)

APPENDIX B – POLICY MEASURES

Appendix A includes all the figures for the policy measures section

Table B.1

Criteron / Instrument	Subsidies	Regulation	Feed-in tariff	Invitation for tender	Quota with certificates	Tax	Emission certificate
Applicability for stages of marketing	R & D, demo projects, introduction	Introduction, readiness	Introduction, readiness	Introduction, readiness	Introduction, readiness	Readiness	Readiness
conformity with objectives							
increase of RES energy production	S – M	L	L [2]	L [2]	L [2]	S	S
reduction in RES prices	M	S	S	M	M - L	O - S	S
Reduction of CO_2	S – M	S – M	S – M	S – M	S – M	L	L
acceleration of the implementation of RES	L	M	L	M	M - L	O - S	O - S
conformity with environment policy principles							
Polluter pays principle	O	S – M	S – M	S - M	L	L	L
Principle of cooperation	L	S	S	M	L	L	L
Principle of main focus	S – M	S – M	S - M	L	L	L	L
Precautionary principle	L	L	L	S	L	L	L
conformity with system							
Intensity of impact on markets[1]	O - S	L	L	S	L	S	S
Reduction of freedom of action	O	L	L	O – S	O	O	O
Promotion of competition	O – S	O	O	M - L	L	L	L
Market integration	S – M	S – M	S – M	L	L	L	L
Negative side effects	O – S	O	O – S	O – S	O	O	S – O
Stability versus political changing	M	M	M	M	L	L	L
Durability	M	M	M	M	L	L	L
Institutional controllability							
Enforceability	L	M	M	M	M	M	M
Administrative expenses [1]	M	S	M	L	M	S	M
economical efficiency							
Cost-efficiency ratio	M	M	M	L	L	L	L
Promotion of innovation	M - L	M	M	M	L	S – M	S - M

TABLE B. 1 - VALUATION OF THE INSTRUMENTS FOR RES REGARDING THE CRITERIA OF SUCCESS – SOURCE: **(PFAFFENBERGER, JAHN, & DJOURDJIN, 2006)**

With rating values:

Rating	Correspondence with criterion
O	no effect / impact
S	Small effect / impact
M	Medium scale effect / impact
L	Large effect / impact

Table B.2

Another RES impact table from (Burgers, van Ommen, & Verheij, 2009):

	FIT	quota + TGC	tendering/bidding systems	fiscal/financial incentives
suitable to encourage specific technology	depends on form (i.e. technology specific FIT tariffs (banding))	yes, this is possible	yes, this is possible	yes, this is possible
take technology learning into account	depends on form; e.g. in Germany: *tariff degression system*	depends on form	depends on form	depends on form
suitable for immature RE market	especially for immature RE market	no, it is a more market conform system	no, it is a more market conform system	instrument for stimulating new technologies and demonstration projects
compatibility with electricity market: supply forecasts	no, it is not entirely certain a priori how much renewable electricity will be produced.	depends	yes	yes
long term confidence for investors	yes	no	depends on form	no, terms can change quite easily
administrative burden	depends on form	depends on form	yes, and complex	yes, and complex
cost for community/ market efficiency	yes	no, for investors	no, for investors	no, for investors

TABLE B. 2 - IMPACT TABLE ACCORDING TO (BURGERS, VAN OMMEN, & VERHEIJ, 2009)

Table B.3

The one used in the model is the following:

	Period of time analysed	RES quantity deployed (W/cap yr)	Magnitude of absolute support level	Decrease in support over time?	Risk for investors	Other important aspects
FIT&premium:						
Denmark	1992-1999	high	low	No	low	
Germany	1998-2005	high	medium	Yes	low	
Spain	2002-2005	high	low (fixed option); medium (premium)	Yes	low	
Austria	2002-2005	high	Medium	No	low	Support level to high because of parallel investment subsidies
Portugal	2002-2005	high	Low	No	low	
France	2002-2005	low	Medium	No	low	High administrative barriers
RPS and quota-based TGC:						
UK (RO)	2003-2005	low (quota not met)	High	Yes	Medium/high	Penalty too low
Italy	2003-2005		High	No	high	Time of validity of RES plants for certificates too low (8 years)
Sweden	2003-2005	high (quota met)	Low	Constant	medium	Windfall profits due to some old capacities also qualifiying for certificates
Belgium	2003-2005	low (quota not met)	High	No	Medium/high	low penalty, Windfall profits due to some old capacities also qualifiying for certificates
Tendering:						
UK (NFFO)	1990-1998	low	Low	Yes	Low after selection	Capacities to low

TABLE B. 3 - IMPACT TABLE ACCORDING TO MEASURES - SOURCE: (HAAS ET AL., 2007)

Table B.4

HOUSEHOLDS	Legislative/ Normative		Definitions according to MURE database:
		Mandatory Standards for buildings	Energy performance standards minimum thermal insulation standards

	regulation for heating systems and hot water systems	minimum efficiency standards for boilers
		compulsory replacement of old boilers above a certain age
		thermostatic zone control
		control systems for heating (regulation)
		mandatory heating pipe insulation
		periodic mandatory inspection of boilers
		periodic mandatory inspection of Heating/ ventilation/ AC
		mandatory use of solar thermal energy in buildings
		individual billing (multi-family houses)
		maximum indoor temperature limits
		minimum efficiency standards for electrical appliances
		mandatory measures for efficient lighting
Legislative/ Informative	mandatory labelling of heating equipment	
	mandatory energy labelling of electrical appliances	
	mandatory energy efficiency certificates for existing buildings	
	mandatory energy efficiency certificates for new buildings	
	mandatory audits in large residential buildings	
	mandatory audits in small residential buildings	
Financial	Grants/ Subsidies	for investments in new buildings exceeding building regulation
		for investments in energy efficiency building renovation
		for the purchase of more efficient boilers
		for the purchase of highly efficient electrical appliances
		for other energy efficiency investments
		for investments in renewables
		for CHP investments
		for energy audits
	Loans/ Others	reduced interest rates (soft loans)
		leasing of energy efficiency equipment
Fiscal/ Tariffs	Tax exemption/ reduction	VAT reduction on retrofitting investment
		VAT reduction on equipment
		Income tax reduction
		Income tax credit
	Tariffs	Linear electricity tariffs
Information/ education	voluntary labelling of building/ components (existent and new)	

		information campaigns (by energy agencies, energy suppliers etc) detailed energy/ electrical bill aiming at EE improvement regional and local information centre on energy efficiency
	Cooperative measures	
	Cross-cutting with sector-specific characteristics	
INDUSTRY	Legislative/ Normative	Mandatory demand side management for energy suppliers/ other actors in energy sector other mandatory standards: for the efficiency of electrical motors; for the efficiency of industrial boilers
	Legislative/ Informative	mandatory appointment of an energy manager mandatory audits for industrial processes/ buildings
	Financial	Grants/ Subsidies: for CHP investments; for energy audits/ training/ benchmarking activities; for energy efficiency investment; for investment in clean fuels (renewables, waste, natural gas etc) Soft loans for energy efficiency, renewables and CHP - reduced interest rates (soft loans) Soft loans for energy efficiency, renewables and CHP - preferential loan guarantee conditions
	Fiscal/ Tariffs	Tax exemption/ reduction/ accelerated depreciation: tax reduction/ tax credit; accelerated depreciation for energy efficiency investment/ renewables/ CHP
	New market based instruments	
	Information/ education/ training	voluntary audits voluntary labelling of cross-cutting technologies (e.g. Industrial motors) information campaigns (by energy agencies, energy suppliers etc) regional and local information centres on energy efficiency information/ training for top-level management/ energy managers
	Cooperative measures	
	Cross-cutting with sector-specific characteristics	

TABLE B. 4 - ENERGY EFFICIENCY MEASURES TABLE

Table B.5

Energy Efficiency Measures in numbers (MURE2 Database)

	EU27		EU15	
	Industry	Households	Industry	Households
Legislative/ Normative	22	176	16	99
Legislative/ Informative	17	80	6	39
Financial	106	130	59	90
Fiscal/ Tariffs	10	14	7	13
Information/ Education	52	84	29	57
Cooperative	43	27	33	12
Cross-cutting	14	8	6	6
New market-based	18		9	

TABLE B. 5 ENEF IN NUMBERS

Figure B.1

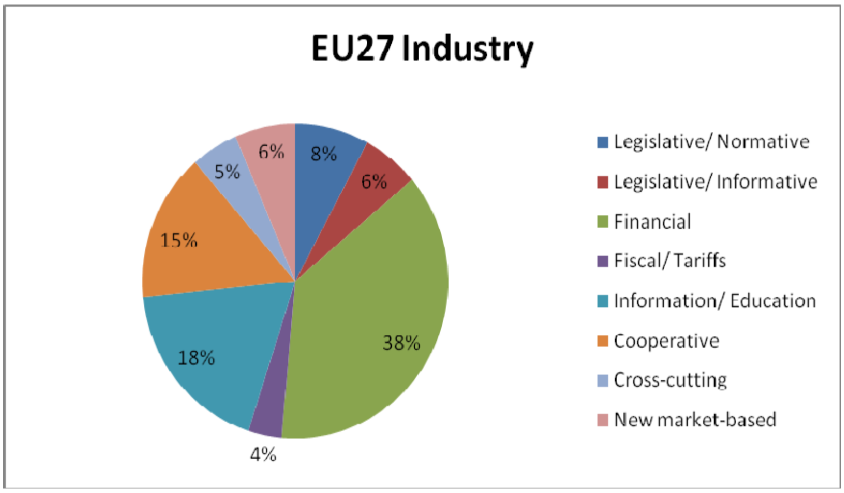


FIGURE B.1 – MEASURES FOR EU-27 INDUSTRY

Figure B.2

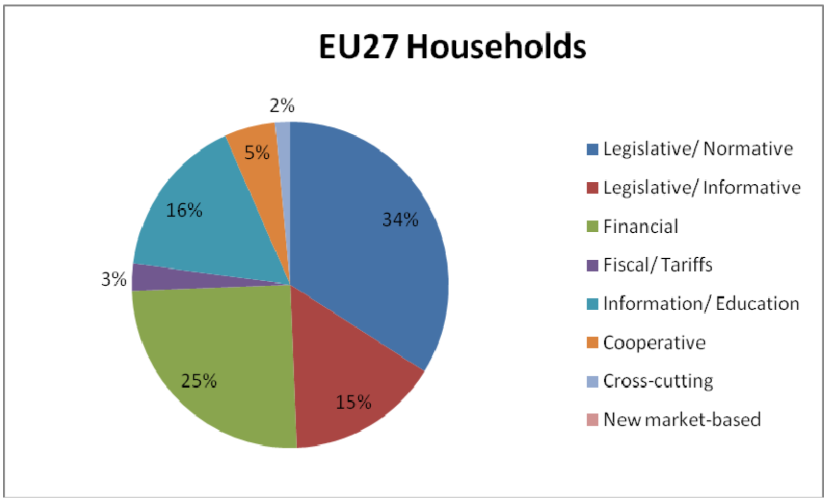


FIGURE B.2 – MEASURES FOR EU-27 HOUSEHOLDS

APPENDIX C – VARIABLES

I. VARIABLES TABLE

	Name	Type	Value	Definition	Source
1	Year	Numerical	1990-2006	Time period of research	
2	Country	String	EU-15	Members of EU-15 (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom)	
3	WindGDP	Numerical, non negative	[0,12.98128]	The ratio of Patent counts for WIND IPC classes divided by the GDP per capita (constant prices) for normalisation	Patent counts for IPC classes are retrieved from (ESPACENET, 2009). GDP per capita comes from (PENN, 2007)
4	SolarGDP	Numerical, non negative	[0,13.93061]	The ratio of Patent counts for SOLAR IPC classes divided by the GDP per capita (constant prices) for normalisation	Patent counts for IPC classes are retrieved from (ESPACENET, 2009). GDP per capita comes from (PENN, 2007)
5	GeothGDP	Numerical, non negative	[0,1.840876]	The ratio of Patent counts for GEOTHERMAL IPC classes divided by the GDP per capita (constant prices) for normalisation	Patent counts for IPC classes are retrieved from (ESPACENET, 2009). GDP per capita comes from (PENN, 2007)
6	OceanGDP	Numerical, non negative	[0,1.604685]	The ratio of Patent counts for OCEAN IPC classes divided by the GDP per capita (constant prices) for normalisation	Patent counts for IPC classes are retrieved from (ESPACENET, 2009). GDP per capita comes from (PENN, 2007)
7	BiomassGDP	Numerical, non negative	[0,2.251564]	The ratio of Patent counts for BIOMASS IPC classes divided by the GDP per capita (constant prices) for normalisation	Patent counts for IPC classes are retrieved from (ESPACENET, 2009). GDP per capita comes from (PENN, 2007)
8	WasteGDP	Numerical, non negative	[0,8.332808]	The ratio of Patent counts for WASTE IPC classes divided by the GDP per capita (constant prices) for normalisation	Patent counts for IPC classes are retrieved from (ESPACENET, 2009). GDP per capita comes from (PENN, 2007)
9	TotalRESGDP	Numerical, non negative	[0,39.28816]	The ratio of Patent counts for TOTAL RES IPC classes divided by the GDP per capita (constant prices) for normalisation	Patent counts for IPC classes are retrieved from (ESPACENET, 2009). GDP per capita comes from (PENN, 2007)
10	ENEFGDP	Numerical, non negative	[0,19.42026]	The ratio of Patent counts for ENEF IPC classes (from TotalRES) divided by the GDP per capita (constant prices) for normalisation	Patent counts for IPC classes are retrieved from (ESPACENET, 2009). GDP per capita comes from (PENN, 2007)
11	ENEF financial	Semi-quantitative, additive	[0, 25]	Subsidies, grants, loans	Mure database (MURE, 2008)
12	ENEF legislative	Semi-quantitative, additive	[0, 26]	Legislative informative/ normative (Standards, Certificates)	Mure database (MURE, 2008)
13	ENEF voluntary	Semi-quantitative, additive	[0, 25]	Voluntary agreements, cooperative measures	Mure database (MURE, 2008)
14	ENEF price based	Semi-quantitative, additive	[0, 7]	Tariffs, taxes, non fiscal	Mure database (MURE, 2008)
15	ENEF taxes	Continuous	[14.37063,	the ratio between energy tax revenues and final energy consumption per year which	Eurostat (thousand tonnes of oil

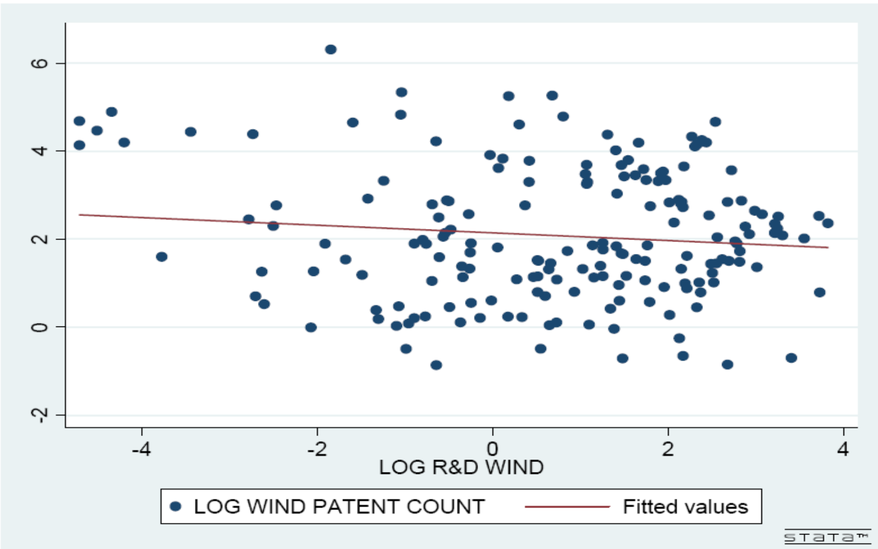
			368.0355]	expresses the taxes levied on the use of energy which contributes to foster energy efficiency	equilavent – TOE per year)
16	RES financial	Semi-quantitative, additive	[0, 1]	Subsidies	(Haas, Held, Resch, Ragwitz, Faber, & Huber, 2007)
17	RES price based	Semi-quantitative, additive	[0, 3]	Tariffs, taxes	(Haas, Held, Resch, Ragwitz, Faber, & Huber, 2007)
18	RES legislative	Semi-quantitative, additive	[0, 3]	Quotas, certificates, tender procedures	(Haas, Held, Resch, Ragwitz, Faber, & Huber, 2007)
19	RES taxes	Continuous	[1.9, 6]	tax revenues from environmental taxation as a percentage of GDP (USD dollars (PPP constant prices) per GDP per capita)	(EUROSTAT, 2009b)
20	RDsolar	Continuous	[0, 106.72]	R&D expenditures on solar renewable technologies in million USD (2008 prices and PPP)	(IEA, 2008)
21	RDwind	Continuous	[0, 45.693]	R&D expenditures on wind renewable technologies in million USD (2008 prices and PPP)	(IEA, 2008)
22	RDocean	Continuous	[0, 8.399]	R&D expenditures on ocean renewable technologies in million USD (2008 prices and PPP)	(IEA, 2008)
23	RDbiomass	Continuous	[0, 35.147]	R&D expenditures on biomass renewable technologies in million USD (2008 prices and PPP)	(IEA, 2008)
24	RDgeothermal	Continuous	[0,16.354]	R&D expenditures on geothermal renewable technologies in million USD (2008 prices and PPP)	(IEA, 2008)
25	RDrest	Continuous	[0, 3.59]	R&D expenditures on the rest of renewable technologies in million USD (2008 prices and PPP)	(IEA, 2008)
26	RDtotalRES	Continuous	[0, 151.134]	R&D expenditures on total renewable technologies in million USD (2008 prices and PPP)	(IEA, 2008)
27	RDenergysavings	Continuous	[0, 8.79403]	R&D expenditures on energy saving technologies in million USD (2008 prices and PPP)	(IEA, 2008)
28	Intensity RD RES	Continuous	[0,18.79403]	Total R&D expenditures on RES normalised per total R&D expenditures (GERD) using a multiply coefficient of 1000	Mixed variable - (IEA, 2008) – the total R&D expenditures is from (EUROSTAT, 2009b)
29	Intensity RD ENEF	Continuous	[0,18.13427]	Total R&D expenditures on ENEF normalised per total R&D expenditures (GERD) using a multiply coefficient of 1000	Mixed variable - (IEA, 2008) – the total R&D expenditures is from (EUROSTAT, 2009b)
30	EPOpatents	Continuous	[4.5, 22723.31]	Total number of EPO applications	(OECD, 2008)
31	Energy consumption	Continuous	[39, 277576]	Energy consumption in thousand tonnes of oil equivalent (TOE)	(EUROSTAT, 2009b)
32	Electricity ratio	Continuous	[0.7470199, 2.430341]	Subsidy for electricity prices defined as the ration of electricity prices in households divided by electricity priced in industry (electricity prices measured in PPS/ USD)	(EUROSTAT, 2009b)
33	Gas ratio	Continuous	[0.8795137, 3.117488]	Subsidy for gas prices defined as the ration of gas prices in households divided by gas priced in industry (gas prices measured in PPS/ USD)	(EUROSTAT, 2009b)
34	RD personnel	Continuous	[0.189571,	Full Time Equivalent normalized per	(EUROSTAT, 2009b)

			7.700042]	population	
35	Openness	Continuous	[27.62135, 296.5986]	exports plus imports divided by GDP (total trade as a percentage of GDP)	(PENN, 2007)
36	PPP	Continuous	[0.3610401, 10.36007]	Purchasing Power Parity in USD – constant prices	(PENN, 2007)
37	GDPperCapita	Continuous	[15064.61, 74366.13]	Gross domestic Product per Capita – USD constant prices	(PENN, 2007)
38	Population	Continuous	[382.966, 82431.39]	Population in million people	(PENN, 2007)
39	Governmental RDratio	Continuous	[0.17625, 2.76]	total government budget appropriations or outlays on R&D (**GBAORD**) as a percentage of total general government expenditure	(EUROSTAT, 2009b)
40	TotalRDexpenditure	Continuous	[84.18925, 57135.36]	R&D expenditures include all expenditures for R&D performed within the business enterprise sector (BERD)	(EUROSTAT, 2009b)
41	TotalEnergyRD	Continuous	[0.0021255, 995.678]	R&D for all energy related activities, such as renewable, fossil fuels, nuclear, energy efficiency	(EUROSTAT, 2009b)
42	Tempcountry	Discrete	[1, 15]	Variable transforming country string to number	

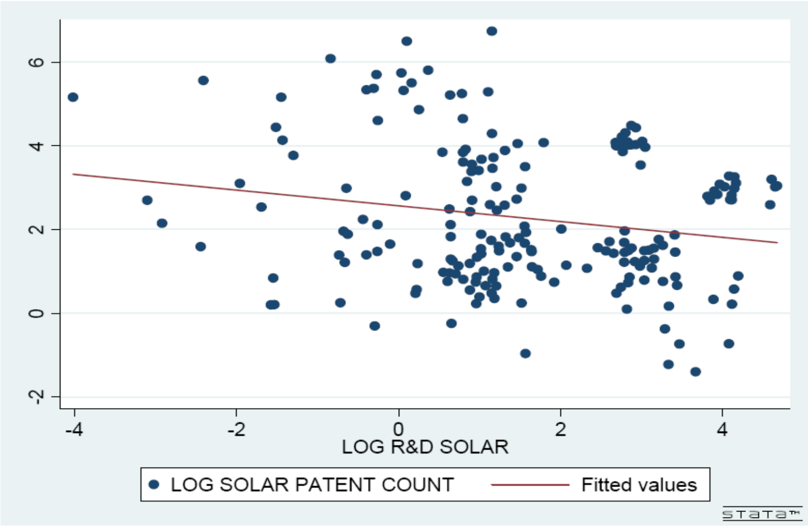
TABLE C. 1 – VARIABLES TABLE

II. SCATTER PLOTS

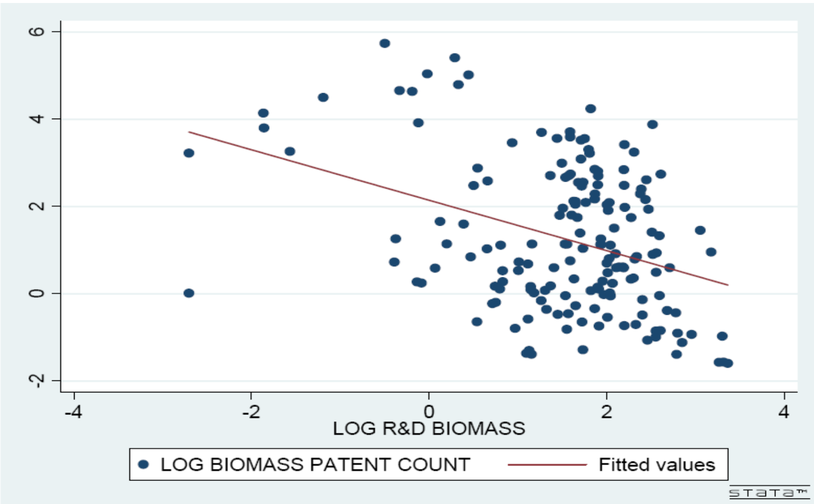
A. R&D EXPENDITURES TO EACH RES



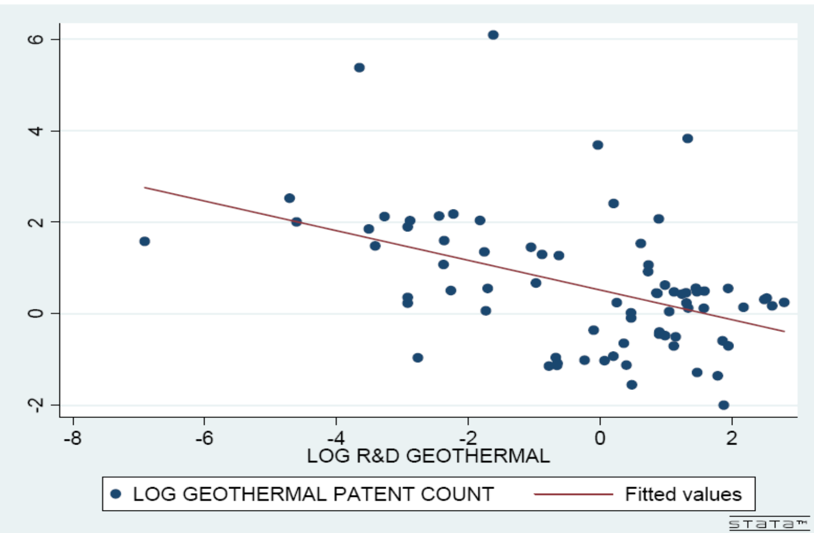
SCATTERPLOT 1 – LOG R&D WIND



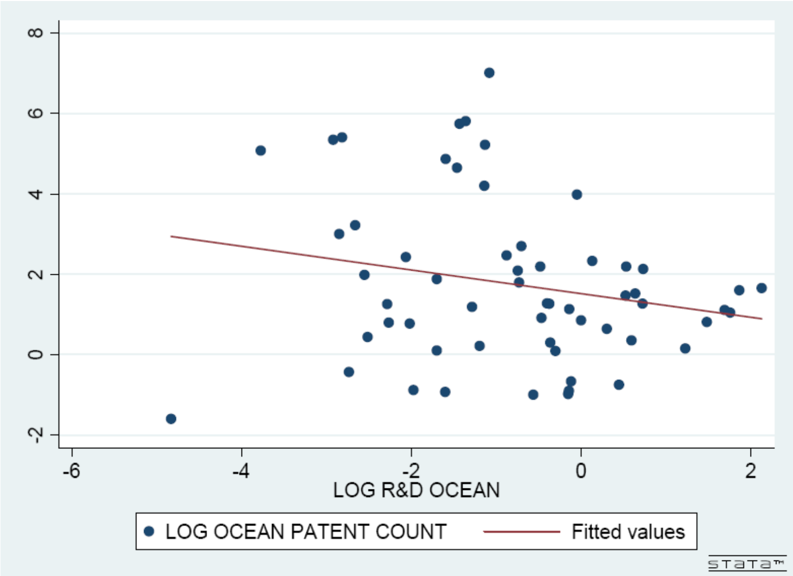
SCATTERPLOT 2 – LOG R&D SOLAR



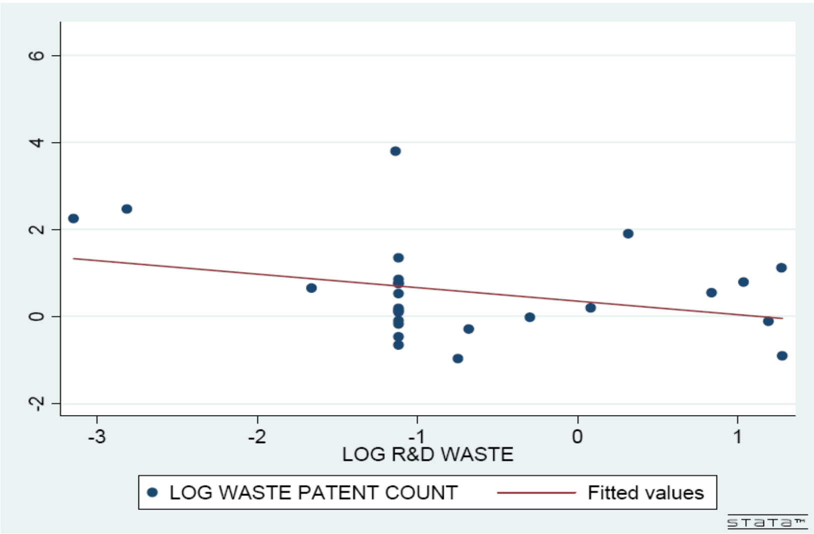
SCATTERPLOT 3 – LOG R&D BIOMASS



SCATTERPLOT 4– LOG R&D GEOTHERMAL

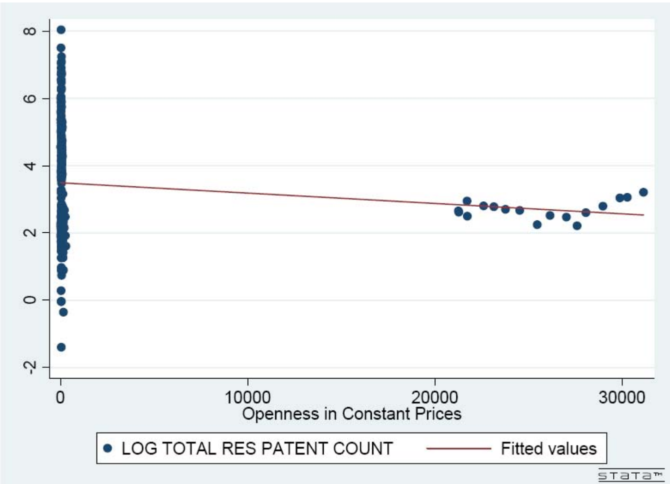


SCATTERPLOT 5 – LOG R&D OCEAN

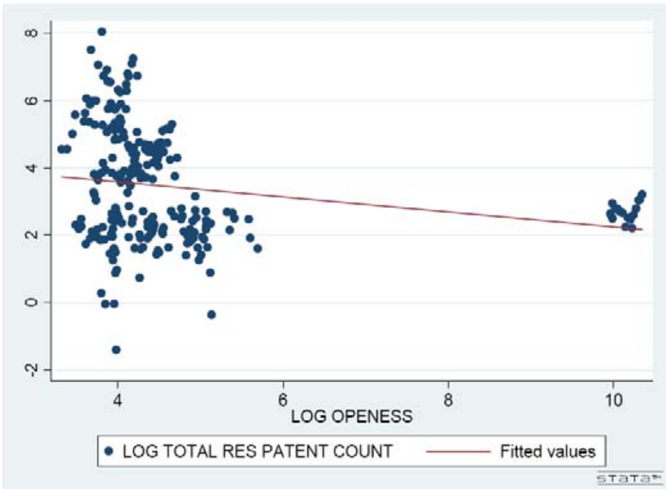


SCATTERPLOT 6 – LOG R&D WASTE

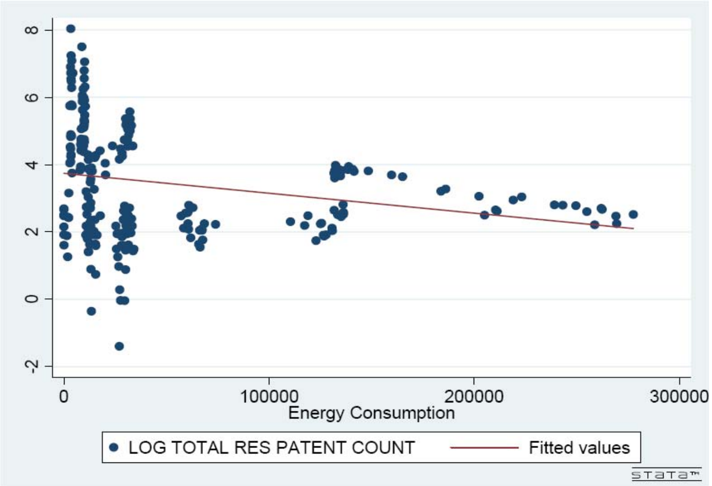
B. General variables (simple and Log values) for total RES



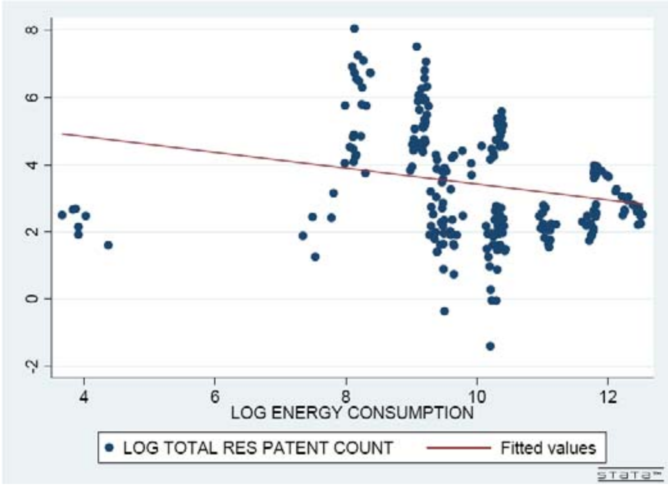
SCATTERPLOT 7 – LOG PATENTS TO OPENNESS



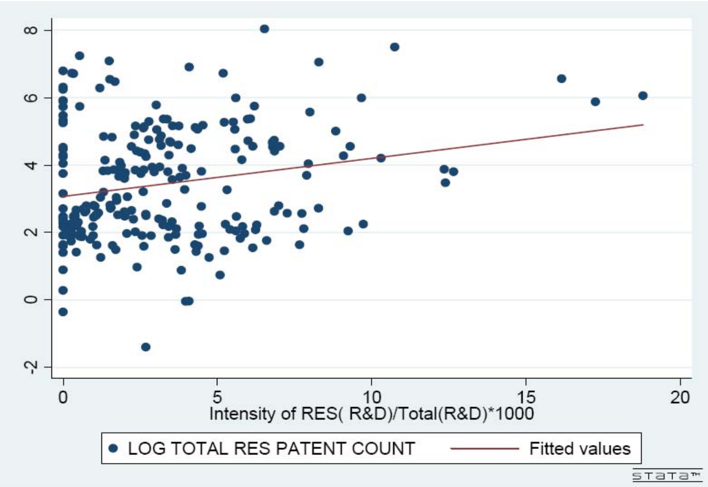
SCATTERPLOT 8 LOG PATENTS TO LOG OPENNESS



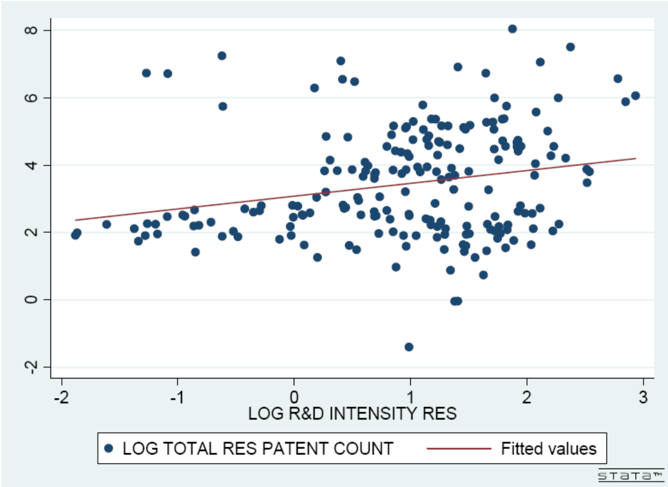
SCATTERPLOT 9 - LOG PATENTS TO ENERGY CONSUMPTION



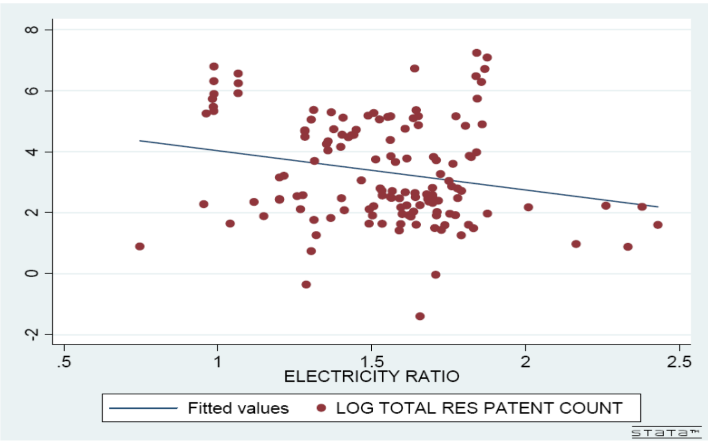
SCATTERPLOT 10 - LOG PATENTS TO LOG ENERGY CONSUMPTION



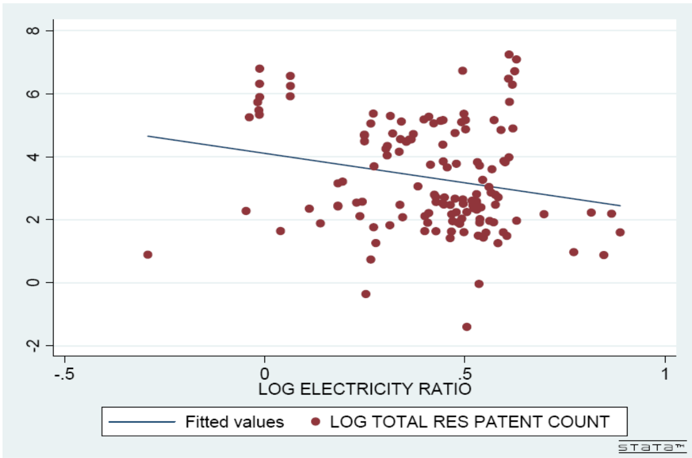
SCATTERPLOT 11 - LOG PATENTS TO R&D RES INTENSITY



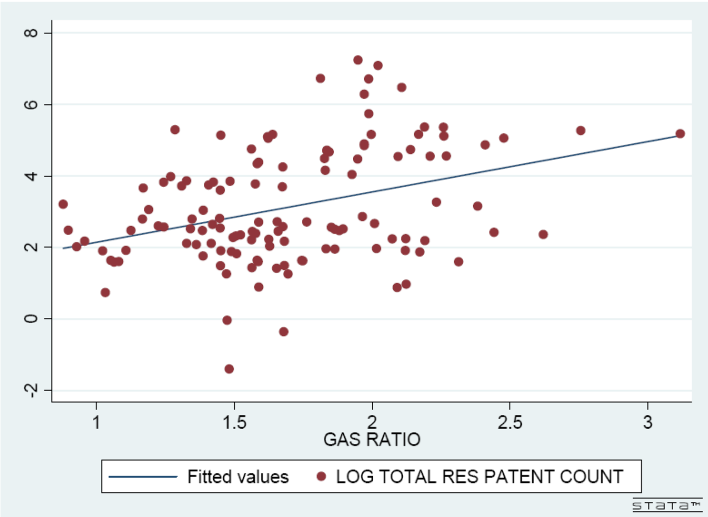
SCATTERPLOT 12 - LOG PATENTS TO LOG R&D RES INTENSITY



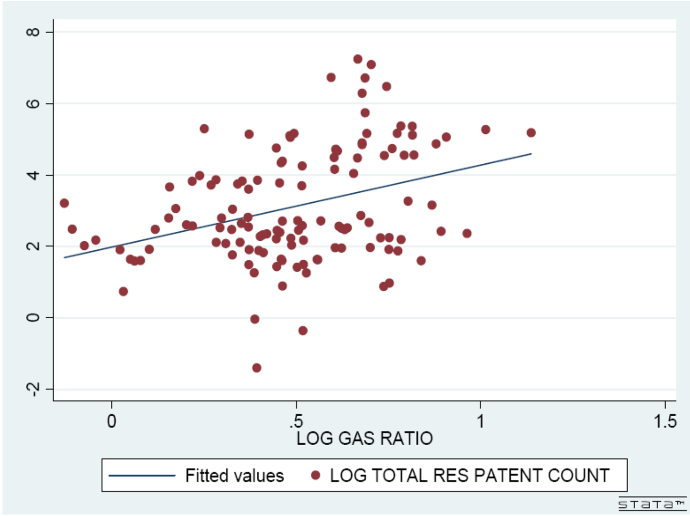
SCATTERPLOT 13 - LOG PATENTS TO RATIO ELECTRICITY



SCATTERPLOT 14 - LOG PATENTS TO LOG RATIO ELECTRICITY



SCATTERPLOT 15 - LOG PATENTS TO GAS RATIO



SCATTERPLOT 16 - LOG PATENTS TO LOG GAS RATIO

APPENDIX D – DATA ANALYSIS

I. POLICY MEASURES

Table D.1

Measures Mean Values							
	RES			ENEF			
	Price based	Financial	Legislative	Price based	Legislative	Financial	Voluntary
AU	1.8	0	0	2	5.941	10.823	5.765
BE	0.5	0	0	1.47	4.176	1	0.706
DK	3	0	0	0	7.529	5.117	1.471
FI	0	1	0	0.412	3.471	1.294	9.766
FR	1	0	0.7	2.647	7.647	6.412	2.765
GE	3	0	0	1.176	14.588	13.823	7.824
GR	1	0	0	0.471	16.824	0	2.294
IE	0.2	0	0.8	0	8.412	2.471	5.765
IT	0.6	0	0.6	0.882	7.588	1.588	1.588
LU	1	0	0	0	1.941	1.059	0
NL	0.3	1	0.3	3.706	5.765	8.706	15.650
PT	3	0	0	0.765	13.529	1.059	0.706
SP	3	0	0	1.588	11.352	13.765	2.471
SE	0	0.6	1.2	0.412	3.176	3.882	1.882
UK	0	0	1	0.412	5.412	5.706	5.765

TABLE D. 1 POLICY MEASURES MEAN VALUES

II. COUNTRY PROFILES

D.2-D.16 Country profiles - Mean estimation

I. Austria (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.7597548	.2237797	.285363	1.234147
solargdp	1.056836	.1267684	.7880989	1.325573

geothgdp	.1585925	.0167655	.1230512	.1941337
oceangdp	.1542989	.0359584	.0780706	.2305272
biomassgdp	.4984479	.0503555	.3916989	.6051968
wastegdp	.681615	.0979727	.473922	.8893079
totalenefgdp	1.069502	.2788421	.4783836	1.660621

TABLE D. 2 AUSTRIA

II. Belgium (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.0835402	.0190178	.0432242	.1238562
solargdp	.0736166	.0147529	.0423418	.1048914
geothgdp	.0039376	.0026959	-.0017775	.0096527
oceangdp	.0055419	.0039742	-.002883	.0139669
biomassgdp	.0183848	.0053353	.0070745	.0296951
wastegdp	.0420113	.0122227	.0161004	.0679221
totalenefgdp	.0790953	.0192889	.0382046	.1199859

TABLE D. 3 BELGIUM

III. Denmark (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.8308134	.1754902	.4587907	1.202836
solargdp	.2576899	.0325858	.188611	.3267688
geothgdp	.0367776	.0103443	.0148485	.0587066
oceangdp	.1570909	.0251981	.1036734	.2105083
biomassgdp	1556918	.0225158	.1079604	.2034231
wastegdp	.3647253	.0460857	.267028	.4624225
totalenefgdp	.9663625	.1846882	.574841	1.357884

TABLE D. 4 DENMARK

IV. Finland (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.190001	.0374713	.1105654	.2694365
solargdp	1547608	.0335746	.0835859	.2259357

geothgdp	.0319365	.0110548	.0085013 .0553716
oceangdp	.0562505	.0112785	.0323413 .0801598
biomassgdp	.2044945	.0426462	.1140886 .2949005
wastegdp	.1509696	.0387011	.068927 .2330123
totalenefgdp	.203765	.0413133	.1161848 .2913452

TABLE D. 5 FINLAND

V. France (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]
windgdp	.4698882	.072548	.3160934 .623683
solargdp	.8825986	.0931924	.6850395 1.080158
geothgdp	.1261508	.0184833	.086968 .1653335
oceangdp	.1424665	.0397382	.0582252 .2267078
biomassgdp	.4809445	.0778153	.3159835 .6459055
wastegdp	.3568269	.031422	.2902152 .4234386
totalenefgdp	.4282656	.0753843	.268458 .5880733

TABLE D. 6 FRANCE

VI. Germany (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]
windgdp	7.017601	.8258381	5.266902 8.768299
solargdp	11.27666	.459782	10.30196 12.25135
geothgdp	.9625833	.0831729	.7862646 1.138902
oceangdp	.9386225	.0724023	.7851366 1.092108
biomassgdp	1.411234	.1178543	1.161394 1.661074
wastegdp	4.430577	.5083637	3.352894 5.50826
totalenefgdp	9.205952	1.292123	6.466774 11.94513

TABLE D. 7 GERMANY

VII. Greece (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]
windgdp	.206844	.0429502	.1157936 .2978944

solargdp	.3868551	.0683745	.2419076	.5318027
geothgdp	.0268946	.0107438	.0041187	.0496704
oceangdp	.1468586	.0317738	.0795013	.214216
biomassgdp	.1078394	.0358398	.0318625	.1838163
wastegdp	.1299474	.0399074	.0453476	.2145473
totalenefgdp	.2297292	.0528047	.1177883	.3416701

TABLE D. 8 GREECE

VIII. Ireland (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.0237666	.0091919	.0042806	.0432527
solargdp	.0257703	.0080969	.0086057	.042935
geothgdp	.0067901	.004649	-.0030653	.0166454
oceangdp	.0328172	.009679	.0122986	.0533359
biomassgdp	.0156944	.007393	.000022	.0313668
wastegdp	.0365372	.0157547	.0031388	.0699357
totalenefgdp	.0301216	.0102955	.0082961	.0519471

TABLE D. 9 IRELAND

IX. Italy (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.0738833	.0313016	.0075269	.1402398
solargdp	.1755386	.0265484	.1192584	.2318187
geothgdp	.0238416	.0124028	-.0024511	.0501344
oceangdp	.0432803	.0131566	.0153895	.071171
biomassgdp	.0547624	.0145288	.0239628	.085562
wastegdp	.1166087	.0206262	.072883	.1603344
totalenefgdp	.1102445	.0330525	.0401763	.1803127

TABLE D. 10 ITALY

X. Luxembourg (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.0008904	.0008904	-.0009971	.0027779
solargdp	.0020693	.0014323	-.000967	.0051056
geothgdp	0	0	.	.
oceangdp	0	0	.	.
biomassgdp	.0017072	.0011724	-.0007782	.0041926
wastegdp	.0036192	.0019553	-.0005259	.0077643
totalenefgdp	.0008904	.0008904	-.0009971	.0027779

TABLE D. 11 LUXEMBOURG

XI. Netherlands (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.3382168	.0495638	.2331463	.4432874
solargdp	.3853348	.0528803	.2732336	.4974361
geothgdp	.0427465	.0130444	.0150936	.0703994
oceangdp	.0572607	.0159279	.0234951	.0910263
biomassgdp	.0311101	.010613	.0086116	.0536087
wastegdp	.1398816	.0241311	.0887258	.1910373
totalenefgdp	.3940903	.0587064	.2696383	.5185424

TABLE D. 12 NETHERLANDS

XII. Portugal (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.5318236	.1931254	.1224161	.9412311
solargdp	.2564832	.0581128	.1332896	.3796768
geothgdp	.0392317	.019484	-.0020726	.080536
oceangdp	.1789529	.0501158	.0727122	.2851936
biomassgdp	.0676073	.0246149	.0154261	.1197884
wastegdp	.1338249	.0303061	.0695789	.1980709
totalenefgdp	.5504936	.1983279	.1300572	.97093

TABLE D.13 PORTUGAL

XIII. Spain (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	1.131278	.2379779	.6267878	1.635769
solargdp	1.322985	.1193214	1.070035	1.575935
geothgdp	.0646967	.0121612	.0389162	.0904772
oceangdp	.2682321	.0473435	.1678684	.3685959
biomassgdp	.4905078	.0701316	.3418354	.6391802
wastegdp	.6357421	.0598911	.5087787	.7627055
totalenefgdp	1.320988	.2497596	.7915216	1.850455

TABLE D. 2 SPAIN

XIV. Sweden (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.2196132	.0401234	.1345553	.3046711
solargdp	.1551541	.0195067	.1138017	.1965065
geothgdp	.1183367	.0267277	.0616764	.174997
oceangdp	.0588139	.0150859	.0268331	.0907947
biomassgdp	.0450505	.0110221	.0216846	.0684164
wastegdp	.0817927	.0148537	.0503043	.1132811
totalenefgdp	.2399018	.0443363	.1459129	.3338906

TABLE D. 3 SWEDEN

XV. United Kingdom (Number of observations = 17)

	Mean	Std. Err	[95% Conf. Interval]	
windgdp	.7844572	.0689154	.6383631	.9305512
solargdp	.5231875	.0382453	.442111	.604264
geothgdp	.0441257	.0123551	.0179341	.0703172
oceangdp	.4144311	.0427043	.3239019	.5049602
biomassgdp	.1535298	.0160782	.1194456	.1876139
wastegdp	.3177703	.0475163	.2170402	.4185004

totalenefgdp	.8819244	.0847131	.7023407	1.061508

TABLE D. 4 UNITED KINGDOM

III. GENERAL VARIABLES

Figure D.1 – Energy Consumption (part 1)

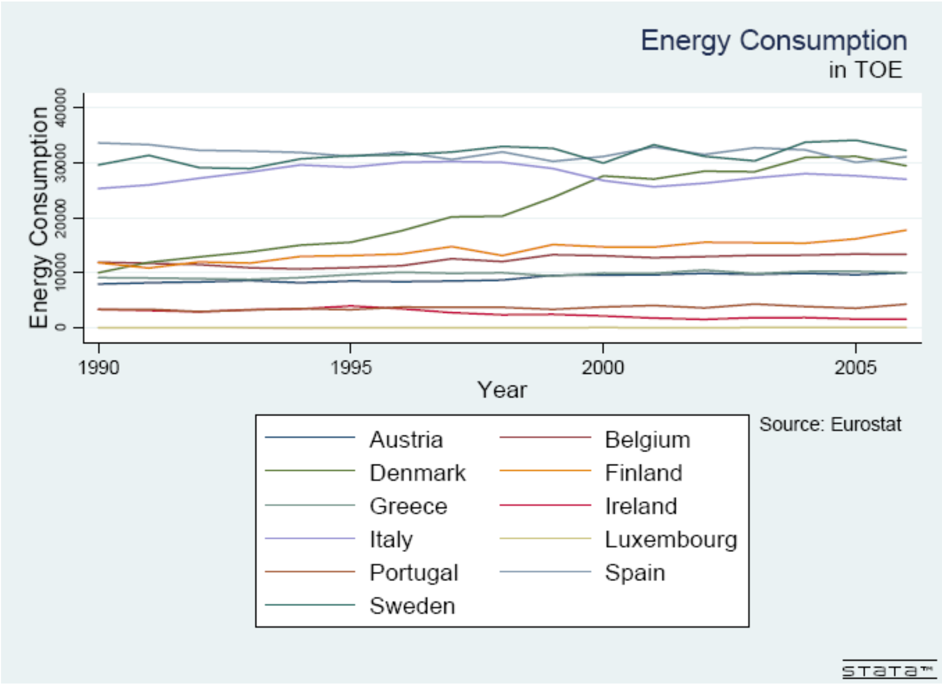


FIGURE D. 1 - ENERGY CONSUMPTION (UNTIL 40000 TOE)

Figure D.2 – Energy Consumption (part 2)

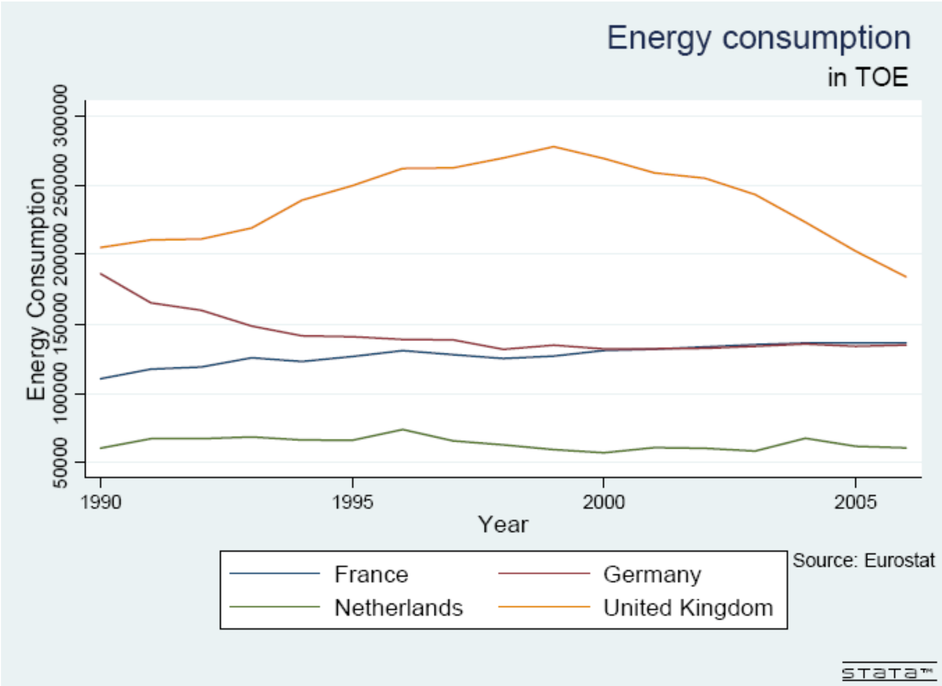


FIGURE D.2 - ENERGY CONSUMPTION (MORE THAN 40000 TOE)

Figure D.3 – Electricity ratio

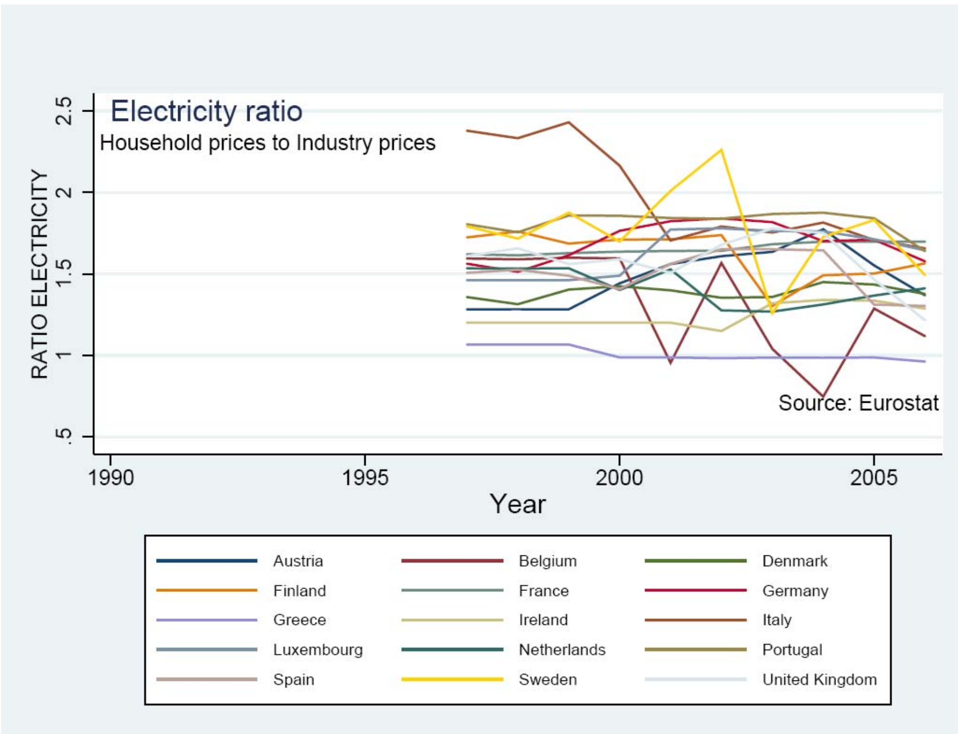


FIGURE D.3 – ELECTRICITY RATIO

Figure D.4 – Openness

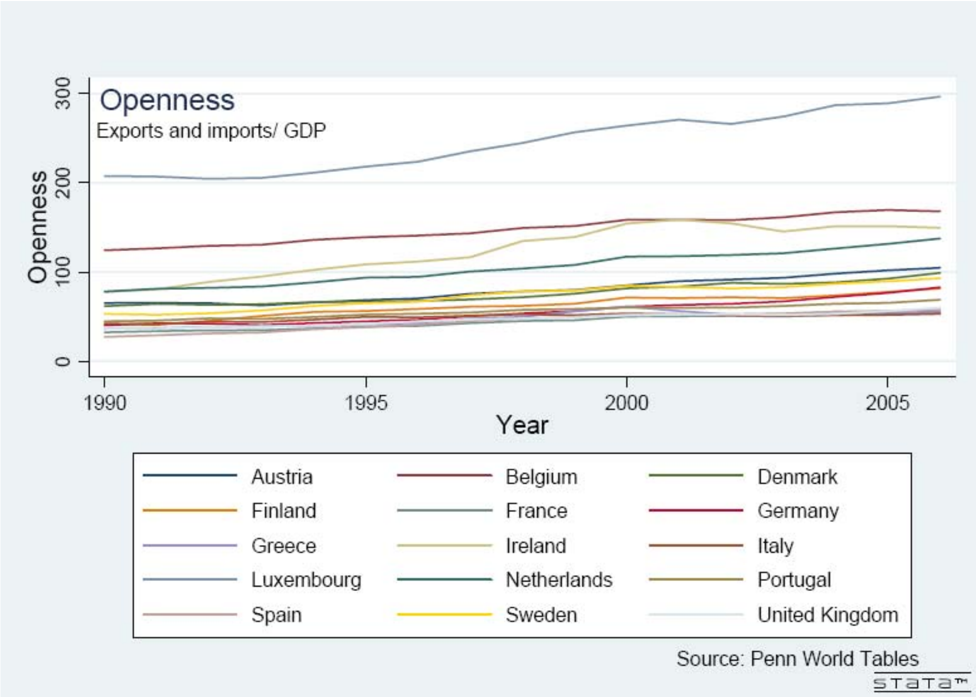


FIGURE D.4 – OPENNESS

Figure D.5 – R&D personnel

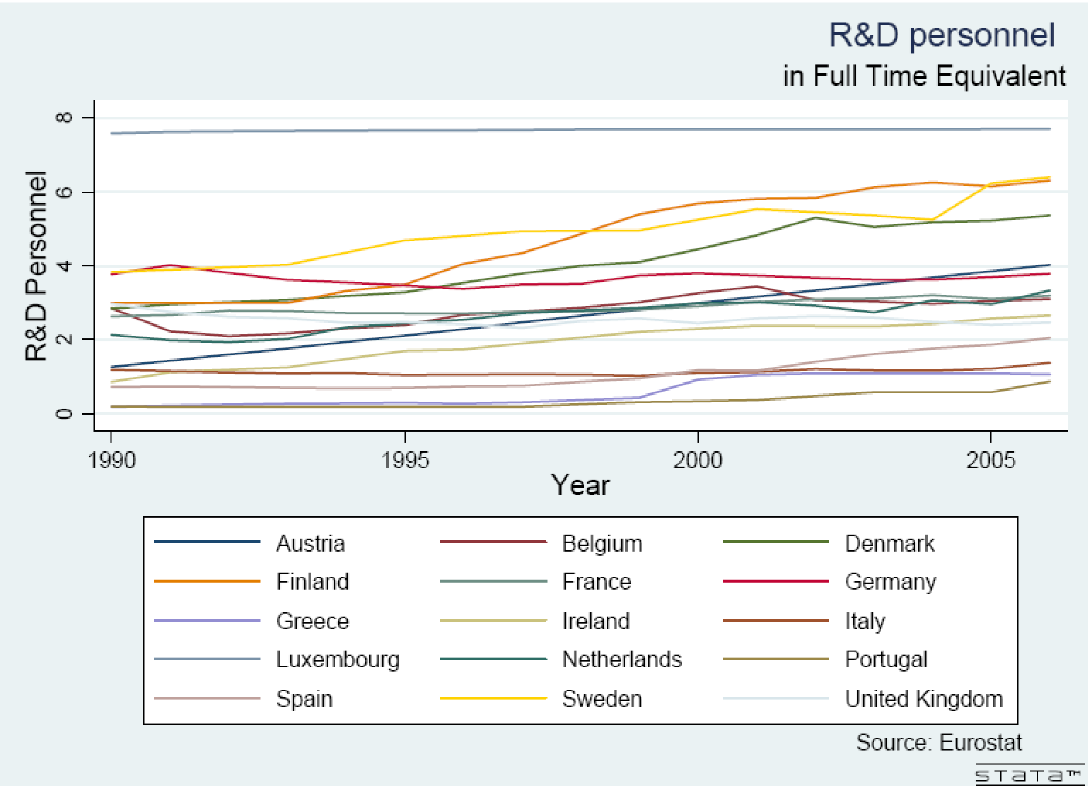


FIGURE D.5 – R&D PERSONNEL

APPENDIX E – REGRESSION ANALYSIS

TABLE E.1 – Correlation Matrix

LN values	Total pat/GDP	EPO patents	Energy cons	Electr ratio	R&D intensity	GDP per cap	R&D pers	Open ness	RES financ	RES legisl	RES price
Total pat/GDP	1.000										
EPO patents	0.3908	1.000									
Energy cons	0.6163	0.7429	1.000								
Electr ratio	0.1393	0.3540	0.1560	1.0000							
R&D intensity	0.1088	-0.1185	-0.0368	-0.1986	1.0000						
GDP per cap	-0.2506	0.3252	-0.2331	-0.0182	-0.0349	1.0000					
R&D pers	-0.056	0.5768	0.1527	0.0601	-0.0515	0.6907	1.0000				
Open ness	-0.5061	-0.0948	-0.5379	-0.2289	-0.0969	0.6801	0.4503	1.0000			
RES financ	-0.1539	0.1861	0.0826	0.1140	0.3145	0.0393	0.3655	0.1829	1.0000		
RES legisl	-0.2266	0.2383	0.2055	-0.0251	-0.2281	0.1092	0.1417	0.0277	-0.1792	1.0000	
RES price	0.5489	-0.1718	-0.0441	0.1015	0.0961	-0.1784	-0.2692	-0.2242	-0.4477		1.0000

TABLE E. 1 – CORRELATION MATRIX RES

Table E.2 General stepwise OLS regression

Dependent variable: LN (patent counts/ GDP)							
Independent variables	**Regression step1**	**Regressio n step2**	**Regressio n step3**	**Regressio n step4**	**Regressi on step5**	**Regressi on step6**	**Regre ssion step7**
LN intensity RES	0.087 (0.09)	0.070 (0.08)	0.086 (0.08)				
LN openness	-0.519 (0.29)	-0.539 (0.28)	-0.539 (0.28)	-0.515 (0.27)			
LN energy consumption	0.606*** (0.07)	0.600*** (0.07)	0.604*** (0.07)	0.599*** (0.07)	0.688*** (0.07)	0.696*** (0.05)	0.674* ** (0.05)
LN ratio electricity	-0.246 (0.42)	-0.301 (0.39)					
LN R&D personnel	0.284* (0.13)	0.274* (0.13)	0.252* (0.12)	0.260* (0.12)	0.115* (0.10)		
RES price based	0.662*** (0.09)	0.686*** (0.07)	0.683*** (0.07)	0.680*** (0.07)	0.696*** (0.07)	0.677*** (0.07)	0.745* **

							(0.06)
RES financial	-0.119 (0.30)						
RES legislative	-0.273 (0.16)	-0.239 (0.14)	-0.234 (0.13)	-0.264* (0.13)	-0.277* (0.13)	-0.280* (0.13)	
Constant	-4.587* (1.80)	-4.459* (1.77)	-4.878*** (1.68)	-4.588*** (1.66)	-7.605*** (1.66)	-7.563*** (0.50)	-7.528*** (0.51)
R2	0.736	0.735	0.734	0.732	0.724	0.722	0.712

TABLE E. 2 - OLS GENERAL STEPWISE REGRESSION

Table E.3 Energy efficiency stepwise OLS regression

Dependent variable: LN patent counts(Energy efficiency) / GDP)					
Independent variables	**Regression 1**	**Regression 2**	**Regression 3**	**Regression 4**	**Regression 5**
LN R&D intensity ENEF	-0.105 (0.058)	-0.108 (0.055)	-0.111* (0.054)	-0.130* (0.053)	-0.164** (0.049)
LN energy consumption	0.164 (0.091)	0.162 (0.089)	0.138* (0.068)	0.113 (0.066)	
LN ratio electricity	1.140** (0.362)	1.142** (0.361)	1.104** (0.348)	1.128** (0.349)	1.216*** (0.348)
LN openness	0.125 (0.287)	0.122 (0.285)			
LN R&D personnel	0.637*** (0.142)	0.635*** (0.140)	0.668*** (0.117)	0.668*** (0.117)	0.668*** (0.117)
ENEF legislative	0.171*** (0.019)	0.170*** (0.019)	0.169*** (0.019)	0.168*** (0.019)	0.164*** (0.019)
ENEF voluntary	-0.002 (0.014)				
ENEF price based	-0.061 (0.047)	-0.063 (0.045)	-0.053 (0.038)		
ENEF financial	0.138*** (0.013)	0.138*** (0.013)	0.137*** (0.013)	0.132*** (0.013)	0.140*** (0.013)
Constant	-6.433** (1.951)	-6.397** (1.924)	-5.635*** (0.723)	-5.451*** (0.714)	-4.369*** (0.331)
R2	0.788	0.788	0.788	0.784	0.779

TABLE E. 3 - ENEF OLS STEPWISE REGRESSION

Table E.4 General RES stepwise GLS regression

Dependent variable: LN (patent counts/ GDP)

Independent variables	Regression step1	Regression step2	Regression step3	Regression step4	Regression step5
LN R&D personnel	0.602*** (0.053)	0.602*** (0.054)	0.605*** (0.052)	0.603*** (0.053)	0.631*** (0.038)
LN ratio electricity	-0.189* (0.089)	-0.200* (0.090)	-0.186* (0.083)	-0.178* (0.083)	
LN energy consumption	0.488*** (0.069)	0.516*** (0.067)	0.482*** (0.069)	0.504*** (0.068)	0.306*** (0.045)
LN intensity RES	1.075*** (0.017)	1.075*** (0.017)	1.073*** (0.017)	1.074*** (0.017)	1.028*** (0.014)
LN openness	0.851*** (0.106)	0.827*** (0.106)	0.838*** (0.103)	0.848*** (0.103)	0.825*** (0.053)
RES price based	0.035 (0.029)	0.028 (0.027)	0.027 (0.026)		
RES financial	0.081 (0.109)	0.015 (0.054)			
RES legislative	0.022 (0.032)				
Constant	-7.448*** (0.828)	-7.587*** (0.816)	-7.312*** (0.814)	-7.536*** (0.806)	-5.587*** (0.515)
N	119	119	119	119	208
Wald chi2	4573.461	4413.596	4672.428	4545.425	6148.360
Prob> chi2	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE E. 4 - GLS RES GENERAL STEPWISE REGRESSION

Table E.5 General ENEF stepwise GLS regression

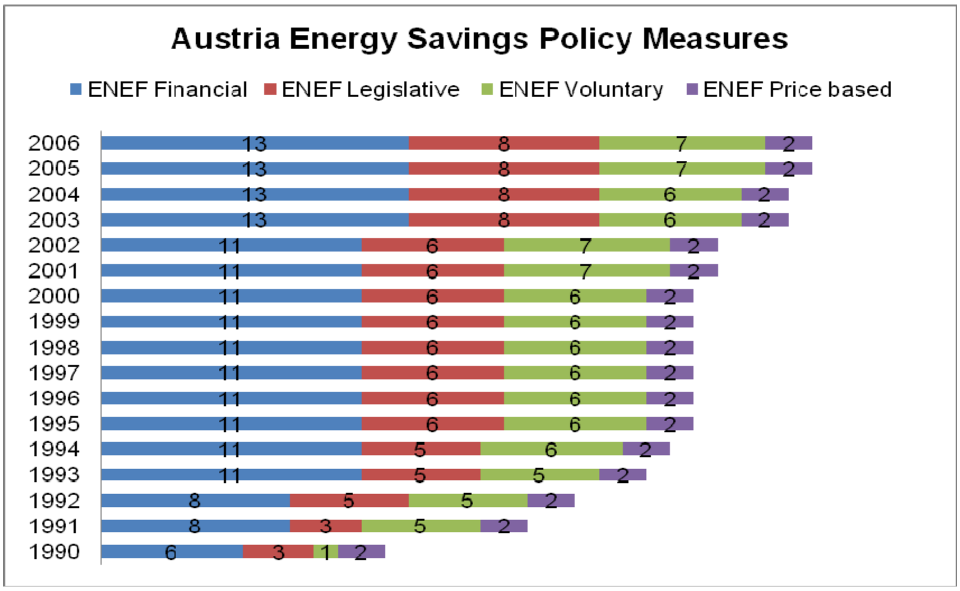
Dependent variable: LN (patent counts/ GDP)					
Independent variables	**Regression step1**	**Regression step2**	**Regression step3**	**Regression step4**	**Regression step5**
ENEF legislative	0.193*** (0.031)	0.191*** (0.030)	0.193*** (0.026)	0.193*** (0.024)	0.092*** (0.015)
ENEF voluntary	-0.007 (0.025)				
ENEF price based	-0.066 (0.065)	-0.070 (0.062)	-0.070 (0.061)		
ENEF financial	0.078** (0.025)	0.081*** (0.022)	0.082*** (0.021)	0.082*** (0.020)	0.070*** (0.017)
LN energy consumption	0.523** (0.191)	0.490** (0.178)	0.504*** (0.136)	0.405*** (0.091)	0.402*** (0.091)
LN ratio electricity	0.627 (0.505)	0.686 (0.497)	0.682 (0.482)	0.708 (0.471)	

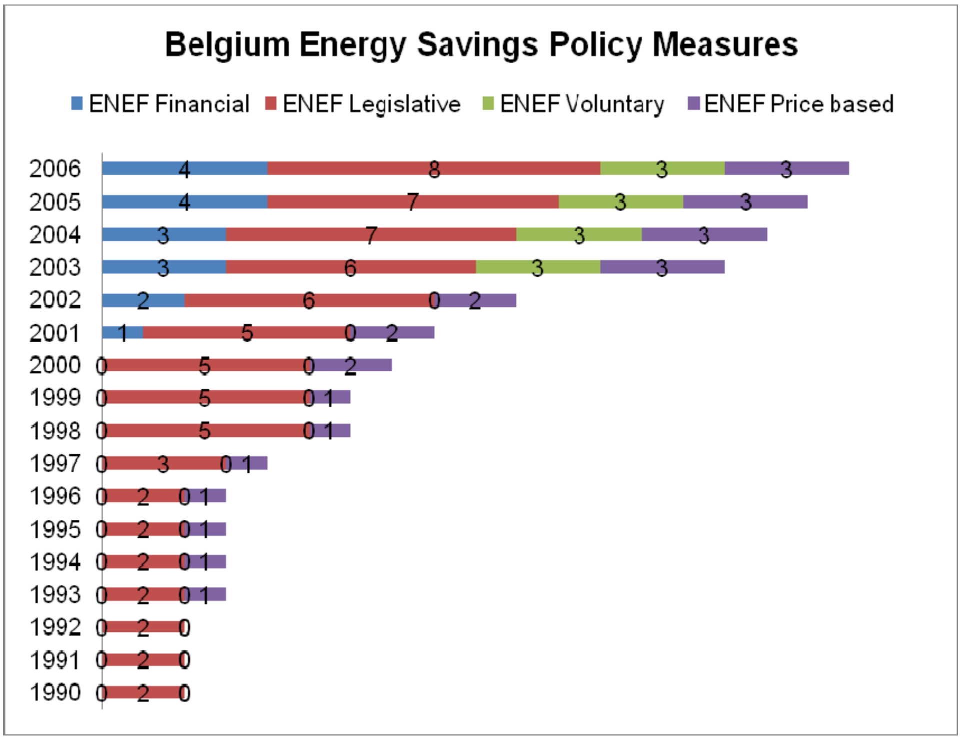
LN openness	0.525 (0.553)	0.440 (0.524)	0.426 (0.510)		
LN intensity RES	0.024 (0.080)	0.007 (0.075)			
LN R&D personnel	0.573* (0.238)	0.565* (0.227)	0.548** (0.207)	0.607*** (0.162)	0.336** (0.124)
Constant	-11.422** (3.669)	-10.765** (3.473)	-10.841*** (3.218)	-8.090*** (0.936)	-6.487*** (0.898)
N	126	126	126	126	211
Wald chi2	0.0000	0.0000	0.0000	0.0000	0.0000
Prob> chi2	104.20	112.24	133.34	145.39	161.69

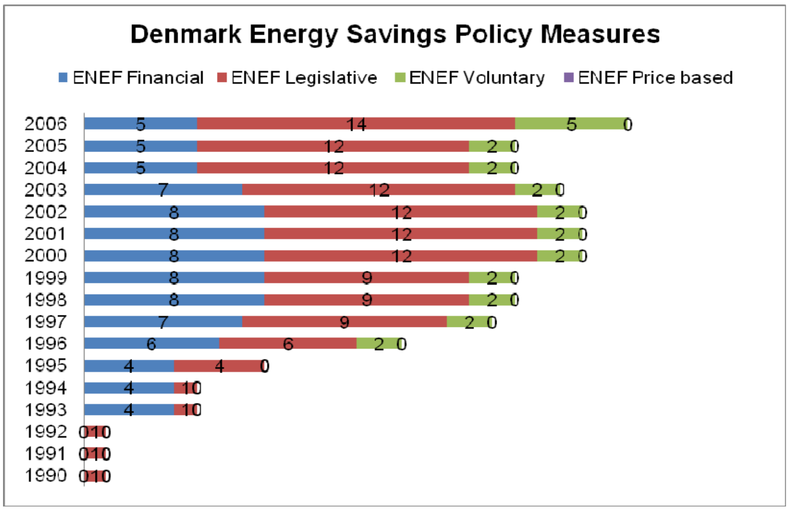
TABLE E. 5 - GLS ENEF GENERAL STEPWISE REGRESSION

APPENDIX F – POLICY MEASURES PER COUNTRY

I. ENEF POLICY MEASURES (MURE, 2008)






Denmark Energy Savings Policy Measures
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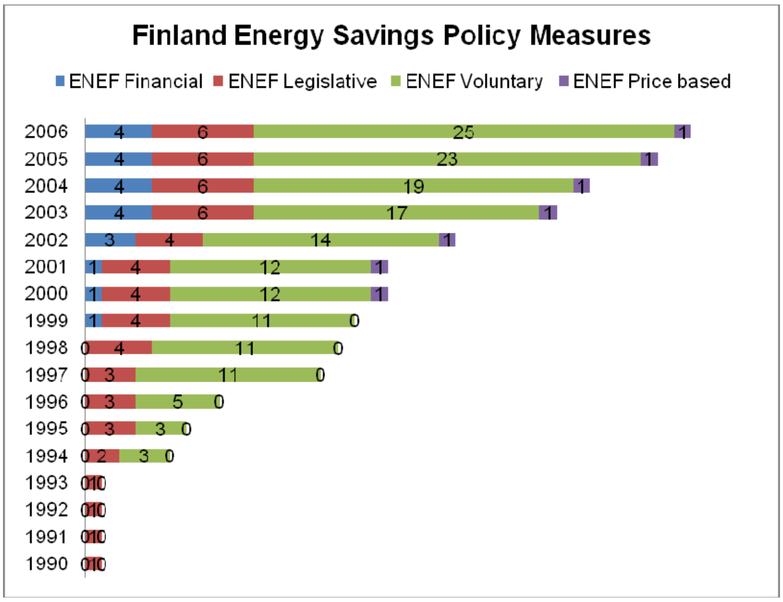
Finland Energy Savings Policy Measures
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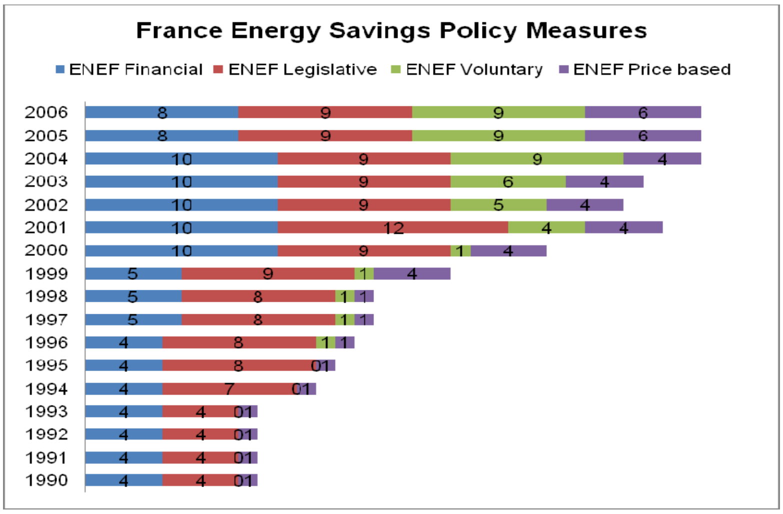
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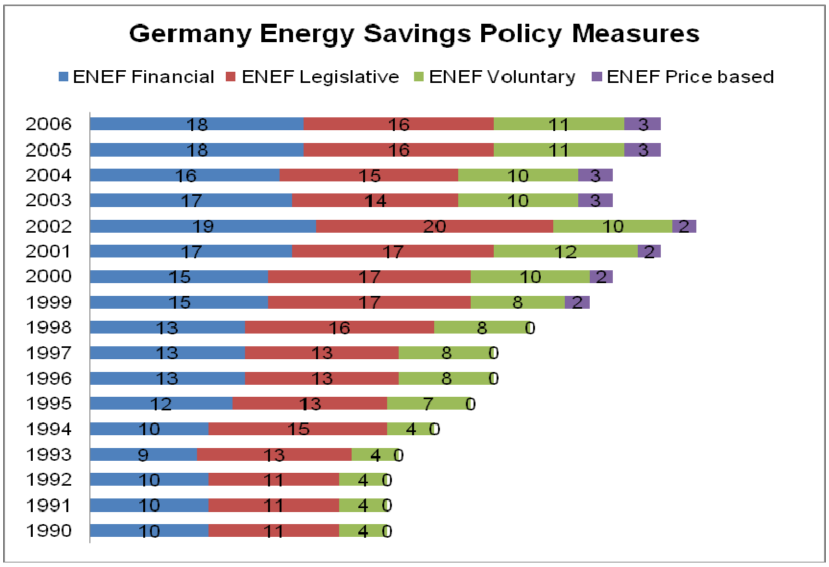
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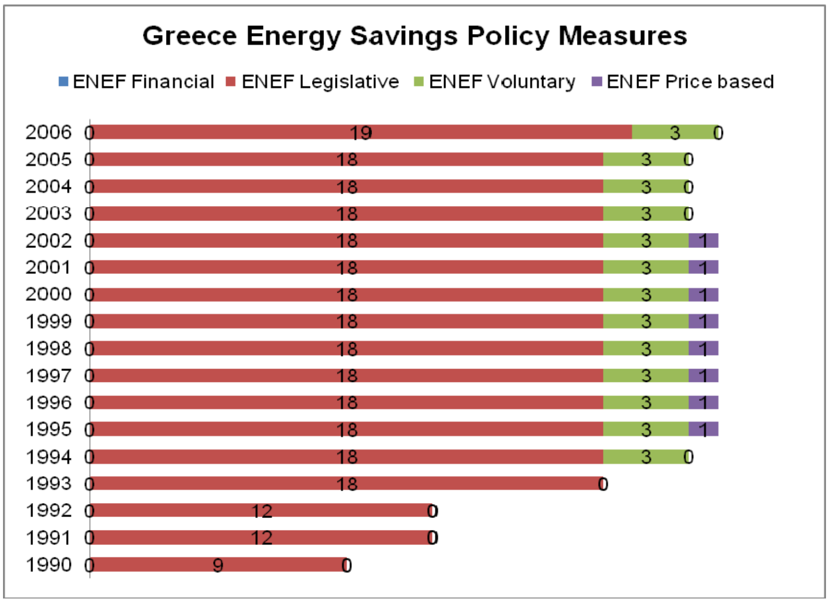
ENEF Legislative
ENEF Voluntary
ENEF Price based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ENEF Voluntary
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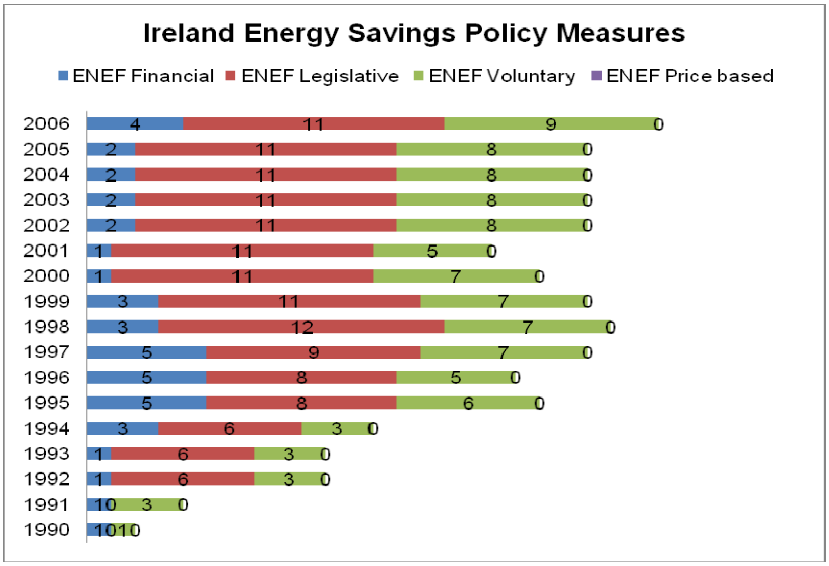
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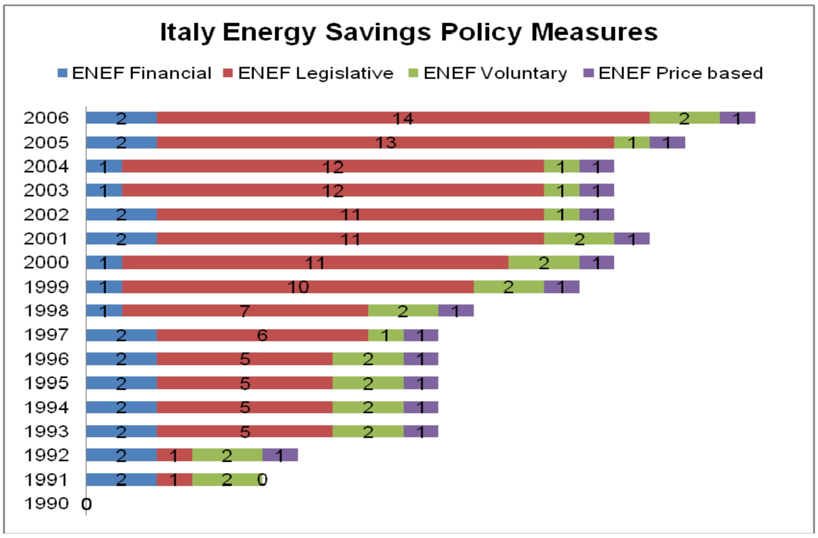
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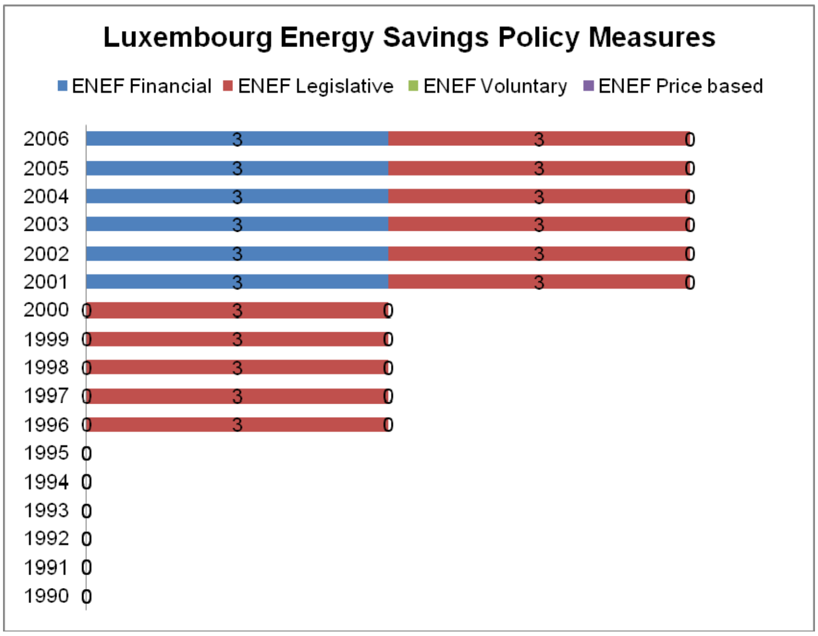
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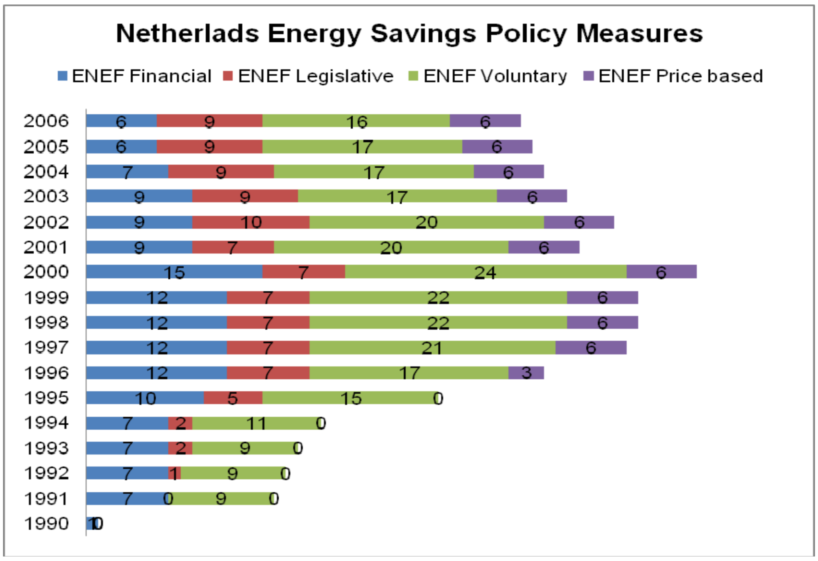
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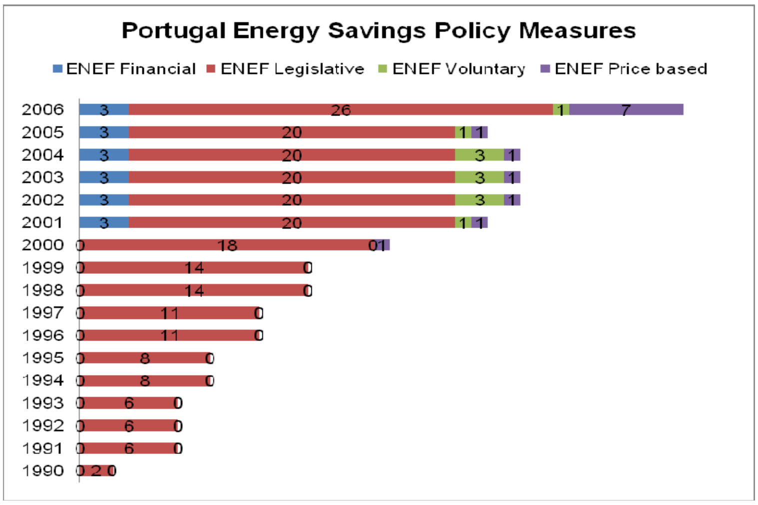
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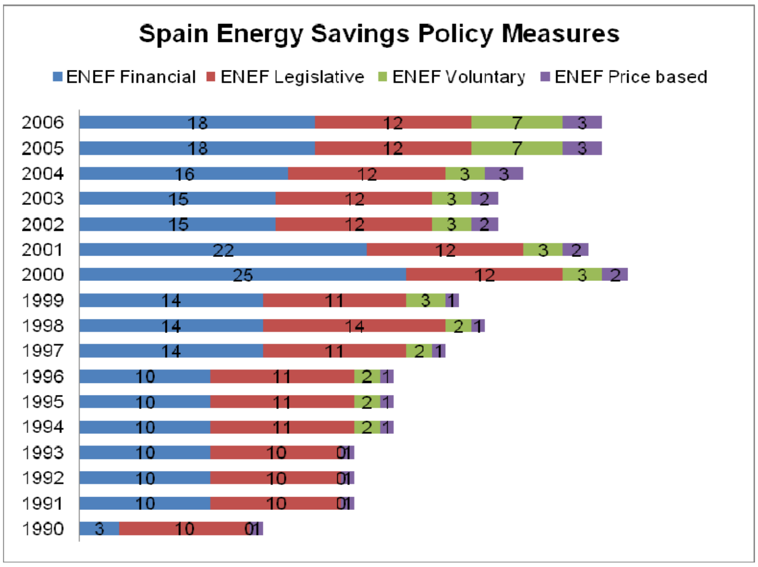
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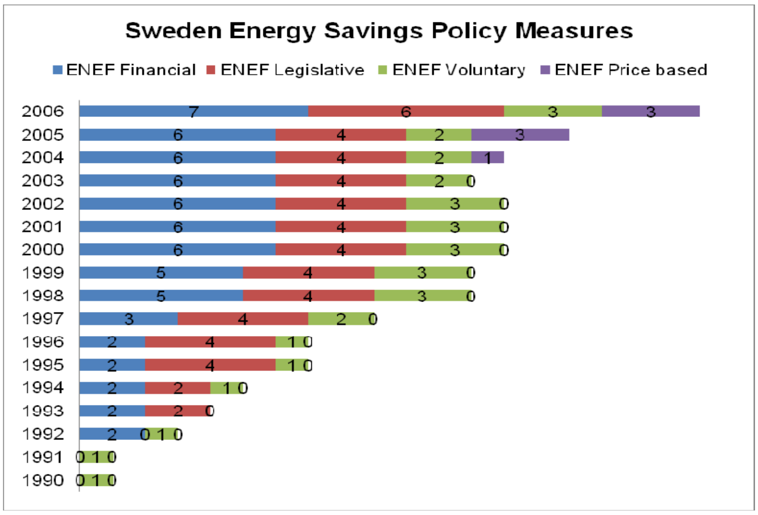
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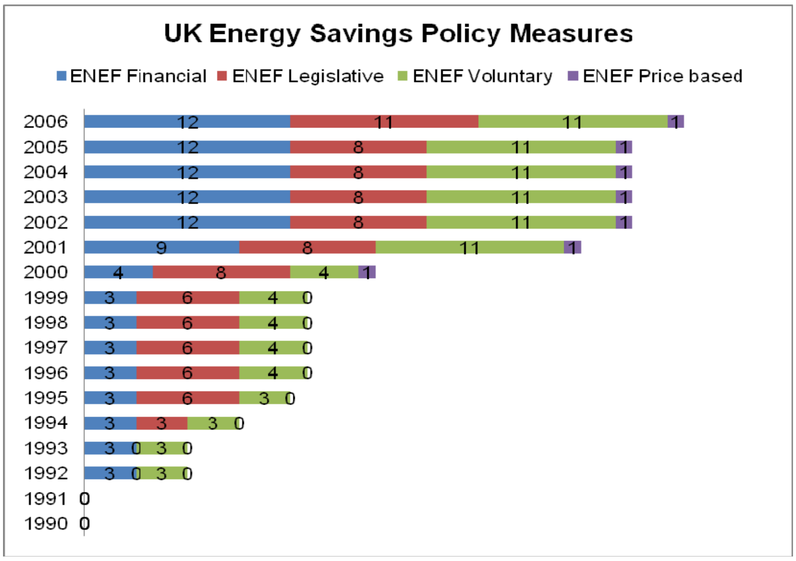
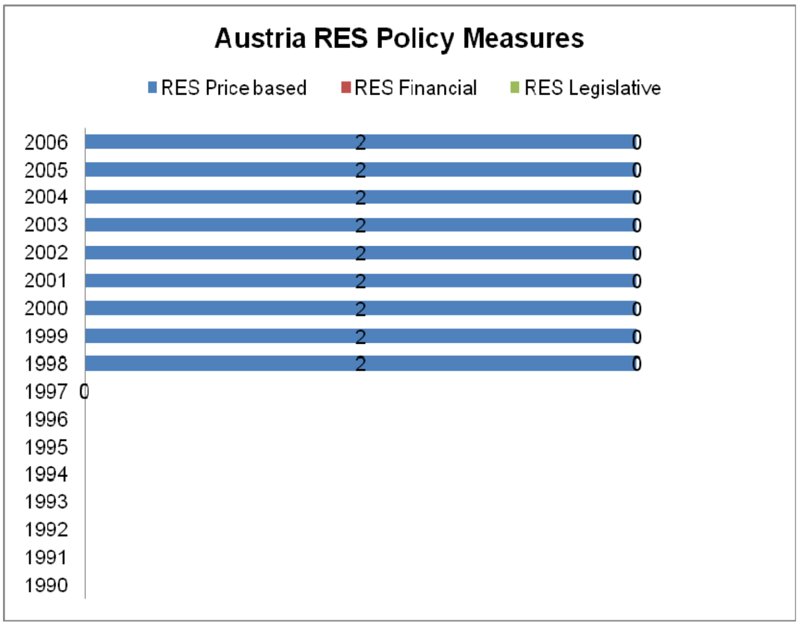
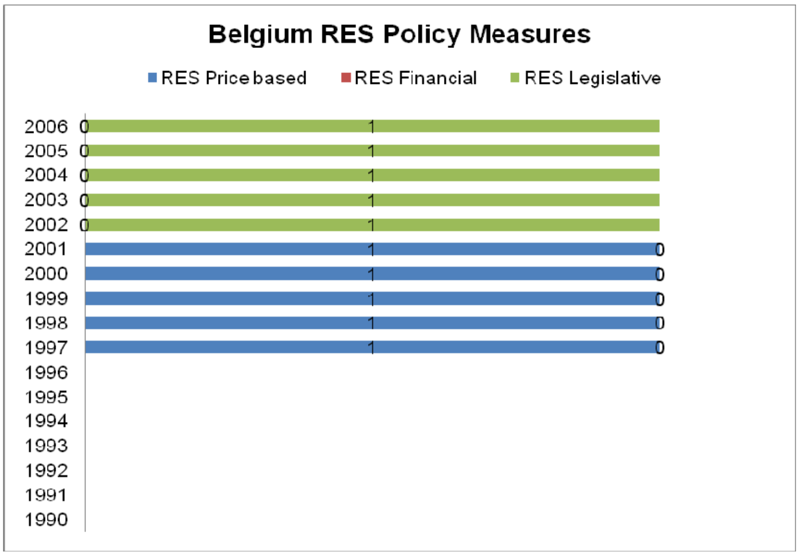


II. RES POLICY MEASURES (HAAS ET AL. 2007)

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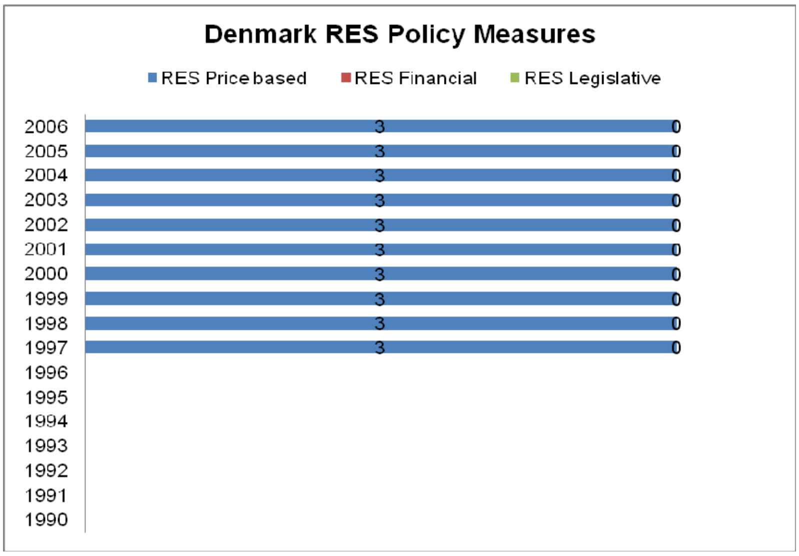
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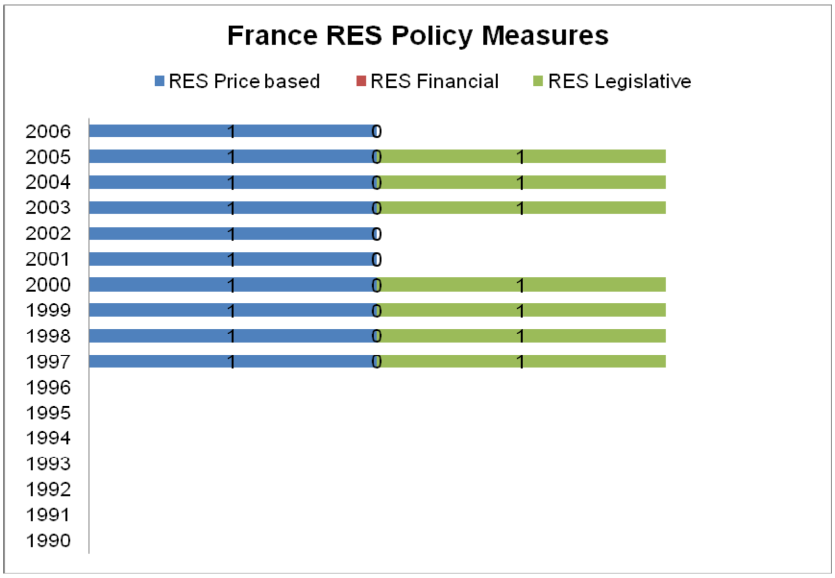
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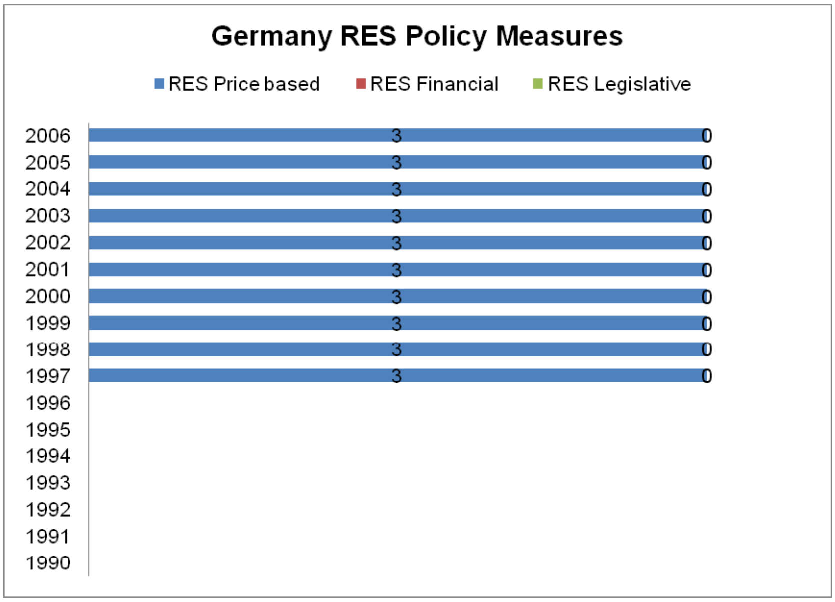
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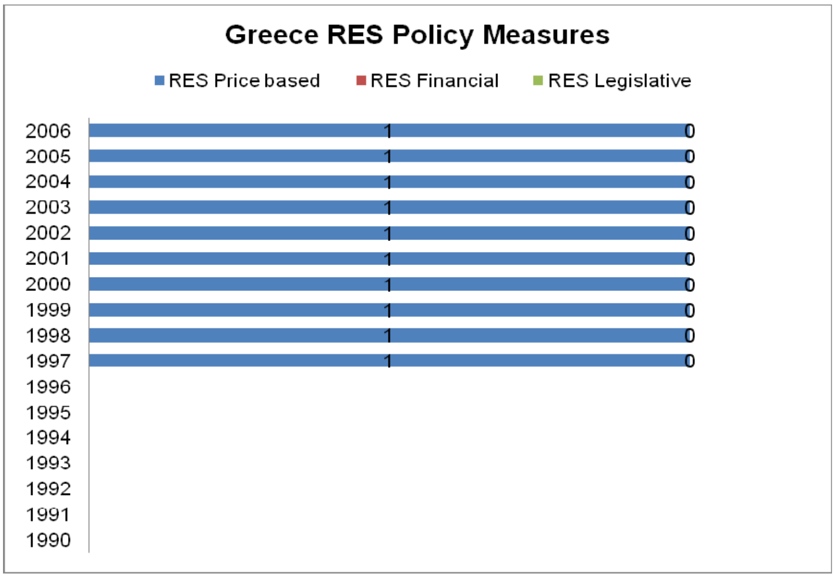
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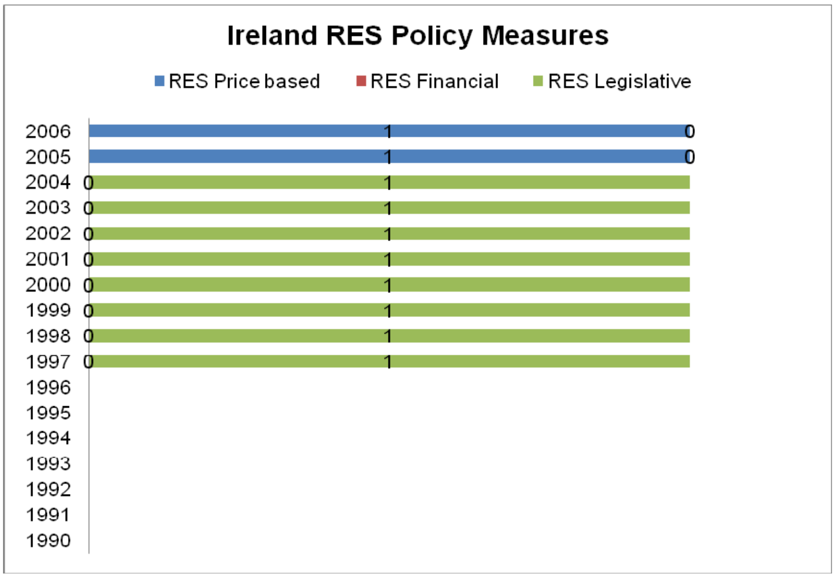
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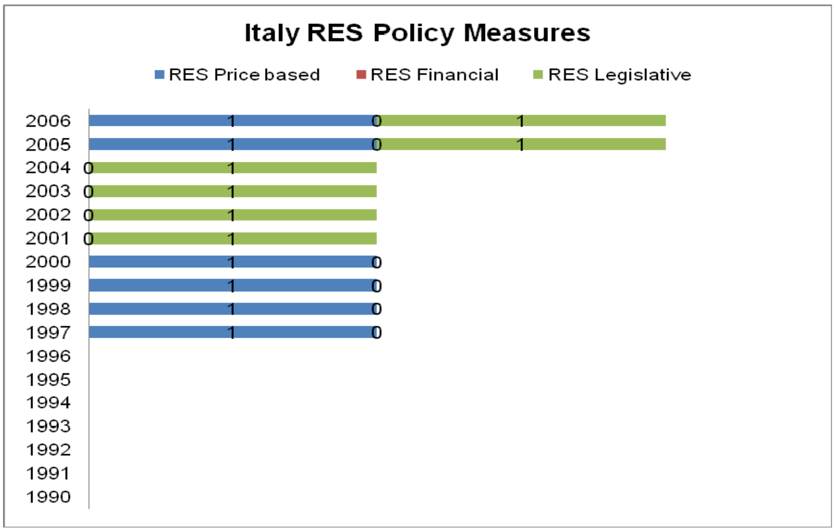
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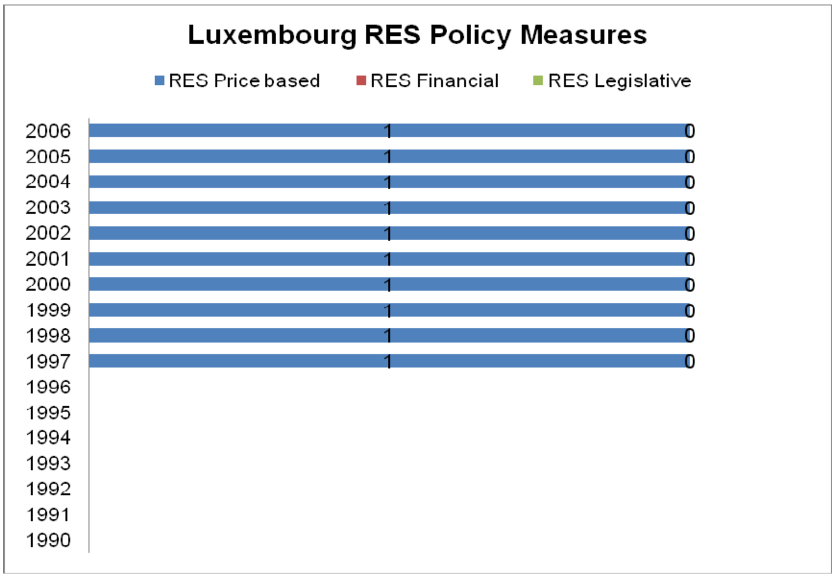
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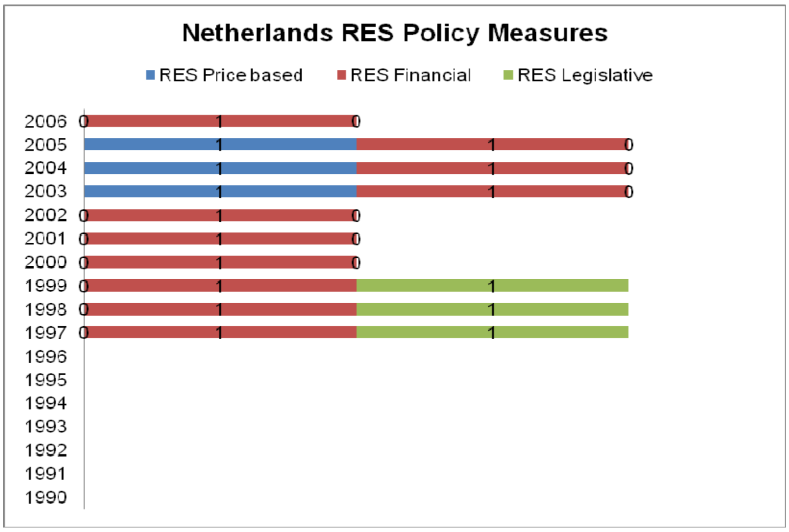
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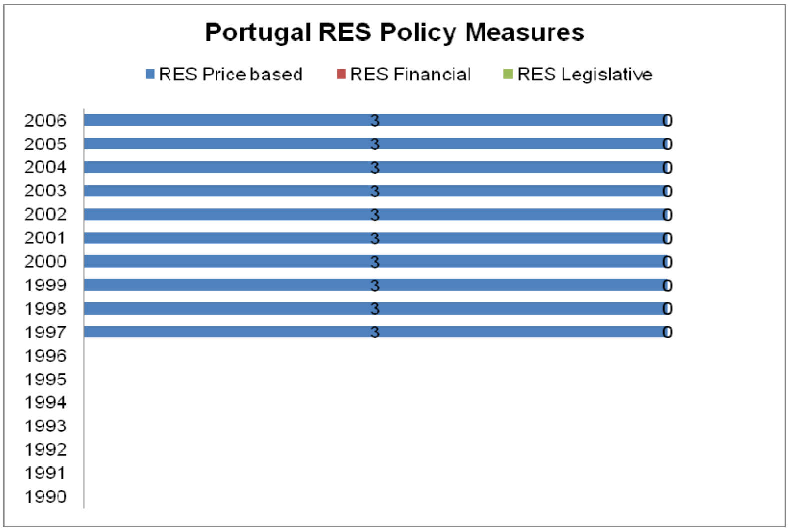
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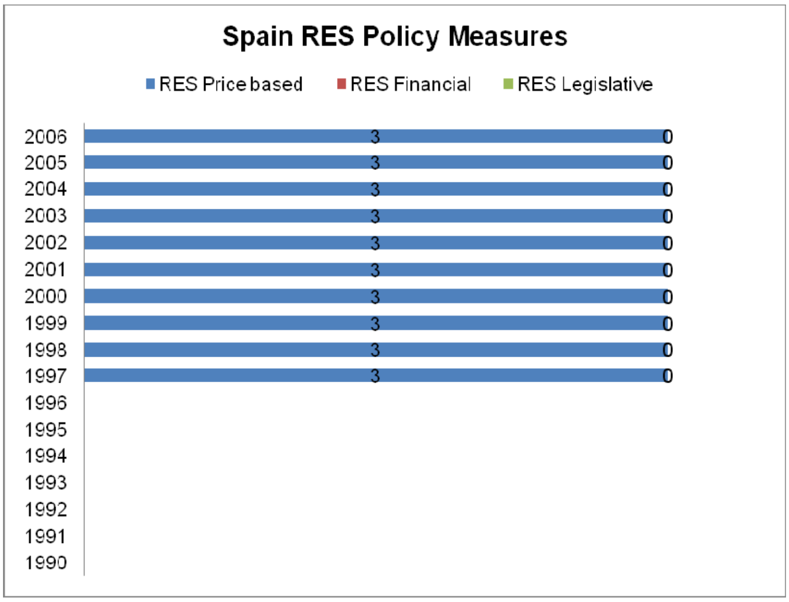
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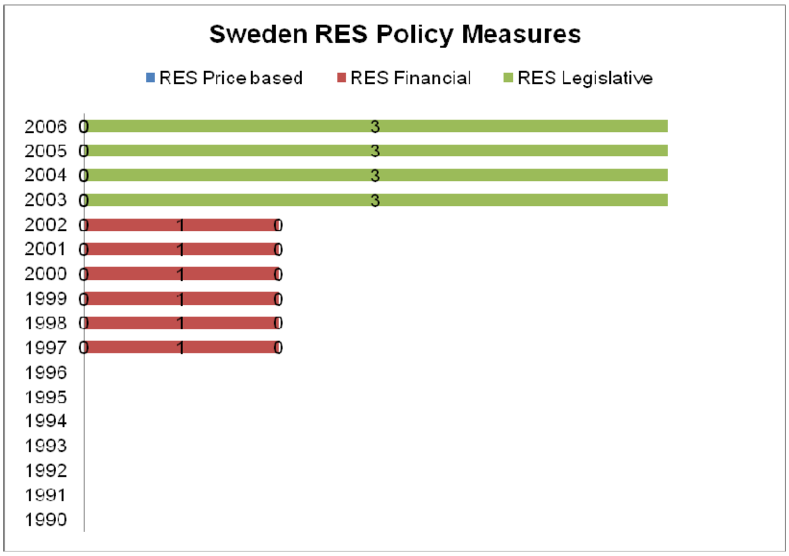
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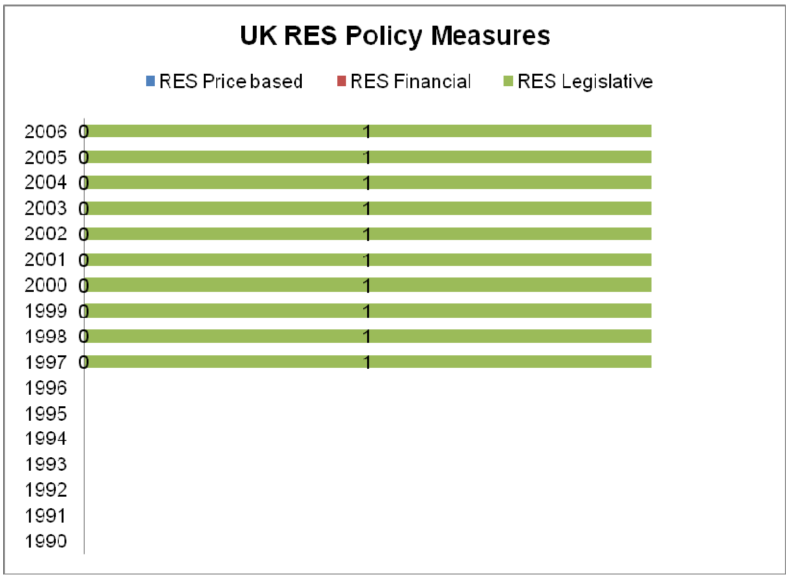
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