Stockholm School of Economics

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Master's Thesis

A Study of the Innovative Capacity in Renewable Energy Technologies in the EU-15 Countries

– a sectoral innovation systems approach

The unsustainability of the current energy provisions in the EU is becoming increasingly evident as the awareness concerning the finiteness of non-renewable resources is increasing, signs of climate change due to pollution arise and the vulnerability of relying on energy imports becomes apparent. One response to these challenges is the promotion of renewable energies, which however still are in an early state of technological development. The EU is therefore promoting innovations within renewable energy technologies, yet with very differing results between the member states. Based on the sectoral innovation systems approach and on the national innovative capacity model developed by Furman *et al.* (2002), this thesis applies a fixed effects regression model to the renewable energy technologies sector for the years 1998 to 2004 in order to identify the determinants of innovation capacity within renewable energies. The aim is thus to understand why some countries have been more successful in creating an innovative capacity in renewable energy technologies than others. It was found that the parameters in the regression are in fact not constant over the countries, but that the patent generation in this sector is determined differently in Germany than in the other countries. For the other 14 countries, the results show that population size, accumulated patents, R&D investments in the sector and the year of introducing tax measure incentives for promoting renewable energies determine the innovative capacity in renewable energy technologies. Besides the intercept dummy variable for Italy, the patent stock was found to have the largest impact on the patent generation in renewable energies, indicating that the national innovation system is in fact the largest determinant for the innovative capacity in the renewable energy sector. The implication of this is thus that it might be more worthwhile investing in the national innovative capacity than in factors specific to the renewable energy sector. Due to the restricted availability of data in this field, the results should however be treated with some caution.

Keywords: Renewable Energy; Sectoral Innovation Systems Approach; EU-15

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1. INTRODUCTION

"The EU and the world are at a cross-road concerning the future of energy. Climate change, increasing dependency on oil and other fossil fuels, growing imports, and rising energy costs are making our societies and economies vulnerable. These challenges call for a comprehensive and ambitious response" (European Commission (henceforth EC), 2007, p. 3).

As this quotation illustrates, the concerns about the unsustainability of the current energy supply and consumption as well as the pressure to act on it are increasing. One such concern is the use of finite resources, which will drive up prices as the resources become increasingly scarce and finally become depleted. A second major worry is climate change caused by greenhouse gas (GHG) emissions. The EU is in fact one of the largest contributors to GHG emissions accounting for about 14 percent of world emissions (EC, 2004a). A third area of consideration is related to the dependence on other countries for imports of energy based on non-renewable sources, such as oil and gas, as several of these countries are politically rather unstable. With the EU importing about 50 percent of its energy needs, this creates an instrument of power for those countries exporting the energy. If nothing is done, this share will rise to 70 percent by 2020 (EC, 1997).

One response to these challenges is the promotion of renewable energy sources. As the EC (2004a, p.1) states, "The development of renewable energy sources is a central aim of EU energy policy". Renewable energies play a central role for energy policy, because "in the complex picture of energy policy, the renewable energy sector is the one energy sector which stands out in terms of ability to reduce GHG emissions and pollution, exploit local and decentralised energy sources, and stimulate world-class high-tech industries" (EC, 2007, p. 3). The sector however relies heavily on technological advance in order to grow and hence the member states are promoting innovation in renewable energies through various incentives. Yet the effect of these incentives on the technological advance, as measured by patent generation, differs considerably across the member states. One question arising is therefore why some countries have been more successful in promoting innovation in renewable energies than others and what this implies for the near future innovative capacity in the renewable energy sector.

One widely used method for studying environments promoting innovation which is also applied by the OECD[1], is the innovation systems approach. An innovation system is defined as "the determinants of innovation processes, which are all important economic, social, political, organisational, institutional, and other factors that influence the development, diffusion, and use of innovations" (Edquist, 2005, p. 182).

This thesis thus sets out to apply the innovation system approach to the renewable energy sector in order to identify the explanatory factors for generating patents within renewable energy technologies. In other words, **this study seeks to identify the factors that drive patent generation in the renewable energy sector in the EU-15 countries with the aim to learn about certain success factors for this industry**. In order to achieve this, a fixed effects model based on the innovative capacity model developed by Furman *et al.* (2002) will be used to identify the key determinants of patent generation in the renewable energy sector in the EU-15 countries in the years 1998 to 2004.

In conducting this study two delimitations will be made. Firstly, hydropower will not be included in the empirical part, as it is conceived as having reached its potential in the EU-15 (EC, 1997) and is hence less relevant for this study that sets out to evaluate the future innovation potential.[2] Focus will thus lie on those technologies with the greatest near-time potential, being wind energy, bioenergy and solar energy. Secondly, as the title indicates, only the EU-15 countries will be included in the study, as the relevant data for the newer member states is not available.

The structure of the thesis is as follows. In section 2, background information on the renewable energies market and the innovation potential in wind, bio- and solar energy will be presented. Section 3 will establish the theoretical framework, beginning with an introduction to the sectoral innovation systems approach followed by a presentation of relevant previous findings. Section 4 will first present the model and the explanatory variables, the patent data and the expected outcomes. In section 5, the data and the results will be presented while section 6 will provide a discussion of the model. Section 7 will conclude the paper.

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[1] See for instance OECD (1996a) on the Austrian National Innovation System or OECD (1996b) on the Danish National Innovation System.

[2] It may be added that large hydropower plants were previously not considered to be a renewable energy source according to the official definition in the EU and are in general not subject to the same policy incentives as the other renewable energy technologies.

2. THE RENEWABLE ENERGIES MARKET

This section provides an overview of the renewable energies market in the EU-15. A general introduction to this market[3] will be given in a first part, followed by a brief presentation of the current state of technology and near-term potential in the fields of wind energy, bioenergy and solar energy in a second part.[4]

2.1 General overview

The underlying framework for the efforts to promote renewable energy in the EU is found in the Directive on Electricity Production from Renewable Energy Sources (2001/77/EC, Article 2a) of the European Parliament and of the Council. The aim of the Directive is to create a framework for electricity from renewables, which will contribute towards achieving the indicative target of a 12 percent renewables share in gross inland energy consumption by 2010 (EEA[5], 2001). The Directive defines the term renewable energy in the following words: "renewable energy sources shall mean renewable non-fossil energy sources, i.e. wind, solar, tidal, hydropower, biomass, landfill gas, sewage treatment gas and biogases" (EC, 2001, p. 35). Hence, renewable energy sources have diverse origins, which require equally diverse technologies to capture them. *Table 1* summarises the current relative importance of the different renewable energy sources:

Table 1: Share of total renewable energy generation (excl. large hydro) in EU-15 2004.

Renewable energy source	**Share**
Wind onshore	41.0%
Wind offshore	1.0%
Biogas	6.0%
Solid biomass	19.0%
Bio-waste	7.0%
Geothermal electricity	4.0%
Hydro – small scale	21.0%
Photovoltaic	0.1%

Source: EWEA[6] (2005a).

[3] In this part all renewable energy sources are presented, i.e. also hydropower, in order to give an accurate picture. However, as already mentioned hydropower will not be included in the empirical part of the thesis.
[4] It should be noted that some information relates to electricity generation, whereas other information describes energy generation. This inconcistency is a result of the lack of better data in the field.
[5] European Energy Agency.
[6] European Wind Energy Association.

Today, wind energy is the most established renewable energy type contributing with 42 percent to the total renewable energy generation (see *Table 1*). Bioenergy is the second largest renewable energy source with 32 percent and small-scale hydro-power is the third largest contributor with 21 percent. However, the contribution of renewable energy sources varies considerably between the member states. Hence, *Table 2* presents the absolute generated electricity from renewable energy sources in the fifteen countries.

Table 2: Generated electricity from renewable energies in EU-15, 2004 [GWh][7].

Country	Bioenergy[8]	Solar energy[9]	Wind energy	Total	Other[10]
Austria	2,359	11	924	3,294	38,968
Belgium	1,947	1	142	2,090	1,607
Denmark	3,545	2	6,583	10,130	27
Germany	16,123	557	25,509	42,189	36,666
Greece	261	1	1,121	1,383	5,205
Finland	10,723	2	120	10,845	15,070
France	5,181	10	573	5,764	65,421
Ireland	109	0	655	764	984
Italy	17,387	29	1,847	19,263	49,908
Luxemburg	96	9	39	144	854
Netherlands	4,677	33	1,867	6,577	95
Portugal	1,810	3	816	2,629	10,147
Spain	6,685	54	15,601	22,340	34,439
Sweden	8,000	0	850	8,850	60,178
United Kingdom	7,880	4	1,935	9,819	7,579

Source: IEA, *Gross Electricity Generation from Renewables in 2004.*

As *Table 2* shows, in the field of bioenergy Italy is the largest generator with 17,387 GWh, closely followed by Germany with 16,123 GWh. In solar as well as in wind energy, Germany has a leading stand with 557 GWh and 25,509 GWh electricity having been generated in 2004 respectively. Putting these three technologies together, Germany, Spain and Italy are the largest generators of renewable energies, while Luxemburg and Ireland have the lowest levels of electricity generated from renewables. However, when expressing the total generation from

[7] One watt-hour is the amount of energy expended by one-watt load drawing power for one hour.
[8] Includes waste, biomass, biogas and biofuels.
[9] Includes solar thermal and photovoltaics.
[10] Includes hydro, geothermal and tide/ wave/ ocean.

renewable energies as a share of total gross electricity generation, as in *Appendix A,* it can be seen that Denmark has the highest share of renewable electricity generation with 21.3 percent, followed by Finland with 12.9 percent and Germany with 7 percent.

In achieving these installed capacities, the renewable energies have been promoted by various policy incentives. The following presentation of the policy incentives is based on EWEA (2005). Although the promotional policies differ across the EU-15 countries, five main groupings of policy mechanisms may be identified: voluntary programs, incentive tariffs, tax measures, investment incentives and trade certificates. Voluntary programmes give the consumer the option to be supplied with electricity originating from renewable energy sources, i.e. Green Marketing Programmes. Incentive tariffs are fixed tariffs that the energy producer receives for generating it from renewable sources, i.e. feed-in tariffs. Tax measures are often implemented in order to internalise the externalities connected with energy generation. Thus, they may either take the form of taxes levied on non-renewable energy sources according to the polluter-pays-principle or income tax reductions for renewable energy sources. Investment incentives include different types of financial support for the construction of a new renewable energy-sourcing site. Finally, trade certificates play a similar role as tariffs, yet are not set at a fixed level, but determined by market forces.

2.2 State of technology and potential

In **wind energy**, the EU has reached a world leading position with 74 percent of worldwide generating capacity and a market share of 90 percent for generating equipment. Since the 1980's, the capacity of an individual turbine has increased from 20 kW up to 5 MW and generation costs have decreased by 80 percent. Germany, Spain and Denmark are the leading generators in the EU with 84 percent of wind power installed capacity, of which half is installed in Germany (EWEA, 2006). However, wind energy is also growing in the other member states. The future potential of wind energy in the EU is seen as large, especially with significant potential in offshore-sites. As the EC (2004, p. 5) states, "it is clear that the directive's target of meeting 12 percent of the EU's electricity consumption from renewable sources depends heavily on a significant contribution from wind power". As Gross *et al.* (2005, p. 109) find when looking at the progress in wind power, "there appears to be considerable scope for continued innovation.[11]"

[11] More specifically, the potential for innovation is recognised in site optimisation, blade generator design and in grid connection using power electronics.

Bioenergy is a rather diverse field with several sources as well as several final usages. Bioenergy can be gained from woody biomass, agricultural and farm residues, energy crops grown for biofuels production and the organic fraction of industrial and urban waste (IEA, 2004). Through various transformation processes, these sources can be used for biofuels, bio-electricity or bio-heating. Finland, Germany and Sweden are currently the leading producers of electricity from biomass. Biomass electricity has gone from a yearly growth rate of 13 percent in 2003 to 23 percent in 2005 (EC, 2007). Following wind energy, the EC (2004b) expects biomass to be the main source of growth in the renewable energy sector. In total bioenergy (i.e. not only biomass), Italy, Germany and Finland are the largest generators (see *Table 2*).

Solar energy technologies are based either on solar thermal panels (exclusively for heating needs) or on photovoltaic (PV) cell modules generating electricity. The photovoltaic industry grew by more than 30 percent on average between 1999 and 2004 and estimates for the future development are positive (EC, 2004b). It is usually recognized that the EU PV market has been pulled by the successful development of the German market, which in 2005 accounted for about one third of the total installed capacity in the EU. Next to Germany, the Netherlands is also a main producer of electricity from solar power. Nevertheless, the EU is still a net importer of solar cell modules (EPIA[12], 2005). Gross *et al.* (2005, p. 111) find that "the potential for profound innovation [in the PV market] sits alongside continued improvements and scale economies in existing module types." In the solar thermal sector, the situation is similar with only a few leading countries driving this development. Thus, almost three-quarters of the EU market are concentrated in Germany, Greece and Austria (ESTIF[13], 2006).

To summarise the main features of the renewable energies market in the EU, wind energy is the most established source, followed by bioenergy and solar energy with Germany being the leading generator of electricity from renewable energies. As Gross *et al.* (2002, p. 105) state, "There is no doubt that the potential scale of their [renewables] contribution is very large, but sustained growth will be needed…" and as we have seen, this growth is dependent on continued innovation in the field.

[12] European Photovoltaic Industry Association.
[13] European Solar Thermal Industry Federation.

3. THEORETICAL FRAMEWORK

This section will outline the theoretical framework of the thesis. In the first part of the section, the sectoral innovation systems approach will be described. A second part will present relevant previous findings and point at the contextual contribution of this thesis.

3.1 Sources of innovative strength – the sectoral innovation systems approach

As Furman *et al.* (2002, p. 900) define it, "the national innovative capacity framework draws on three distinct areas of prior research: first, ideas-driven growth theory, second, microeconomics-based models of competitive advantage and industrial clusters, and third research on national innovation systems". These three perspectives thus each highlight distinct drivers of the innovation process. Underlying the innovation systems approach is the idea that firms do not normally innovate in isolation, but in collaboration and interdependence with other organisations and institutions, as described by Edquist (2005). Edquist (2005, p. 182) concludes that "these organisations and institutions are components of systems for creation and commercialisation of knowledge and that innovations emerge in such 'systems of innovation'". Such systems of innovation may be identified on several levels: national, sectoral or regional. In this study, the framework will be applied on a sectoral level. A sectoral innovation system can be defined as "that system (group) of firms active in developing and making a sector's products and in generating and utilizing a sector's technologies" (Breschi and Malerba, 1997, p. 262). This framework will be presented in greater detail in this section by looking at each of the three perspectives mentioned above, starting with ideas-driven growth theory.

Ideas-driven growth theory or endogenous growth theory may be regarded as an extension of Solow's neoclassical growth model by adding technological progress to it. Although the neoclassical growth model highlights technological progress as the engine of economic growth, it is treated as exogenous to the model. Hence, endogenous growth theory builds on this knowledge and endogenises technological progress (Jones, 2002). The key determinants stressed by this theory are the number of researchers and the stock of ideas available to researchers, as expressed in the following model known as the Ideas Production Function or the Romer Model:

$$\dot{A}_t = \delta H_{A,t}^{\lambda} A_t^{\phi} \qquad (1)$$

where $\dot{A}_t$ is the number of new ideas produced at any given point in time[14], H_A is the number of researchers in the labour market, A_t is the stock of ideas at time t, δ and ϕ are constants and λ is a parameter taking a value between 0 and 1.

This model thus suggests that the rate of technological change is endogenous in two distinct ways. First, the share of the economy devoted to the ideas sector is a function of the R&D labour market and second, the productivity of new ideas generation is sensitive to the stock of ideas discovered in the past (which corresponds to A). Prior research can either increase current R&D productivity through the "standing-on-shoulders-of-giants-effect" ($\phi > 0$) or make it more difficult to find new ideas, as the most obvious ones have already been found ($\phi < 0$), (Jones, 2002).

The second approach to sources of innovation mentioned before, the **microeconomics-based approach** has been especially stressed by Porter (1998a). In this framework, the dynamic interactions between clusters and specific institutions (such as universities and public institutions) are stressed. More specifically, the Porter framework identifies four key drivers. The first is the availability of high-quality and specialized innovation inputs, such as R&D personnel specialized in cluster-related disciplines. The second key factor refers to the extent to which the local competitive context is both intense and rewards successful innovators, i.e. intellectual property protection, regulations etc. The third factor, domestic demand is assumed to play an essential role in stimulating firms to offer best-in-the-world technologies. Finally, Porter (1998a) suggests that the existence of clusters generate positive externalities both from knowledge spill-overs, transactional efficiencies and cluster-level scale economies.[15] As Porter (1998a, p. 209) states, "close linkages with buyers, suppliers, and other institutions contribute importantly not only to efficiency but to the rate of improvement and innovation".

Finally, the **national innovation systems approach** focuses on the policy environment. It identifies those institutions and actors that play a decisive role in particular industries, emphasizing the diversity in national approaches to innovation. While both the ideas-driven growth models and theories of national industrial competitive advantage incorporate the role

[14] i.e. $\dot{A}_t = (dA/dt)$.

[15] Porter (1998b, p. 78) defines clusters as "geographic concentrations of interconnected companies and institutions in a particular field. Clusters encompass an array of linked industries and other entities important to competition."

of public policies in shaping the rate of innovation, the national systems literature emphasizes the active role played by governmental policy and specific institutions (Furman *et al.,* 2002).

3.2 Previous findings and contribution of the thesis

Jensen (2004) focuses on the analysis of technological development in renewable energies by the use of experience curves[16] and multiple regression, which are applied to the wind power market in Denmark and the PV market in Japan. From the multiple regression model, the author finds that the only independent variable explaining unit cost[17] is accumulated capacity. Although this function explains the historical development well, it was not found to be appropriate for predicting the future development. From the application of the experience curve on the other hand, R&D was also found to be a significant explanatory variable for the unit cost development.

These findings are supported by **Klaassen *et al.*** (2005) who apply a fixed-effects model to study the impact of (subsidy-induced) capacity expansion and public R&D expenditures on cost reducing innovation for wind turbine farms in Denmark, Germany and the UK. In other words, they use panel data to estimate the learning curve in this field. They find that the cost reductions are indeed explained by cumulative capacity and R&D and that the learning parameters for the three countries are not significantly different.

Johnson and **Jacobsson** (2002) also deal with the emergence and development of industries in the field of renewable energy technology. They apply the innovation systems framework to a cross-country comparative analysis of the evolution of the wind turbine industry in Germany, the Netherlands and Sweden over a period of twenty years. They identify two phases in the wind turbine industry. The first of these two phases is characterised by substantial technological variety, uncertainty, underdevelopment of the market and entry of many firms. The second phase is characterised by considerable turbulence, which is driven by rapid growth in the market and an up-scaling[18] of the turbines, as well as by many exits but also some new entrants, including some larger firms. They then study four specific aspects of

[16] This concept is based on the idea of ”learning-by-doing” developed by Arrow in the 1960’s. The learning curve was developed in order to describe the cost reduction of a product over time. The experience curve on the other hand, describes the cost reduction over time for a technology in general (Jensen, 2004).
[17] Here, unit cost is defined as ”the investment cost for wind and government prices for photovoltaic respectively” (Jensen, 2004, p. 116).
[18] This should be interpreted as a technological improvement that can be seen as a ”technological discontinuity” (Johnson and Jacobsson, 2002, p. 6).

the industry development: the creation of a wide variety of technologies and the establishment of legitimacy for the technology in the first phase, and market formation and the use of industrial policy in the second phase. As to the first aspect [variety creation], Sweden compared to Germany and the Netherlands, was found to have promoted variety in the first stage to a lesser extent, as promotion was focused on MW turbines rather than large as well as small ones. Also in the field of legitimacy they found that Sweden had less favourable conditions, implying that Swedish firms responded differently to the same stimuli that made some German firms entering the industry. This then facilitated the market formation for wind turbines in Germany, while the absence of initial variety in Sweden made the market too weak to respond to the growing demand. Finally, regarding the use of industrial policy, the authors found that it was of vital importance for the German industry, compared to the Swedish energy policy, which didn't really include an industrial policy element.

Furman *et al.* (2002) conduct an empirical examination of the determinants of country-level production of international patents based on the concept of national innovative capacity. They categorize the determinants into three groups: first, a nation's common innovation infrastructure, second, the environment for innovation in a country's industrial clusters and third, the strength of linkages between these two. The first category consists of cross-cutting factors contributing to innovativeness throughout the economy, such as a country's overall science and technology policy environment, the mechanisms in place for supporting basic research and higher education as well as the cumulative stock of technological knowledge upon which new ideas are developed and commercialized. The second category on the other hand refers to factors specific to certain industrial clusters. Finally, the third category is concerned with the linkages between the common innovation infrastructure and the specific clusters. Given these three categories of determinants, Furman *et al.* (2002) model the innovative capacity.[19] They find that a great deal of variation across countries is explained by differences in the level of R&D investments and in the productivity in R&D. Their study also identifies a trend of convergence among OECD countries, as the estimated level of innovative capacity has been increasingly similar over the past 25 years.

This thesis will apply the empirical model of innovative capacity developed by Furman *et al.* (2002) in order to build on the findings from Jensen (2004), Klaassen *et al.* (2005) and

[19] The model will be described in greater detail in part 4.1.

Johnson and Jacobsson (2002). Yet, while Johnson and Jacobsson (2002) conduct a theoretical study and Jensen (2004) and Klaassen *et al.* (2005) apply an experience curve model explaining the unit cost development in the renewable energy sector, this study will apply the model used by Furman *et al.* (2002) in order to identify the determinants of innovation in renewable energy technologies. This has the advantage of allowing more countries to be included in the study. Thus, whereas Johnson and Jacobsson (2002) and Klaassen *et al.* (2005) compare three countries' developments in the renewable energy sector, this study will compare 15 countries' renewable energy innovation systems. However, it should also be noted that the level of detail can therefore not be the same. Thus, rather than focusing on the differences in the systems, this study will focus on how the common factors contribute to the different levels of renewable patent generation.

4. THE MODEL

This section will introduce the model that will be applied for identifying the significant determinants of patent generation within renewable energy technologies in the EU. The first part presents the model equations and the explanatory variables, while the second part provides some further information regarding the dependent variable, i.e. the patent data. The third part will outline the expected outcomes of the model.

4.1 Model specification

The following description of random and fixed effects models is based on Halpin (2006). In studying panel data, there is a choice between using a fixed effects model and a random effects model. A random effects model can be applied when there is reason to believe that some omitted variables may be constant over time but vary between the cases. Put differently, the regression coefficients are allowed to vary over subjects. The **random effects model** takes the basic functional form expressed in model (2):

$$y_{i,t} = \alpha + \beta x_{i,t} + v_i + \varepsilon_t \tag{2}$$

where y is the dependent variable, α is the intercept, β is the coefficient estimate, x is the explanatory variable, v represents the influence of subject i on its repeated observations, ε is the error term, i is the subject index and t is the time index. The more common approach for studying cross-sectional time series data, the fixed effects regression, instead allows for using the changes in the variables over time to estimate the effects of the independent variables on the dependent variable. In this case, a dummy is fit for the individual. The basic form of the **fixed effects model** is given by model (3):

$$y_{i,t} = \alpha + \delta_i + \beta x_{i,t} + \varepsilon_t \qquad (3)$$

where δ is the subject dummy. In this thesis, the fixed effects model will be applied. As Baltagi (2001, p. 12) notes, "the fixed effects model is an appropriate specification when focusing on a specific set of *N* countries and the inference is restricted to the behaviour of these sets of countries", which is the case in this thesis. [20] This fixed effects model will be used to study the innovative capacity in the same three-step manner as Furman *et al.* (2002) use, meaning that the ideas production function (4) will first be tested, then the common innovation infrastructure model (5) and finally the innovation capacity model (6). The empirical version of the **ideas production function** is assumed to be as follows:

$$RET\_Pat_{i,j} = \alpha + \beta_1 Pop_{i-3,j} + \beta_2 GDP_{i-3,j} + \beta_3 RRDmill_{i-3,j} + \varepsilon_{i,j} \qquad (4)$$

where *RET_Pat* is the number of patents in renewable energies, *GDP* is a country's GDP, *Pop* is the population (expressed in thousands), *RRDmill* is the number of researchers per million inhabitants, ε is the error term, i is the year index and j is the country index. The population and the share of researchers are included on the basis of Romer's endogenous growth model (Jones, 2004). The GDP variable is added as a complement to the population variable, in order to capture national wealth.

As can be seen, the explanatory variables are lagged by three years. This is because, according to a statistician working at the Swedish Patent and Registration Office (PRV), the application and registration process of a patent takes about 2-3 years.

[20] The choice between a fixed and random effects model can also be tested using a Hausman test. It checks a more efficient model against a less efficient but consistent model to make sure that the more efficient model also gives consistent results (Halpin, 2006).

Second, variables reflecting the sector environment will be included, resulting in the **common innovation infrastructure model:**

$$RET\_Pat_{i,j} = \alpha + \beta_1 Pop_{i-3,j} + \beta_2 GDP_{i-3,j} + \beta_3 RRDmill_{i-3,j} + \beta_4 RD\_RET_{i-3,j} + \beta_5 AccPat_{i-3,j} + \beta_6 AccCap_{i-3,j} + \beta_7 D_{i-3,j}\_PI\_TradeCert + \beta_8 D_{i-3,j}\_PI\_Vol\Pr og + \beta_9 D_{i-3,j}\_PI\_TaxMeas + \beta_{10} D_{i-3,j}\_PI\_IncTarr + \beta_{11} D_{i-3,j}\_PI\_InvInc + \varepsilon_{i,j} \quad (5)$$

where *RD_RET* is the amount of R&D (in million euros) invested in renewable energies by the government, *AccPat* is the patent stock in all areas (i.e. not only renewable energies), *AccCap* represents the accumulated capacity in renewable energy (in GWh) and the "*PI*"-variables represent policy incentives. More specifically, *TradeCert* represents the start of trade certificates as policy incentive, *VolProg* represents the start of voluntary programs as policy incentive, *TaxMeas* represents the start of tax measurements as policy incentive, *IncTarr* represents the start of incentive tariffs as policy incentive and *InvInc* represents the start of investment incentives as policy incentive.[21]

The role of R&D for the innovative capacity has been shown by Furman *et al.* (2002) on a national level and by Jensen (2004) and Klaassen *et al.* (2005) on the renewable energy sector. The number of accumulated patents is identified for instance by Furman *et al.* (2002) as an important determinant for the innovative capacity and is hence included in the model. Since the number of generated patents within renewable energy is the dependent variable and the number of accumulated patents (from all fields) is an explanatory variable, the model might be said to be dynamic. However, there are two reasons why this has been chosen to be disregarded. The first reason is that the data for these two variables stems from two different databases, namely the espacenet database, which is operated by the European Patent Organisation (EPO) and supported by the competent national organisations in the respective member states, and the United States Patent Organisation (USPTO) database. This use of two different databases implies that the risk of duplication is rather small. Secondly, the share of renewable energy patents is so low, that even subtracting these from the accumulated patents would have a negligible effect on the accumulated patent level.

[21] For descriptions of these policies, see part 2.1.

As was found by Jensen (2004) and by Klaassen *et al.* (2005), alongside R&D, accumulated capacity is a main determinant of the technological development within renewable energy technologies and hence a variable representing the accumulated capacity in renewable energy is also included in the model. Concerning the policy incentives variables, they are introduced in order to represent the institutional conditions of the market. This is supported by both Gross *et al.* (2003) and EWEA (2005a), who point at the important role that policy incentives play for the renewable energy sector. These policy incentives are expressed as dummy variables that take the value 0 before the policy was introduced and the value 1 for those years where it had been introduced. Expressing the policy incentive variables as dummies is done at the loss of a higher level of detail. Although the overall policy categories are the same in the EU-15 countries, the level and quality of these differ. Such information is though not readily available for all policies in all countries.

The complete model, the **sectoral innovation capacity model**, also reflects the extent of linkages between different organisations in the sector. This linkages component will be represented by the variable Cooperation (Coop), which is the number of EU-projects within renewable energy (Altener-projects)[22] that various organisations of a country have coordinated during a given year.

$$\begin{aligned} RET\_Pat_{i,j} &= \alpha + \beta_1 Pop_{i-3,j} + \beta_2 GDP_{i-3,j} + \beta_3 RRDmill_{i-3,j} + \beta_4 RD\_RET_{i-3,j} + \\ &\beta_5 AccPat_{i-3,j} + \beta_6 AccCap_{i-3,j} + \beta_7 D_{i-3,j}\_PI\_TradeCert + \beta_8 D_{i-3,j}\_PI\_Vol\Pr og \\ &+ \beta_9 D_{i-3,j}\_PI\_TaxMeas + \beta_{10} D_{i-3,j}\_PI\_IncTarr + \beta_{11} D_{i-3,j}\_PI\_InvInc \\ &+ \beta_{12} Coop + \varepsilon_{i,j} \end{aligned} \tag{6}$$

where *Coop* represents cooperation as a variable for linkages (number of coordinated Altener-projects). Using data on how well different institutions cooperate in different countries would have provided a superior measurement of these linkage, yet such data could not be found for the renewable energies market. However, since the Altener-projects are conducted in cooperation with one organisation having the coordinative responsibility, it is assumed that a high number of such projects indicates an efficient level of cooperation between the different actors. For further details on the variables included in the models, see *Appendix B*.

[22] The Altener-projects aim at increasing the use of new and renewable energy sources, focusing on electricity production, heat production, alternative fuels and small-scale applications. They are part of the "Intelligent Energy" programme, which addresses key energy challenges of the EU (EC, 2005).

In applying these models a number of assumptions are made. First, it is assumed that the renewable energy sector may be viewed as one sector, as opposed to studying bioenergy, solar energy and wind energy separately. Furthermore, it is assumed that the slope coefficients are constant across time and space, while the intercepts differ across the countries. Further underlying assumptions of the model correspond to those for a classical normal linear regression model; see for example Gujarati (2003, p. 335) for details.

4.2 Variables and data collection

As already mentioned, the patent data stems from the espacenet-database operated by the EPO and supported by the competent national institutions (in Sweden by the PRV). However, since the data is not processed in the database, the statistics had to be collected by searching the database. In doing so, a consistent definition for every renewable energy technology had to be identified and then applied to the years of interest and for all EU-15 countries. Thus, this definition of the patent category plays a crucial role for the number of patents registered within each technological field. In order to get as accurate as possible definitions of the different fields, technicians from each of the fields studied (wind energy, bioenergy and solar energy) working at the PRV were consulted. The definitions decided upon are as follows:

- Solid fuels, essentially based on material of non-mineral origin
- Solid fuels, based on industrial residues and waste materials
- Adaptations of machines or engines for special use; Combinations of machines or engines with driving or driven apparatus; Power stations or aggregates
- Use of solar heat, e.g. solar heat collectors
- Wind motors

These definitions offer a rather narrow representation of the renewable energy field, yet the technicians recommended these definitions in order to avoid including patents not really related to the field as well as patents for minor improvements rather than for technological advances.

In general, patenting activity provides a good indicator of invention, but it also has some disadvantages as a measure of innovative activity. For instance, there are inter-sectoral differences in the relative importance of patents, yet as this study compares one sector across a number of countries, this effect is offset. On the other hand, differences among countries in procedures and criteria for granting patents exist, although the systems within the EU are quite similar. Furthermore, patents also differ in their economic value, though this is not represented in the data (Smith, 2005).

4.3. Expected outcomes

First, it is expected that support will be provided for the theory of innovation systems. In other words, it is expected that the variables reflecting the innovative infrastructure, the industry-specific preconditions and the linkages will have significant effects on the level of patent generation within the field of renewable energy technologies. For the first category, reflecting the national innovation system, this means that the coefficient estimates for the variables population, GDP and number of researchers in the economy are expected to be significant. While GDP and the share of researchers are expected to have positive impacts on the patent generation, the expectations on the effects of country size are somewhat ambiguous. On the one hand, larger countries are expected to have higher levels of patent generations due to scale- and spill-over effects. On the other hand, Carlsson and Stankiewicz (1991) have shown that small countries have generally done well in previous surveys of innovation systems for two reasons. The first is that smaller economies tend to be more open and international, thus providing small countries with a possibility to neutralize some of the limitations of size. The second explanation is that small countries may have some advantages, because they are less constrained by nationalistic ambitions and have in many cases developed organisational and cultural features which make them effective operators in an international system. The findings from this study are expected to give support to either of these hypotheses.

For the second category of variables, which describe the sectoral innovation system, the coefficient estimates for R&D within renewable energy technologies, the accumulated capacity of renewable energy installed, as well as the renewable energy sector policy incentives are expected to be positive and significant. Regarding the patent stock, the expectations on the sign are not clear, as theory suggests that a large patent stock can either facilitate finding further patents (standing-on-shoulders-of-giants-effect) or make it more difficult to find further patents, as the most obvious ones have been discovered already (Jones, 2002).

Finally, for the third category reflecting the linkages between the different institutions, the coefficient estimate for the number of EU-projects within renewable energy (Altener-projects) coordinated by an organisation in a country, is also expected to be positive and significant.

Based on the previous findings of Jensen (2004) and of Klaassen *et al.* (2005), R&D investments in the renewable energy sector are expected to be a main determinant of renewable energy technology patent generation, as is accumulated capacity. The expectations described in this section lead to the hypotheses summarized in *Appendix C.*

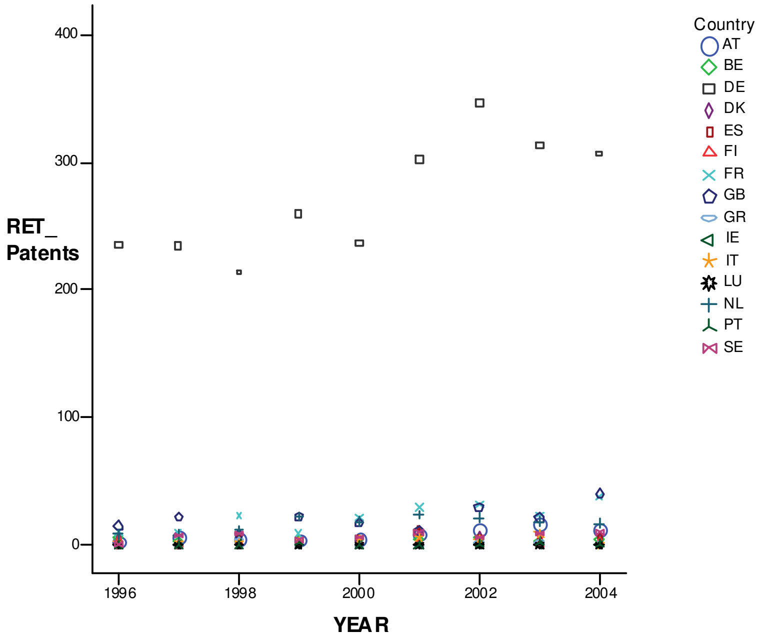
5. DATA AND RESULTS

In this section, the data and the results from the model will be presented. In the first part, an introduction to the dataset will be given outlining the main features to be derived from it. The second part will present the results from applying the model to the full dataset, whereas the third part will present the results from applying the same model to the dataset excluding the German observations.

5.1 The data

When looking at the data for the patent generation level of the EU-15 countries, depicted in *Figure 1*, the first striking observation is the exceptionally high level of patent generation in Germany. While most countries generate between 0-30 patents a year, Germany's corresponding level is at 200-300 patents. This leads to a second observation, namely the overall low level of patent generation in the other EU-15 countries.

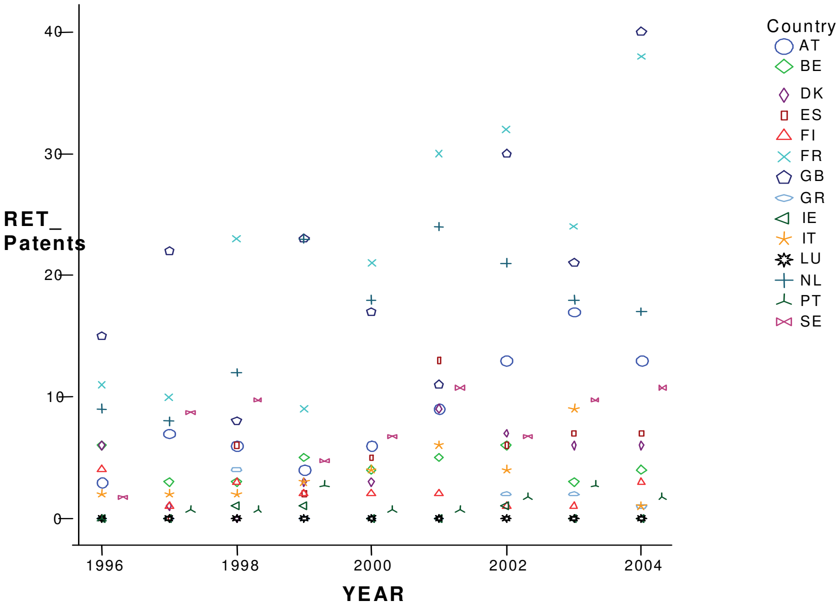
Figure 1: Generated patents within renewable energies 1996-2004.



Source: Espacenet, EPO.

This could perhaps have implications for the statistical modelling of the data, as the German observations might need to be treated as outliers. Hence, when looking at a scatter plot without the German observations, as shown in *Figure 2*, the variation over time for the other countries seems greater, yet for a fairly large number of countries it becomes even clearer that there is no clear positive trend with the time. It can also be seen that the countries with the highest level of patent generation besides Germany are United Kingdom, France and the Netherlands. The fact that the three largest countries of the EU (Germany, United Kingdom and France) also are the main generators of patents within renewable energies, points at the hypothesis that the larger countries benefit from certain scale- and spill-over-effects.

Figure 2: Generated patents within renewable energies excl. Germany 1996-2004.



Source: Espacenet, EPO.

As can be seen in *Figure 2,* no trend of convergence is recognisable. Rather, the gap in patenting activity has been increasing between the EU-15 countries from 1996 to 2004. Furthermore, those countries that had the highest level of generated patents in renewable energy 1996 were also the ones with the highest level in 2004.

As was pointed at in the previous section, the level of R&D investments in renewable energy technologies is expected to be the single most important explanatory variable for the variation in patent generation in this field. Hence, *Table 3* summarises the development from 1998 to 2004, as well as expresses the *per capita* investment levels for 2000:

Table 3: R&D budgets for renewable energies in million euros 1998-2004 and *per capita* for 2000.

Country	**1998**	**2000**	**2002**	**2004**	**2000 p.c.**
Austria	10,708	6,966	10,019		862
Belgium	1,395				
Denmark	20,059	17,499	10,070	13,659	3,299
Germany	82,936	76,590	76,925	59,800	934
Greece		2,014	3,492		186
Finland	8,831	9,128	9,933		1,771
France	4,146	14,120	34,482		242
Ireland			0,616	2,728	
Italy	36,422	24,920	54,908	50,800	437
Luxemburg	0,164	0,380			0.086
Netherlands	44,153	34,422	45,770	41,500	2,192
Portugal	1,393	0,875	1,318	0,322	0.086
Spain	20,411	18,946	17,360	28,483	477
Sweden	13,507	25,588	28,855	23,229	2,891
United Kingdom	5,540	7,217	16,312	17,250	123

Source: IEA (2005).

As can be seen in *Table 3*, the level of R&D invested in renewable energy technologies is the highest in Germany with 82,936 million euros invested in 1998 and 59,800 million euros invested in 2004. The lowest investment in R&D in the renewable energy field is in Luxemburg, with less than half a billion euros per year. It might thus be observed that Germany is the country with highest investments in R&D as well as with the highest level of patent generation in this field, whereas Luxemburg is the country with the lowest corresponding investments in R&D and also with the lowest patent generation (see *Appendix D*). Furthermore, there seems to be no clear trend in the development of the investments, although most countries have increased their investments from 1996 to 2004. However, looking at the *per capita* investments in the last column of *Table 3,* it can be seen that not Germany, but Denmark in fact has the highest *per capita* R&D investment with 3,299 euros in 2000. Sweden, the Netherlands and Finland also have higher *per capita* investments in R&D in renewable energies than Germany. These observations could suggest that there might be a critical mass of R&D investments that enables a greater productivity in R&D. Luxembourg and Portugal have the lowest *per capita* investment levels at less than one euro in 2000.

5.2 Results – including the observations for Germany

In order to test the hypotheses summarised in *Appendix C,* tests of significance will be conducted at a ten percent level, which is a commonly used level of significance (Gujarati, 2003). It might be noted that only the hypotheses *A* and *E* are expressed as two-sided tests, whereas the other hypotheses are one-sided. For the two-sided tests the level of significance thus needs to be divided by two, implying that the required p-value for hypotheses *A* and *E* is five percent instead of ten.

Since the patent level within renewable energies is so much higher in Germany in comparison to the other countries, it was expected that an intercept dummy would be needed for Germany to take this observation into account. As the results summarised in *Appendix E* show, the country intercept for Germany is indeed significant and hence a dummy taking the value 1 for Germany and 0 for the other 14 countries was included when applying the ideas production function variables (GDP, population size and number of full-time researchers per million inhabitants).

It was found that the share of researchers does not have a significant effect on the observed level of patents in renewable energy technologies as the null hypothesis *C* is not rejected at a ten percent level. The results for the other variables are summarised in *Table 4:*

Table 4: Results for model (4).

Variable	Estimate	St. Error	t	p-value
Intercept	264.553	6.360	41.597	0.000
Dde = 0	-260.8937	5.720	-45.640	0.000
GDP	8.3E-005	1.5E-005	5.783	0.000
Population	-1.597	0.321	-4.983	0.000

We can thus see that the population, i.e. country size, has a negative impact on the generation of renewable energy patents. This result thus supports the hypothesis of Carlsson and Stankiewicz (1991) that smaller countries tend to have an advantage in that they are less constrained by nationalistic ambitions and thus develop organisational and cultural features, which make them more effective operators internationally. As a result, the null hypotheses *A* and *B* are rejected at a ten percent level, since they do impact on the patent generation level in renewable energy technologies.

In a next step, the variables for the infrastructure are included in order to test the innovation infrastructure model (model (5)). As can be seen in *Table 5*, only the intercept, the dummy for Germany, the variable for accumulated patents and the dummy for tax measure policies are significant at a ten percent level. It might be noted that although the coefficient estimate for accumulated patents is almost zero, looking at the standardised coefficients indicates that it is in fact the second largest determinant, as only the dummy coefficient for Germany has a larger standardised coefficient. Regarding the estimate of the dummy coefficient for tax measure policies it shows that, *ceteris paribus,* introducing tax measures one year earlier would lead to 10.372 more patents being generated in the EU-15. This important role of tax measures is in line with the idea that the market failure of the energy market to internalise the externalities can effectively be corrected by tax measures (EC, 2004). However, when looking at the countries that implemented tax measures for renewable energies the earliest *(Appendix F)*, namely France (1980), Ireland (1984) and Luxemburg (1989), only one of these, France, has a relatively high level of patent generation. The results thus imply that the null hypotheses *D, F, G, H, I,* and *J* are accepted at a ten percent level, while the null hypotheses *K* and *E* are rejected.

Table 5: Results for model (5).

Variable	**Estimate**	**St. Error**	**t**	**p-value**
Intercept	216.125	9.494	22.756	0.000
Dde = 0	-223.261	8.488	-26.304	0.000
AccPat	0.000	3.66E-0.55	7.456	0.000
PI_TaxMeas	10.372	2.777	3.735	0.000

Finally, when including the variable for coordinated Altener-projects (Coop), in order to test the sectoral innovation capacity model (model (6)), it turned out to be statistically insignificant with a p-value of 0.893. Thus, *Table 5* represents the results for Model (6) when applied to the EU-15 countries.

Yet, when comparing these results with the expected outcomes, there is some discrepancy. Firstly, neither the coefficient for R&D invested in renewable energy technologies, nor the one for accumulated capacity are significant, although they were expected to be the main determinants. Secondly, other variables such as population and further policy incentives were expected to have significant coefficients, but do not. Also, when running the model as an

Ordinary Least Squares (OLS) regression, the coefficient of determination obtained is suspiciously high at 0.976. For these reasons, the results seem somewhat dubious.

5.3 Results – excluding the observations for Germany

As an alternative, these models were applied to the data excluding the observations for Germany. As the scatter plot in *Appendix G* shows, the residuals of the German observations cause a heteroscedastic pattern, which supports the exclusion of them. In this application, an intercept dummy for Italy needed to be included. *Table 6* shows the results of model (4) when excluding the observations for Germany.

Table 6: Results for model (4) excluding the German observations.

Variable	**Estimate**	**St. Error**	**t**	**p-value**
Intercept	-14.195	2.484	-5.714	0.000
Population	-0.567	0.136	-4.188	0.000
Dit = 0	16.667	2.274	7.328	0.000
GDP	4.15E-005	6.29E-006	6.602	0.000

As can be seen in *Table 6*, the coefficient for the same variables as in the application to the full EU-15 dataset are in fact significant and the GDP coefficient takes approximately the same size.

However, when including the innovation infrastructure variables, the results differ to a larger extent compared to the application to the full dataset. The results for the significant variables are summarised in *Table 7*:

Table 7: Results for model (5) excluding the German observations.

Variable	Estimate	St. Error	t	p-value
Intercept	-24.123	3.927	-6.143	0.000
Population	0.156	0.052	2.989	0.000
Dit = 0	19.399	2.832	6.849	0.000
AccPat	0.001	2.98E-005	4.361	0.000
RD_RET	0.255	0.043	5.991	0.000
PI_TaxMeas	5.309	1.399	3.795	0.000

Now the population coefficient is positive, which could be a sign that the GDP and population variables are actually correlated. Indeed as can be seen in *Appendix H*, the correlation coefficient for these two variables is very high at 0.988. The high correlation coefficient could be explained by the fact that the EU-15 countries are fairly equally rich, thus rendering both GDP and population a measure of country size.

These results seem more reliable than those for the same model when including the observations for Germany, since now the coefficient for R&D invested in renewable energy technologies is both positive and significant, as was expected; even though the coefficient for accumulated capacity is still not significant. Once more, except for the dummy coefficient for Italy, the coefficient for accumulated patents is the largest determinant as it has the largest standardised coefficient. Furthermore, the obtained coefficient of determination now seems more credible at 0.755. Yet, once more, when including the variable for coordinated Altener-projects, its coefficient is again not significant with a p-value of 0.192.

To summarise the findings, the results for model (4) were quite similar in the case with all EU-15 countries and in the case of excluding the German observations. Model (5) however yielded more credible results when excluding the observations for Germany, with the coefficient for R&D invested in renewable energies then being significant, alongside the coefficients for accumulated patents and tax measures already identified in the first application.

6. DISCUSSION OF THE MODEL

The fact that the application of the model to the data excluding Germany seems to yield more credible results leads to the question whether the German innovative capacity is determined differently than for the other EU-countries. In order to test this hypothesis, a post-sample predictive test is applied to the full dataset versus the dataset excluding the German observations. The hypotheses are defined as:

H_{0M}: The model is correctly specified and the parameters (β_i and σ^2)[23] are constant over space.

H_{1M}: The parameters vary over space and/ or the model is misspecified.

and the test statistic is given by (Baltagi, 2001, p. 14):

$$F = \frac{\left(RSS_{n+p} - RSS_n\right)/\,p}{RSS_n\,/\left(n-k\right)}$$

with F following the distribution $F_{p;\,n-k}$ and where *RSS* is Residual Sum of Squares[24], n is number of observations excluding the German observations, p is number of German observations and k is number of regressors.

As the observed value was found to exceed the critical value, the post-sample predictive test suggests that the null hypothesis *M* is rejected at the ten percent level. In other words, the dubious results of the application to the full dataset seem to be a consequence of the parameters not being constant over space, i.e. the extraordinary level of patent generation in Germany seems to be determined by another function than it is in the other EU-15 countries. This finding stands somewhat in contrast to that made by Klaassen *et al.* (2005), namely that the learning parameters in the wind turbine industry in Denmark, Germany and the UK are not significantly different. However, the foci of the studies are somewhat different and hence it could well be that the learning (i.e. cost reduction) parameters do not differ, while the innovation capacity (i.e. patent generation) parameters do. The question then is why the parameters for the German innovative capacity in the renewable energy sector differ from the other countries.

[23] Where β_i is the variable coefficient and σ^2 is the variance.

[24] Obtained through OLS estimation.

One possible explanation could be connected to the fact that Germany is the only country, which is leading within both wind energy, bioenergy and solar energy. This could create synergies that enable Germany to achieve a greater level of productivity in innovation. Similarly, as observed in part 5.1, it could be that Germany's high investments in R&D reach a critical mass allowing for certain productivity gains. As mentioned in part 3.2, Furman *et al.* (2002) found that productivity in R&D is indeed one of the main determinants of innovative capacity.

It could also be that the explanation for Germany's exceptionally high patent generation in renewable energy technologies should be looked for beyond the sectoral level. Hence, looking at the patent generation at an aggregate level, it is indeed striking that the average level of *per capita* patent generation in Germany is much higher than in the other countries, as illustrated in *Table 8*:

Table 8: Per capita means of accumulated patents (granted 1963-2003) on an aggregate level.

Country	**Mean**	**Country**	**Mean**
Austria	10,350	Greece	351
Belgium	11,028	Ireland	1,299
Denmark	6,495	Italy	32,636
Germany	222,709	Luxemburg	662
Spain	3,645	Netherlands	26,800
Finland	7,060	Portugal	168
France	85,657	Sweden	28,684
United Kingdom	98,426		

Source: USPTO (2006).

Table 8 shows that Germany has a *per capita* patent stock that is more than twice as high (222,709) than for the second largest country (UK, with 98,426). As stated in the previous section, the patent stock was found to be the largest determinant of patent generation in renewable energy technologies, as it has the largest standardised coefficient next to the intercept dummy for Italy. This could help explaining the exceptional observation for Germany. In a way, the patent stock can be interpreted as a measure of the national innovation system, implying that the results of this study actually indicate that the most important determinant for the sectoral innovation system in renewable energies is in fact the national innovation system. Thus, while Jensen (2004), Klaassen *et al.* (2005) and Johnson and Jacobsson (2002) found that the most important determinants of technological development in the renewable energy sector are accumulated capacity, R&D and productivity in R&D, the results of this study point at the conclusion that the “success factors” for the innovative capacity in this sector do not actually lie on a sectoral level, but in the strength of the national innovation system. A word of caution regarding the results is in place though, as the available data was not as detailed as would have been desirable.

7. CONCLUSION

In response to the deficiencies of the current energy supply in the EU, such as the use of finite resources, the impact of GHG emissions on climate change and the high dependency on politically unstable countries for energy imports, the EU has declared the promotion of renewable energy sources as a central aim of its energy policy. Furthermore, it has been recognised that a large technological potential exists, which needs to be promoted through effective incentive policies. However, as we have seen, the patent activity in renewable energies differs considerably between the EU-15 countries, with Germany generating about ten times as many patents per year as the other member states and with a trend of divergence, rather than convergence, being visible. Thus, this thesis set out to study the determinants of innovative capacity in renewable energy technologies in order to understand why some countries are so much more successful in generating patents in this field than others.

In order to study this question, a sectoral innovation systems approach was applied, which takes infrastructure and sectoral factors into account, as well as the level of cooperation between different organisations and institutions. Based on the study of Furman *et al.* (2002) a three-step model was developed and applied to the renewable energy sector for the years 1998 to 2004 where the ideas production function was first applied, then the innovation infrastructure model and lastly the sectoral innovation capacity model. This three-step method was first applied to the renewable energy sector in the EU-15 countries, with the results that the number of accumulated patents and the year of introducing tax measures were identified as the main determinants next to the dummy variable for Germany. However, the results seemed somewhat dubious as the variables expected to be the most important (accumulated capacity and R&D) did not have significant coefficient estimates and the coefficient of determination was suspiciously high. Consequently, a second application was made to the data excluding the observations for Germany. Three main findings were made from this second application of the models. First, the patent stock, the population size, the R&D investments and the year of introducing tax measures were found to determine the innovative capacity in renewable energy technologies and to explain 75.9 percent of the variation in patent generation. Second, the finding of accumulated patents being the largest determinant (next to the dummy variable for Italy) in a way means that we have come full circle - having derived the model used in the study from the national innovative capacity model, it was found that the latter is in fact the largest determinant of the innovative capacity in the renewable energy sector. Third, it was found that the innovative capacity in renewable energy technologies is determined differently in Germany than in the other EU-15 countries. It seems that Germany has a higher level of productivity in R&D, either due to synergies from being leading in the three fields of renewable energies studied, or from investing a critical mass in R&D, or both.

The conclusion drawn from these findings is that while previous studies have stressed the importance of sectoral factors for the success of renewable energy technologies, the results from this study stress the importance of a strong national innovation system. The implication for the future innovative capacity in renewable energy is thus that it might be more worthwhile investing in the national innovative capacity than in sector-specific factors. Due to the restricted availability of data in this field, the results should however be treated with some caution.

For future research, it could be relevant to pursue how the innovative capacity is determined in the German renewable energy sector. Furthermore, it could be interesting to study whether the finding that the national innovative capacity is the most important determinant for the renewable energy technology sector applies for other sectors as well. It would also be interesting to study whether perhaps even greater benefits could be earned from focusing on an even higher level, i.e. on an EU level rather than on a national one. The answers to these questions may contribute in developing the best response to the challenges concerning our future energy supply, as well as in improving the competitiveness of the EU built on a strong innovative capacity.

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APPENDICES

Appendix A – Share of renewable energy generation in total gross electricity generation

Country	Share	Country	Share
Austria	5.5%	Greece	2.4%
Belgium	2.5%	Ireland	3.0%
Denmark	21.3%	Italy	6.6%
Germany	7.0%	Luxemburg	4.0%
Spain	5.9%	Netherlands	6.8%
Finland	12.9%	Portugal	5.6%
France	1.0%	Sweden	6.5%
United Kingdom	2.5%		

Source: IEA (2004) and own calculations.

Appendix B - Explanation of model variables

VARIABLE	FULL VARIABLE NAME	MEASURE	SOURCE
RET_Pat	Patents granted within any renewable energy technology	Number of patents granted per year	Espacenet (PRV)
AccPat	Accumulated patents granted	Number of patents granted from 1963-2004	USPTO (2006)
GDP	GDP	Constant 2000 US $	World Development Indicators Database (World Bank)
RD_RET	Total R&D spent on renewable energy by governments	Million $ 2004 price and PPP	IEA (2005)
Pop	Total population	Thousands	OECD (2005)
RRDmill	Researchers in R&D per million people	Number	World Bank (2005)
Coop	Number of Altener-projects coordinated	Number	Intelebase (2006)
PI_InvInc	Policy incentives in form of Investment Incentives for renewable energies	Year of start	IEA (2004)
PI_TaxMeas	Policy incentives in form of Tax Measures for renewable energies	Year of start	IEA (2004)
PI_IncTarr	Policy incentives in form of Incentive Tariffs for renewable energies	Year of start	IEA (2004)
PI_VolProgr	Policy incentives in form of Voluntary Programs for renewable energies	Year of start	IEA (2004)

PI_Oblig	Policy incentives in form of Obligations for renewable energies	Year of start	IEA (2004)
PI_TradeCert	Policy incentives in form of Trade Certificates for renewable energies	Year of start	IEA (2004)
AccCap	Installed Capacity in Renewable Energy	GWh	IEA (2004)

Appendix C - Hypotheses formulations

Hypothesis *A*: Expectation that population size impacts on RET patent generation.

$H_{0A}: \beta_1 = 0$
$H_{1A}: \beta_1 > 0$ or $\beta_1 < 0$

Hypothesis *B*: Expectation that GDP has a positive effect on RET patent generation.

$H_{0B}: \beta_2 < 0$
$H_{1B}: \beta_2 > 0$

Hypothesis *C*: Expectation that the share of researchers will have a positive impact on RET patent generation.

$H_{0C}: \beta_3 < 0$
$H_{1C}: \beta_3 > 0$

Hypothesis *D*: Expectation that the investments in R&D within RET will have a positive impact on patents in RET:

$H_{0D}: \beta_4 < 0$
$H_{1D}: \beta_4 > 0$

Hypothesis *E*: Expectation that the number of accumulated patents will have an impact on RET patent generation.

$H_{0E}: \beta_5 = 0$
$H_{1E}: \beta_5 > 0$ or $\beta_1 < 0$

Hypothesis *F*: Expectation that accumulated capacity in renewable energy will have a positive impact.

$H_{0F}: \beta_6 < 0$
$H_{1F}: \beta_6 > 0$

Hypothesis *G*: Expectation that policy incentives in form of trade certificates will have a positive impact.

$H_{0G} : \beta_7 < 0$
$H_{1G} : \beta_7 > 0$

Hypothesis *H*: Expectation that policy incentives in form of voluntary programs will have a positive impact.

$H_{0H} : \beta_8 < 0$
$H_{1H} : \beta_8 > 0$

Hypothesis *I*: Expectation that policy incentives in form of tax measures will have a positive impact.

$H_{0I} : \beta_9 < 0$
$H_{1I} : \beta_9 > 0$

Hypothesis *J*: Expectation that policy incentives in form of incentive tariffs will have a positive impact.

$H_{0J} : \beta_{10} < 0$
$H_{1J} : \beta_{10} > 0$

Hypothesis *K*: Expectation that policy incentives in form of investment incentives will have a positive impact.

$H_{0K} : \beta_{11} < 0$
$H_{1K} : \beta_{11} > 0$

Hypothesis *L*: Expectation that the number of coordinated Altener-projects will have a positive impact.

$H_{0L} : \beta_{12} < 0$
$H_{1L} : \beta_{12} > 0$

Appendix D - Patent generation in renewable energies (per year)

Country	1996	1998	2000	2002	2004
Austria	3	6	6	13	13
Belgium	6	3	4	6	4
Germany	235	214	237	347	307
Denmark	6	0	3	7	6
Spain	0	6	5	6	7
Finland	4	3	2	1	3
France	11	23	21	32	38
United Kingdom	15	8	17	30	40
Greece	0	4	0	2	1
Ireland	0	1	0	1	1
Italy	2	2	4	4	1
Luxemburg	0	0	0	0	0
Netherlands	9	12	18	21	17
Portugal	0	0	0	1	1
Sweden	1	9	6	6	10

Source: Espacenet (2005).

Appendix E - Country intercept dummies

Variable	Estimate	St. Error	t	p-value
Intercept	7.714	4.905	1.573	0.119
Austria	2.000	6.937	0.288	0.774
Belgium	-3.429	6.937	-0.494	0.622
Germany	275.142	6.937	39.661	0.000
Denmark	-2.857	6.937	-0.412	0.681
Spain	-1.143	6.937	-0.165	0.870
Finland	-5.714	6.937	-0.824	0.412
France	17.571	6.937	2.533	0.013
United Kingdom	13.714	6.937	1.977	0.051
Greece	-6.429	6.937	-0.927	0.357
Ireland	-7.286	6.937	-1.050	0.296
Italy	-3.571	6.937	-0.515	0.608
Luxemburg	-7.714	6.937	-1.112	0.269
Netherlands	11.286	6.937	1.627	0.107

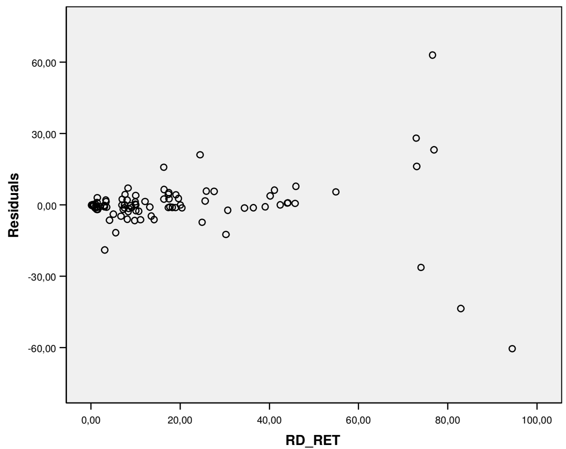
Portugal	-6.857	6.937	-0.988	0.326
Sweden	0	0		

Appendix F - Starting years of policy incentives

Country	InvInc	TaxMeas	IncTarr	VolProg	TradeCert
Austria	1992	1995	1994		2001
Belgium	1992	1992	1995		2002
Denmark	1979	1997	1981		2003
Germany	1985	1999	1991	1996	2004
Greece	1990	1990	1994		2004
Finland	1991	1994			2001
France	1980	1980	1996		2004
Ireland		1984	1995		2004
Italy	1982	1992	1992	1999	1999
Luxemburg	1994	1989	1993	2001	2004
Netherlands	1990	1990	2003		1997
Portugal	1994	1999	1988	1994	2004
Spain	2000	2001	1980		2004
Sweden	1997	1994	1997		2002
United Kingdom	2000	2001	1990		2002

Source: EWEA (2005a)

Appendix G – Scatter plot of residuals



Appendix H - Pearson correlation matrix

	GDP	Pop	RD_RET	Coop
GDP	1	0.988	0.617	0.408
Pop	0.988	1	0.606	0.440
RD_RET	0.617	0.606	1	0.116
Coop	0.408	0.440	0.115	1