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How regulation influences innovation: an indicator based approach for the case of renewable energy technologies

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Abstract:

Regulation is especially important for infrastructure systems which are characterised by a triple regulation challenge in the fields of spillovers of R&D, environmental protection, and access to monopolistic bottlenecks. The paper starts from a system of innovation approach and distinguishes different innovation functions. The effect of regulation on innovation depends on how regulation influences these functions. An important role can be assigned towards regulation at the demand side of the technology markets.

This paper analyses the relationship between regulation and innovation on an indicator based empirical base. Patents as an intermediate innovation indicator, and the success in international trade as an output-oriented indicator are used for measuring innovations. The results show an above average innovation dynamics of the renewable energy technologies. The technological capabilities of the countries differ, depending on the technology analysed. This underlines the need for a technology specific analysis. In general, countries use both traditional technology policies on the supply side such as R&D sub-

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sidies but also demand oriented policies such as feed-in-tariffs or quota systems. Proxies for regulatory indicators are developed indicating the level of regulatory activity for each country. Furthermore, a policy indicator of innovation friendliness of regulation is constructed, which reflects expert opinions on how the regulation in the countries affects additional innovation functions. An econometric analysis which matches the results of the policy analysis with the outcome of the innovation indicator analysis shows that R&D subsidies, diffusion of the technologies as a result of demand side regulation, capabilities in complementary sectors and the policy indicator are important determinants for the development of the innovation activities.

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1 Introduction

Increasing environmental pressure, e.g. in the form of global warming, and increasing energy prices have highlighted the need to increase the use of renewable energy in the future. At the same time, electricity generated with renewable energy sources is still, on average, above the costs of traditional electricity generation. The need to increase renewable energy quickly on the one hand, and its present costs at the other, lead to increasing interest on the conditions under which technological innovations will take place.

At the same time, regulation is especially important for infrastructure systems which are characterised by a triple regulation challenge in the fields of spillovers of R&D, environmental protection, and access to monopolistic bottlenecks. According to the taxonomy of Blind et al. (2004), the term “regulation” is used in a broad sense. It is not only restricted to regulations which state the enhancement of the innovation process as explicit goal, but also includes regulation which aims at different goals, e.g. improvement of the environment. Thus, it includes subsidies on the supply side of the technology markets, such as R&D subsidies, but also various instruments used on the demand side, such as feed-in-tariffs or tax subsidies. Clearly the development of renewable energy sources depends on these forms of regulation as well. Thus, there is a strong interest in analyzing the relationship between regulation and innovation in the case of renewable energy technologies. Various studies have been performed recently, which deal with this issue on a case study level. Previous reflections on the innovation effects of policy instruments in the energy field, however, have concluded that it is necessary to move from the empirical analysis in case studies towards results which can be generalized to a greater extent (Walz 2004). At the same time, the search for aggregated indicators for regulatory regimes has received increased interest lately (Blind et al. 2004; Nicoletti/Pryor 2006).

These developments shape the research interest of this paper. In chapter 2, we describe the methodological background for analysing the relation between regulation and innovation. Chapter 3 deals with measuring innovation in renewable energy technologies and presents empirical findings. The various forms of regulation used are analysed in chapter 4. Chapter 5 presents the results of an econometric analysis of the effects of regulation on the innovation in the case of wind energy. Based on these experiences, preliminary conclusions are drawn in chapter 6.

2 Methodological background

2.1 The triple regulatory challenge

The case of renewable energy has received increased interest in the literature lately. It is seen as a promising case for radical technical change, in which a traditional technological trajectory is substituted by a new technological trajectory even under the conditions of high path dependency. However, renewable energy also makes a particularly interesting example for analyzing the interaction of regulation and innovation:

- The traditional aspects of regulation with regard to typical problems of innovations, such as standardization, intellectual property regimes, or (external) spillover effects of R&D as justification for technology policies, also apply to renewable energy. However, they are not specific to renewable energy, and are therefore not in the centre of the analysis in this paper.
- Some of the key actors involved in renewable energy are operating under very specific market conditions, which became prominent under the heading of natural monopolies or more precisely as monopolistic bottlenecks. Even after privatization and liberalization of electricity markets, these actors are subject to specific economic regulation in one form or another (e.g. regulation of access to the grid, control with regard to monopolistic behaviour).
- Within electricity supply, there are also various aspects of externalities, which call for environmental and safety regulations. Thus, innovations in these fields face a third externality problem. The demand for new technologies and the pressure to innovate are much more driven by regulatory action than in other fields.

To sum up, sustainable innovations in infrastructure fields with monopolistic bottlenecks face even a triple regulatory challenge (Walz 2007). This triple regulatory problem makes the case of renewable energy a very interesting example to study the interaction between regulation and innovation.

2.2 Disciplinary paradigms to explain the effects of regulation

The traditional case for regulation of public utilities was the existence of a natural monopoly, resulting in a rate-of-return regulation or in some form of cost-based pricing. In relation to innovation, theoretical work has shown that rate-based regulatory schemes can result in a biased technical change towards capital intensive production (Averch-Johnson Effect, see Averch/Johnson 1962, Zajac 1970). There has not been much empirical work on the influence of different regulatory designs on technological innovation in the energy sector. However, the work of Walz (1995 and 2002) suggests that even minor details in the regulatory design may trigger important effects on innovation.

Theoretical insights of the theory of contestable markets (e.g. Panzar/Willig 1977, Baumol 1982) led to the conclusion that only monopolistic bottlenecks characterized by both sunk cost and natural monopoly cost functions should be regulated. Clearly, infrastructure systems based on physical networks such as electricity/gas, water supply and sewage treatment, or railways include such a monopolistic bottleneck. Regulation has to deal with the problem that the market power within the monopolistic bottlenecks can be carried on to the potentially competitive stages either by excessive charges for access to the monopolistic bottlenecks, or by hindering or even foreclosing the downstream market to competitors (see Knieps 2001). As a result, there is no level playing field between incumbent utilities and newcomers such as independent power producers using renewable energy. To sum up the theoretical arguments, access to the grid plays a very important role for the development of renewable energy.

Environmental regulation is another key aspect of the innovation processes in the energy sector. The increase in renewable energies plays a very prominent role within the debate about sustainable development. This can be attributed to the effect that renewable energy in general tackles various problems discussed in energy strategies:

- Renewable energy sources do not lead to CO_2-emissions; thus they are an important piece of the strategy to reach the CO_2-reduction goals. They are even more important, if one looks into the long-term reductions necessary to reach a stabilization of CO_2-concentrations.
- Renewable energy sources do not face the same problems of long-term security of supply associated with the depletion of fossil fuels.
- Renewable energy is not (or less) dependent on imports. Thus, problems of short to medium security of energy imports do not occur.

As long as the external costs and benefits described above (climate change, fossil fuel depletion, security of supply) are not fully included in the energy prices, the competition between renewable energy and conventional electricity supply is biased in favour of the latter. Regulations, which in one form or the other work towards a level playing field, are the key for further development of renewable energy. This opens up the questions, how the various forms of environmental regulation affect the innovation process.

Depending on the paradigm used, different aspects are highlighted to explain the innovative effects of environmental regulation. One paradigm is environmental economics (see Jaffe et al. 2003 for an overview). In general, environmental economics argues within a rather linear model of sequential innovation stages: inventions lead to new technical development, which then diffuse through the market. There is a tendency to analyse the effects on the different stages of innovation separately. Assuming perfect economic rationality, the innovation decisions are based on microeconomic optimization behaviour. The theory of induced innovation states that changing relative prices induces innovations to substitute the production factor becoming more expensive. Thus, environmental economics highlights the incentive structure which results from different policy instruments. In general, environmental economics clearly sees more positive effects on the development and diffusion of environmentally friendly technologies with market-based instruments.

The approach of environmental economics is challenged by evolutionary and institutional economic thinking. Two key concepts play an important role:

- First, the key assumption of a rational profit maximizing behaviour of all actors is challenged. With regard to behaviour, the strict rationality of the "homo oeconomicus" is softened. Instead, the concepts of bounded rationality and the role of routines are highlighted (see Conlisk 1996 for an overview). Nelson (2002) stresses the point that behavioural routines which have evolved over a longer period of time play an important role. They take the place of the permanent optimisation due to smallest modifications in the frame conditions which dominates neoclassical theory. This behavioural assumption is implicitly linked with a restriction of the induced innovation hypothesis based on relative price changes of neoclassical theory and the resulting instrument preferences. If innovation behaviour is determined by behavioural routines, not only changes due to altered relative prices by environmental regulation are decisive, but how this regulation changes the behavioural routines themselves.
- The second important key concept relevant for environmental regulation is transaction costs. They play a considerable role and have to be accounted for in energy and environmental policy (see Ostertag 2003). These include resources necessary for the creation, maintenance, support and equipment of institutions and organisations. In addition, search and information costs occur, negotiation and decision costs and monitoring and implementation costs as soon as players become active in markets. High transaction costs can act as drivers for and barriers to technical and organisational or institutional innovations.

Another view of the effects of environmental regulation has been developed by political scientists within the so-called policy analysis paradigm (see Heritier 1993, Howlett/Ramesh 1995; Jänicke et al. 1999). In contrast to environmental economics, this paradigm downplays the importance of the choice of instrument and emphasises the perception of the environmental problems and the agenda setting process. Thus, factors such as strength and strategic ability of the various actors, the nature of the problem, political environment, and policy style are particularly important (Jänicke/Weidner 1995; Jänicke et al. 1999).

Especially the policy style can be influenced by policy makers. In a complex world, policies should be part of a learning process involving both government and business (Richardson 1982; Jänicke et al. 1999). A precondition for such a co-operation is a policy style which enables a dialogue between the actors (Solsberg 1997). Furthermore, firms need reliability before they engage in innovative activities. With regard to environmental innovations, this requires that the political priorities are known well in advance. Thus, one key factor for an innovation friendly environmental policy is seen in the existence of a long-term policy plan naming the environmental medium and long-term targets (Jänicke et al. 1999). To sum up, policy analysis implicitly uses a decision model in which psychological elements seem to play an important part. It downplays the importance of microeconomic incentives from environmental regulation, and highlights the importance of the soft context factors.

There have been several case studies in the field of innovation effects of environmental and energy policies in the late 1990s, which were based on the approaches described above (for an overview see Klemmer 1999 and Kemp et al. 2000). Reflections on the case studies have concluded that neither of the used paradigms alone is able to account for all of the relevant aspects. Thus, a heterodox approach is argued for which draws on a combination of the paradigms (Blazejczak et al. 1999; Klemmer et al. 1999, Walz 2004).

2.3 Systems of Innovation as an integrating framework

In the 1990s, the heuristic approach of systems of innovation gained wide acceptance (for an overview, see Lundvall et al. 2002 and Edquist 2005). In addition to the demand and technology factors, this approach underlines the manifold aspects of the intra-firm determinants of innovation, the characteristics of innovation as an interactive approach, the role of institutions in shaping activities, the importance of the home (lead) market as a base for competitiveness on the international markets, and the regulatory framework. The key notion of the systems of innovation approach is that these factors influence each other, highlighting the importance of feedback mechanisms.

The experiences with this framework have led to conclusions about the conditions which shape innovation processes. The following factors are especially important:

- Innovation is not a linear process, but consists of many feedback loops between invention, technology development, and diffusion.

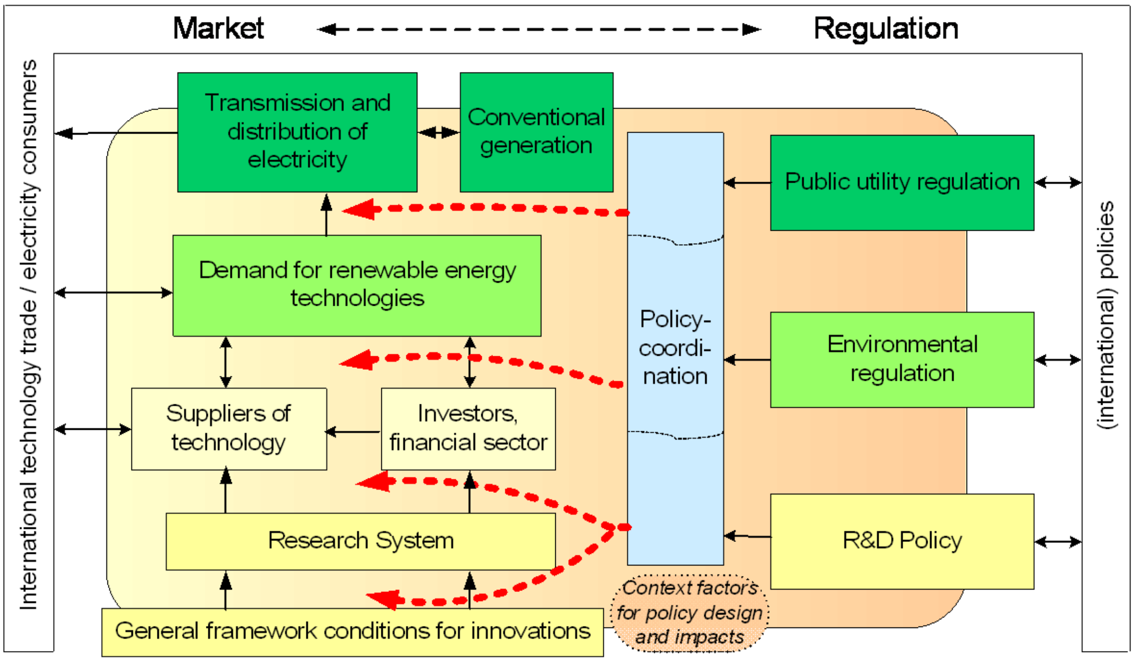
- Innovation is embedded in production of knowledge and socioeconomic development and institution leading to path dependency.
- Producer-user interaction and learning in the market makes early diffusion important.
- There is a need for diversity of solutions on the one hand, and selection towards a dominant design at the other.
- Stability of framework conditions, in general, enhance innovation processes.
- Communication between actors on various levels is essential in order to disseminate knowledge and to gain new insights.

In contrast to traditional thinking, policies pushing the diffusion of the technology are also an important prerequisite for new technical solutions. Furthermore, the lock-in effects creating the path dependency are also linked to the diffusion of the traditional technologies. This highlights the role of the demand side. Furthermore, the demand for renewable energy is dependent on regulation (triple regulatory challenge). Thus, the role of demand regulation arises as a key for the analysis of the relation between regulation and innovation.

The framework of systems of innovation has been traditionally applied to national innovation systems. More recently, however, it has been also applied to analyze technological or sectoral systems (e.g. Carlsson/Stankiewicz 1995; Carlsson et al. 2002, Malerba 2002 and 2005). These approaches share the starting point that innovations can be best explained by characterizing the components of an innovation system, such as actors, networks and institutions (including regulation), and their interaction with each other.

Figure 1 shows the results of delineation of the most important actors for the case of renewable energy: Firstly, there is the demand for renewable energy technologies, which depends on the diffusion of the technology. Secondly, there are the suppliers of renewable energy technologies. They consist of companies which have a quite similar structure as other companies within the investment good sectors. Thirdly, there are the investors in renewable energy technologies and the financial institutions supplying capital. Fourthly, the electricity produced by the renewable energy must be transmitted and distributed to the customers. Thus, access to the grid is vital for renewable electricity. Here the electric utilities play a key role. They are responsible for the transmission and the distribution of electricity on the one hand. On the other hand, electricity from renewable energy is substituting electricity supplied from other conventional power plants. Thus, the electric utilities are at the same time a competitor. Figure 1 also highlights the prominent role of the triple regulatory challenge in the system. Besides the direct influences on the actors affected, there are also indirect effects, as the direct influences are transmitted via the interactions of the actors with each other. Furthermore, many context specific "soft" factors influence the design of policies and the impacts with a system of innovation.

Figure 1: The triple role of regulation within the system of innovation of wind energy



It has been suggested that a technological innovation system can be best analyzed by looking at how the different functions an innovation system has to meet are fulfilled (Johnson 1998, Johnson/Jacobsson 2000, Bergek/Jacobsson 2003, Smits/Kuhlmann, 2004; Hekkert et al. 2007; Bergek et al. 2008 a and b). There is no final list yet, and differences in wording, however the following functions can be distinguished:

- creation of positive external economies through exchange of information and knowledge between producers, but also along the value chain (including supplier-user interaction),
- search activity, including guidance in search with respect to technological and market choice,
- legitimacy of a new technology, which is closely connected with recognition of a growth potential,
- facilitation of market formation,

- supply of resources, which is especially important for new technologies which are associated with a higher risk of failure, and
- diversity in experimentation, and variety of solutions, in order to have a sufficient large stock of technologies from which selection processes can develop a dominant design.

Most case studies undertaken in the system of innovation tradition dealt with "normal" innovations in manufacturing, which do not face the triple regulatory challenge. These case studies had not to concentrate on the specific role of regulations which address the second and third form of the regulatory challenge, which are especially important for innovations in the energy, water and transportation field. And even the few case studies from this research tradition, which deal with energy issues (e.g. Jacobsson/Johnson 2000; Bergek/Jacobsson 2003; Agterbosch et al. 2004, Foxon et al. 2005), do not go into detail with regard to the effects of specific forms of utility regulation or the role of the type of policy instruments used.

In this paper, we follow the authors quoted above and also use the functions of a system of innovation as an intermediate bridge between the structure of the innovation systems (e.g. actors, regulation) and the performance with regard to developing and diffusing innovations (Figure 2). Furthermore, we parallel the approach of Walz 2007 and incorporate the various paradigms of the effects of environmental and utility regulation in this scheme. The rationale of this heterodox approach is the notion, that the paradigms from economics and policy research can be used to explain the effect of regulation on the functions of the innovation system, leading to a better understanding of the complex interplay between innovation and regulation.

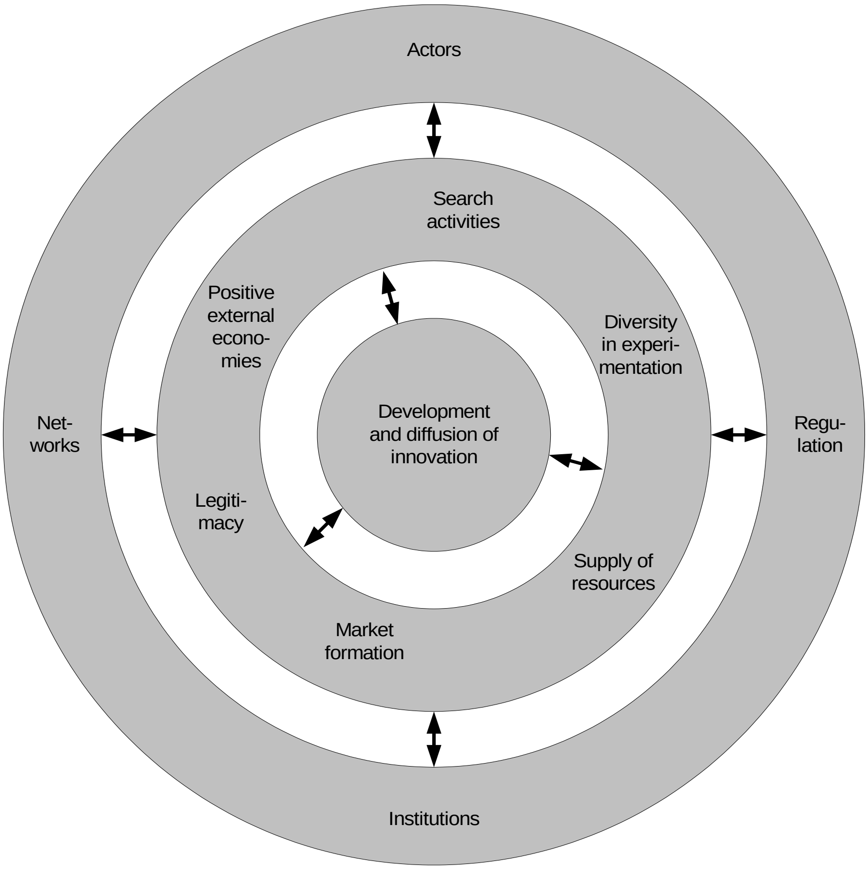
Starting from this approach, the following conceptual hypotheses can be developed:

- Regulation of the demand side (e.g. feed-in-tariffs, production subsidies, quota systems) creates demand and is prerequisite for market formation, supply of resources and exchange of information by user-producer interaction.
- Regulation of the supply side, e.g. R&D subsidies, not only supply resources and help in guiding search, but can also be used to establish networks between suppliers and facilitate exchange of information.
- The stability and long term vision of target setting are important policy style variables, which act on the legitimacy of technology and give guidance of search.
- The design of regulation (e.g. feed in versus quota; degression of feed in tariffs) influence the risk perception and transaction costs and thus act on supply of resources and market formation.

- The number of different technologies which are promoted is a key design variable of demand regulation, which also influences the variety of solutions which can benefit from learning in the market.

In contrast to existing case studies, this paper aims at analysing these hypotheses empirically with a statistical approach for many countries. This requires measuring both innovations and regulation with indicators.

Figure 2: Role of functions of an innovation system as intermediate between structure and performance of an innovation system

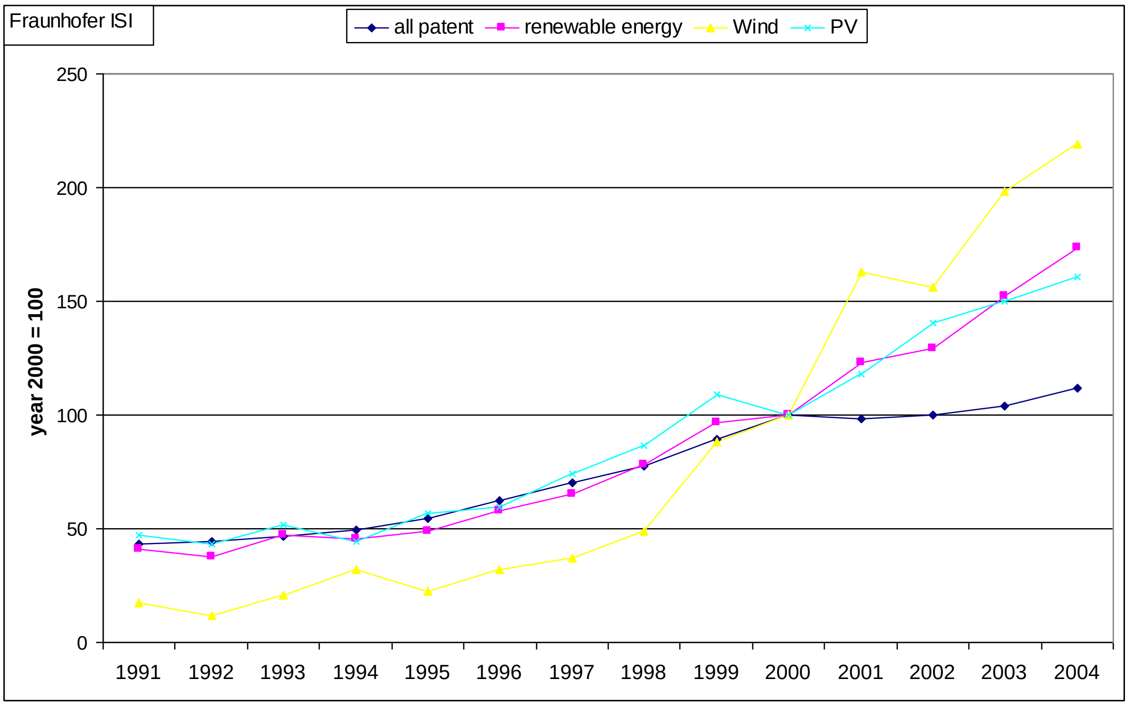


3 Measuring Innovation

There are various innovation indicators which can be used to measure innovations (see Archibugi/Pianta 1996; Grupp 1998 and Smith 2005). The innovation dynamics of the renewable energy technologies was analysed with the help of patent indicators. The technological capabilities of the countries were measured with both patent indicators and trade indicators. For both types of indicators, the share of the countries at the world total was calculated (patent share, world export share). Furthermore, relative indicators (relative patent share (RPA); relative trade share (RTS) and revealed comparative advantage (RCA) were calculated, in order to analyse whether or not the countries specialize on the sustainability technologies.

Renewable energy technologies are neither a patent class nor a classification in the HS-2002 classification of the trade data from the UN-COMTRAD databank which can be easily detected. Thus, for each technology, it was necessary to identify the key technological concepts and segments. They were transformed into specific search concepts for the patent data and classification schemes for the trade data. This required an enormous amount of work and substantial engineering skills. Furthermore, there is a dual use problem of some of the identified technological segments. In order to reflect that ambiguity the term "potential concept" is used to describe this kind of analysis (Legler et al. 2006). Based on prior work in developing the classification system (Walz et al. 2008 a and b), the following renewable energy technology fields were analysed with this concept: Solar thermal, photovoltaics, wind power, water turbines, biomass related technologies, and geothermal electricity.

Figure 3: Innovation dynamics for renewable energy technologies



source: calculations of Fraunhofer ISI

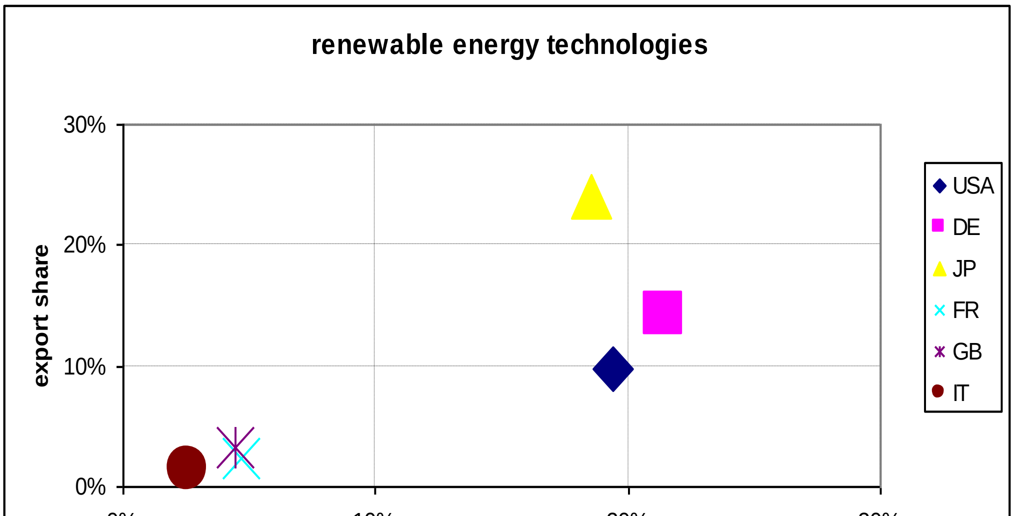
Figure 3 shows the results of patent analysis for the innovation dynamics. It can be seen that during the 1990s, the patent dynamic of renewable energy technologies has been roughly the same as for all patents. In the 2000s, however, the innovation dynamics of renewable energy technologies has been outpacing the average substantially. This holds for all of the renewable technologies analysed, however, with varying degree. Especially the dynamics for wind energy technologies increased substantially.

The analysis of the countries capabilities with regard to renewable energy shows the following results: Germany has emerged as leader in patents, while Japan leads in exports. The US is now trailing behind Germany and Japan. The other major OECD-countries, such as UK, France, and Italy, each only account for less than 5 % of world trade or international patents of renewable energy technologies. The ten OECD countries most active in renewable energy technologies together account for 80 % of all international patents in the world (Table 1).

However, these numbers do neither reflect the size of a country, nor the level of its integration into the world economy. Thus, specialization measures are used describing whether or not the country is specializing on the technologies analyzed. The specialization indicators used in this paper are the Relative Patent Acticvity (RPA) and the Relative Trade Share (RTS). Both are normalized between +100 and –100. A positive value indicates an above average specialization on the analyzed technologies, a negative value shows that the country is more specializing on other technologies.

The result of the specialization analyses reveals that among the 6 largest OECD economies, both Germany and Japan have been specializing on renewable energy technologies. The US, UK, France and Italy, on the other hand, have been specializing on other technologies. Both their patent activity and export performance is below average for renewable energy technologies. A closer look on other countries, however, reveals that some of the smaller countries are also specializing heavily on renewable energy technologies, such as Denmark or Spain.

Figure 4: Patent and Trade Shares of major OECD countries at renewable energy technologies



source: calculation of Fraunhofer ISI

Figure 5: Patent and Trade Specialisation of major OECD countries at renewable energy technologies

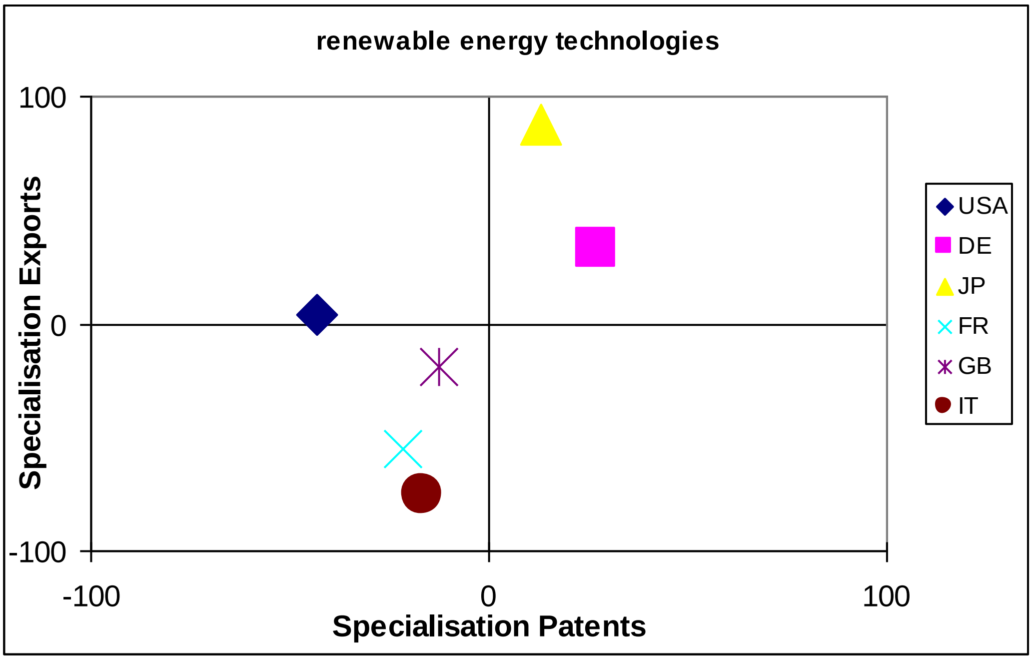


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Table1: Results of innovation indicators for renewable energy technologies for the most active OECD-countries

	Patent share (2001-04)	RPA (2001-04)	Export Share (2005)	RTS (2005)
US	19%	-43	9,7%	4
DE	21%	27	14,3%	33

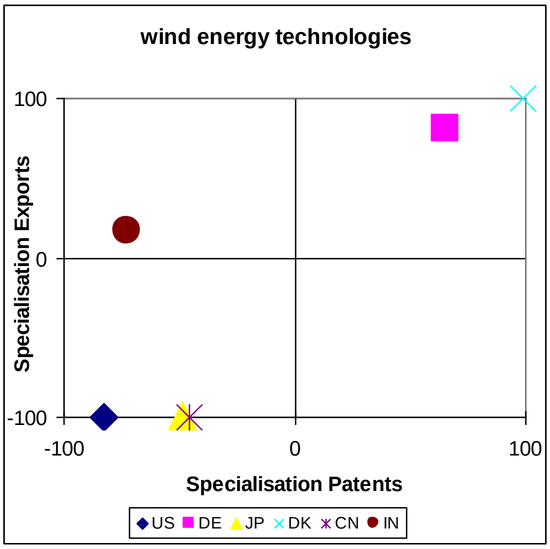
JP	19%	13	24,0%	88
FR	5%	-22	2,4%	-55
GB	4%	-12	3,29%	-19
IT	3%	-16	1,5%	-75
NL	3%	14	2,0%	-47
SE	1%	-24	1,5%	9
ES	2%	63	2,4%	19
DK	3%	87	5,6%	96
CN	1,2 %	14	6,3%	-22
IN	0,2 %	-62	0,61%	-51

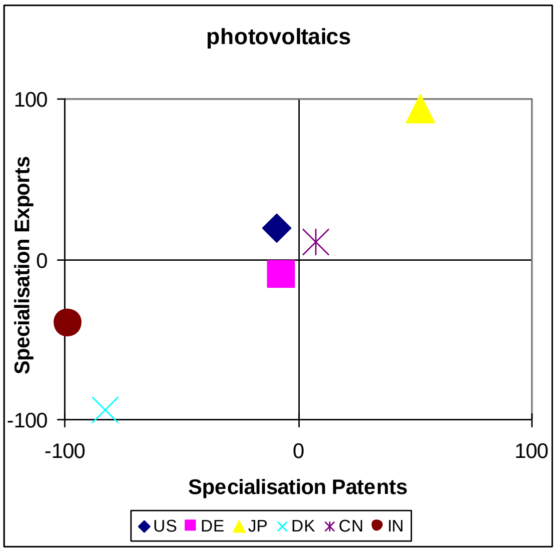
The numbers presented so far are aggregated values for all renewable energy technologies. A disaggregated analysis on the technology level reveals that there are enormous differences within the countries. Archibugi and Pianta (1992) have shown that the level of specialization decreases with the size of the technology base, because larger countries can afford more easily to spread out their technological advances into different directions. Nevertheless, the specialization is still very high for the two leading countries Germany and especially Japan[2], which both are countries with a very large technology basis.

The differences in specialisation are even more pronounced on a disaggregated technology level. This can be seen by comparing specialisation for wind and photovoltaics technologies. Clearly this is the case for Denmark and Japan, which heavily specialise on wind energy technologies and photovoltaic, respectively. Finally the numbers for India and China also indicate substantial differences for very large catching up economies.

Figure 6: Patent and trade specialization for wind and PV technologies

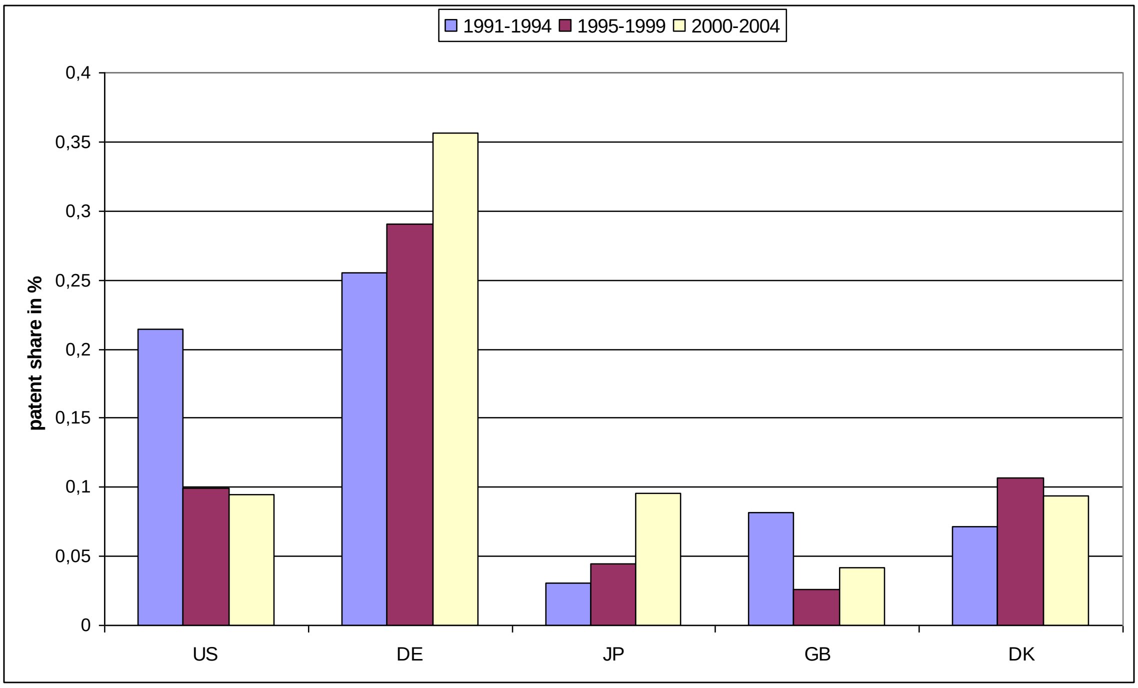
2 This is in line with the results from Archibugi/Pianta 1992, which have shown that Japan has a history of higher specialization degree than would be expected from the size of its Science&Technology activities.





source: calculations of Fraunhofer ISI

Figure 7: Patent shares for most active countries in wind energy technologies



Source: calculations of Fraunhofer ISI

The relative capability of the countries has not been constant over the years. Figure 7 demonstrates in the case of wind energy the changes since the early 1990s for the most important countries active in patenting wind technologies. Most remarkable has been the decline of the US and UK since the early 1990s, and Germany's constant rising. Lately, also Japan is increasing its activity, starting from a low level, however. Given its size of the economy, the level of Denmark's activity is highly remarkable. However, the numbers are indicating that Denmark's position has been peaking at the end of the 1990's.

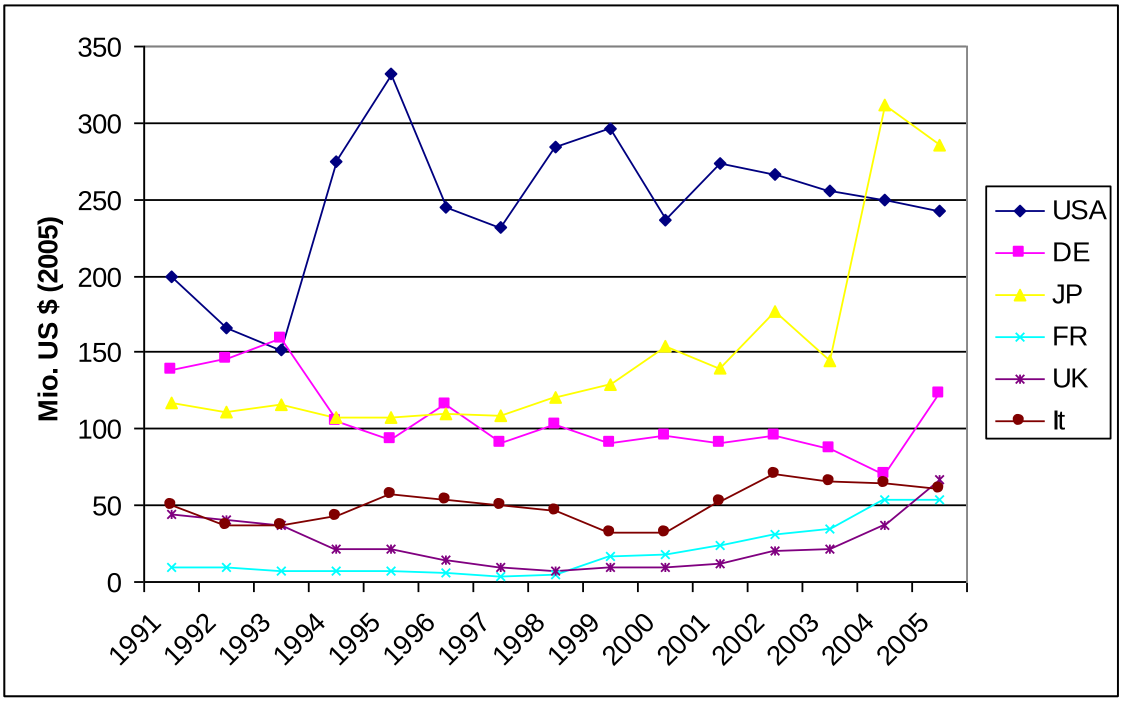
To sum up the argument, there are clear differences and clear specialization patterns among the leading countries, which have been changing over time. Furthermore, there are also clear differences within the countries with regard to different technologies. At the same time, the innovation dynamics of renewable energy technology, which is above average, still differs between the technologies. This implies that the relation between regulation and innovation must be analysed on a detailed technology level.

4 Regulation in the field of renewable energy

4.1 Regulation on the supply side of the technology markets

In the context of regulation, R&D subsidies (mainly to technology providers) are one of the most common forms of regulation. They not only supply resources and help in guiding search, but can also be used to establish networks between suppliers and facilitate exchange of information. Indeed, Bergek et al. (2008 a and b) mention R&D programs as one of the most typical inducement blocks for building innovation systems. This kind of regulation is also used in most countries active in patenting renewable energy technologies.

Figure 8: Public R&D expenditures for renewable energy technologies



Source: Data from IEA/OECD energy statistics

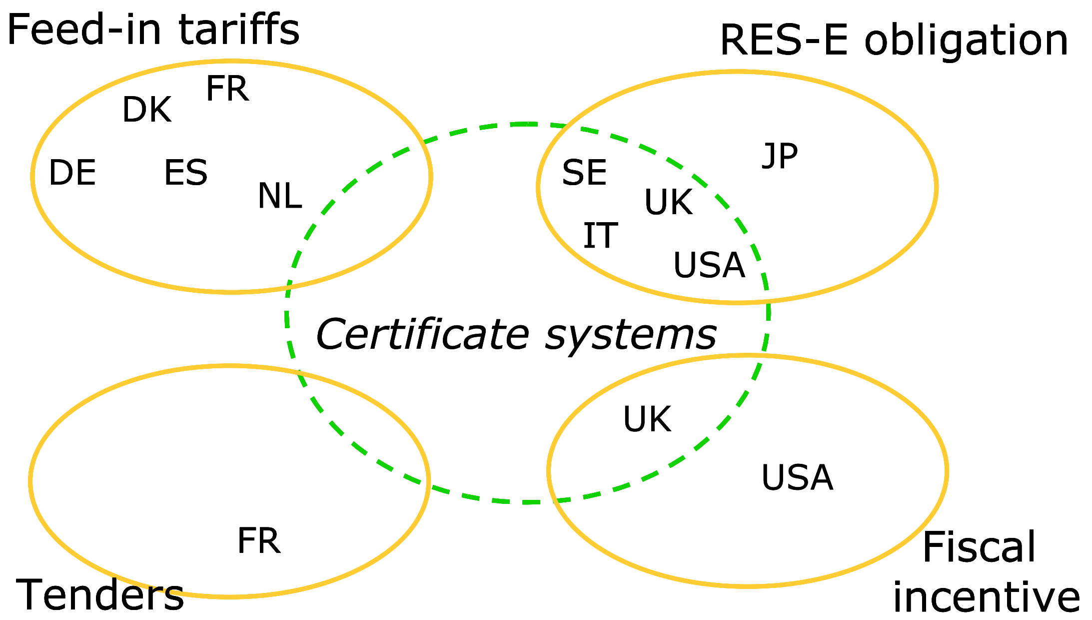
The different intensity in this kind of regulation can be taken into account by looking at the IEA/OECD energy statistics, which include a breakdown of R&D subsidies according to different energy technologies. Figure 8, for example, shows the trend in public R&D budgets for the accumulated renewable energy technologies for the 6 major OECD-economies. The U.S. had the world's largest public R&D budget for many years. Under the Clinton administration, renewable energy budgets were increased and stayed at around that level since. During the 1990's, the changes in the other countries were rather modest. In some countries, like Germany, a slow decline happened during the 1990s. Other countries, notably Japan, slowly increased their budget. In the 2000's, however, a stronger tendency towards increasing public R&D budgets for renewable energy technologies can be seen. Japan doubled its budget and surpassed even the U.S. This development reflects an increasing role assigned to renewable energy technologies in solving the world's energy problems.

4.2 Regulation on the demand side

A variety of policy instruments is currently implemented on the demand side for renewable energy technologies. These regulatory instruments include feed-in tariffs, quota obligation systems, tax measures and investment incentives. Figure 9 provides an overview of the renewable electricity support systems in OECD countries:

- Feed-in tariffs are generation-based, price-driven incentives. Thereby, the price per unit of electricity that a utility or supplier or grid operator is legally obligated to pay for electricity from RES-E producers is determined by regulation. FITs allow technology-specific promotion as well as an acknowledgement of future cost-reductions. In many countries, fixed feed-in tariffs are the main instrument used to support the generation of renewable electricity. They are well known for their success in deploying large amounts of wind, biomass and solar energy in Germany, Denmark and Spain among others.
- Production tax incentives are generation-based, price-driven mechanisms. They can be an attractive instrument as has been observed in the case of onshore wind in the United States. This instrument can be very similar to a premium feed-in tariff, by offering additional income to the investor.
- Quota obligations are generation-based, quantity-driven instruments. The government defines targets for RES-E deployment and obliges a particular party of the electricity supply-chain (e.g., generator, wholesaler, consumer) with their fulfilment. Once defined, a parallel market for renewable energy certificates is established and their price is set following demand and supply conditions (forced by the obligation). Quota obligations are now used in Italy, Sweden, Japan, the United Kingdom and the United States.
- Tendering systems are also quantity-driven mechanisms and work similar as a quota. The advantages of a tender scheme include the amount of attention it draws towards renewable energy investment opportunities and the competitive element incorporated in its design. However, the overall number of projects actually implemented in the UK has been very low, resulting in a much lower penetration of renewables than originally anticipated.

Figure 9: Overview of renewable electricity support systems in EU-15



Regulation of the demand side creates demand and is prerequisite for market formation, supply of resources and exchange of information by user-producer interaction. Typically, they also include regulation for access to the grid, which forms a monopolistic bottleneck. In chapter 2, the important role of regulation at the demand side for renewable energy technologies has been stated. Indeed, most of the renewable energy technologies are currently more expensive than the traditional forms of electricity generation (excluding the external costs associated with their generation). Without regulation, the level of diffusion of renewable energy technologies would be much lower. Due to this direct link between regulation and diffusion, the level of diffusion of renewable technologies not only describes directly how much the function of market formation - and other functions depending on the diffusion of the technology such as supply of resources and exchange of information by user-producer interaction - are fulfilled, but also serves as a rough proxy on the stringency of demand regulation.

The diffusion of many renewable energy technologies has been very dynamic at a global scale during the last decade. In particular wind energy and photovoltaics have seen strong growth during recent years. This development is shown in Figure 10 and 11.

As can be seen Germany, Spain, the USA and Denmark have become the largest markets for the case of wind energy. Whereas the USA has already seen significant deployment in the 80s the other three countries have experienced the strongest market diffusion during the last decade. The contribution of the other countries included in the present analysis is only moderate. Especially countries with favourable wind conditions like UK or Japan showed a relatively low market growth. It can be stated that the highest growth during the last decade was achieved in countries using feed-in tariff as their main support system. The development in the United States was mainly driven by federal production tax incentives combined with state level renewable portfolio standards.

Figure 10: Historic deployment of wind electricity generation in selected countries 1990-2005

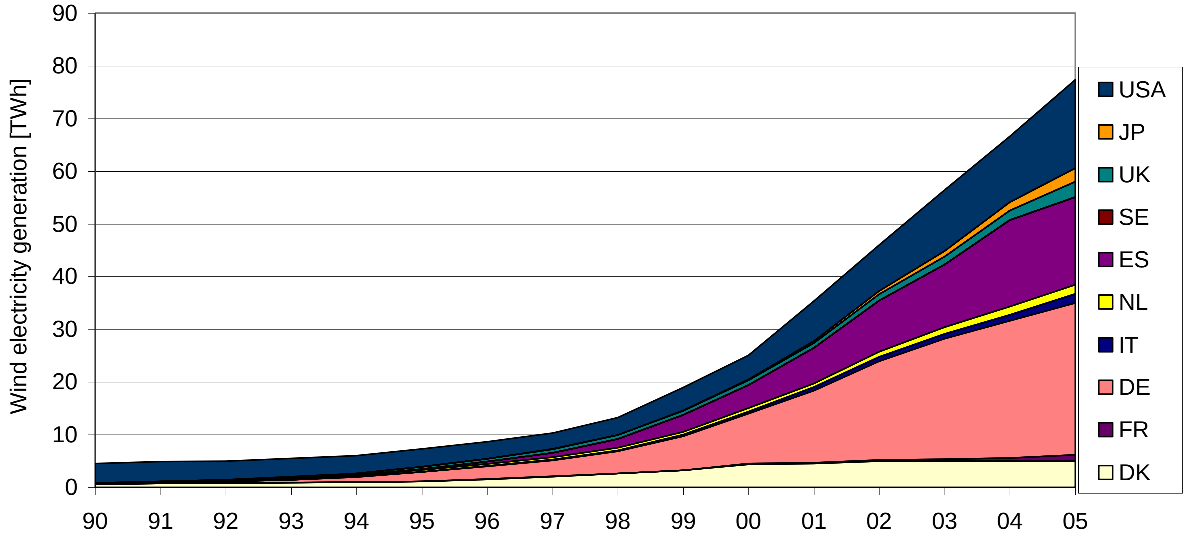
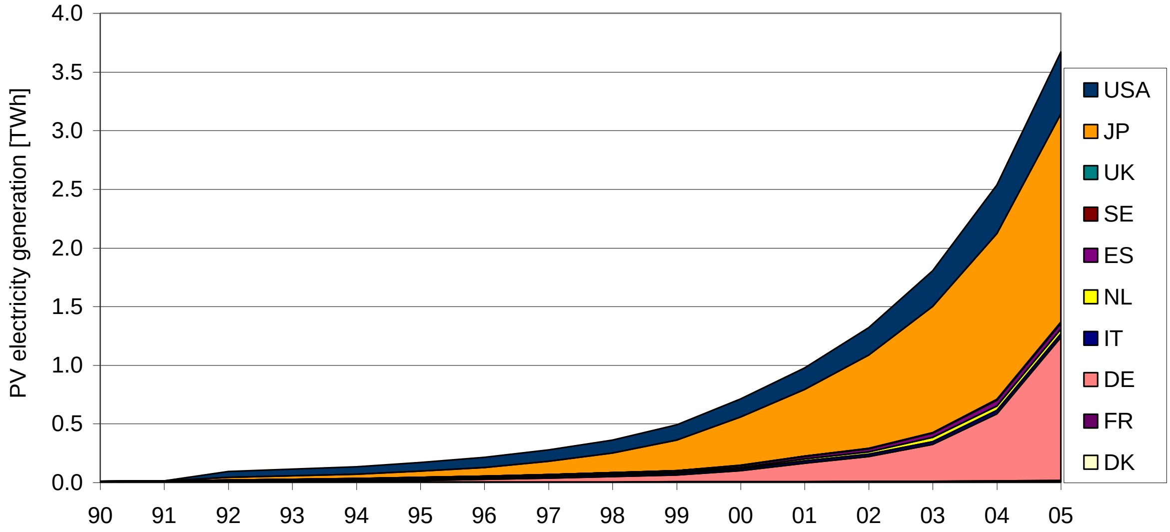


Figure 11: Deployment of photovoltaic electricity generation in selected countries



The diffusion of photovoltaics in terms of total installed capacity has been dominated by two countries, Germany and Japan, which are followed in some distance by the USA. These three countries were responsible for roughly 88% of the globally installed capacity at the end of 2005. The recent development in these three countries was mainly driven by fixed feed-in tariffs in Germany and investment incentives in Japan and the USA.

4.3 Indirect Effects of regulation

The main effects of demand side regulation on the innovation functions are already included in the rough proxy of diffusion of the technology. However, there are also some additional aspects which have to be accounted for. They relate to the

- type of instrument used,
- specific details within the regulation, and
- stability and predictability of regulation.

It has been already noted that demand side regulation is necessary for market formation. However, the type of instrument used can also have an effect on the functions of an innovation system. There have been numerous case studies in the field of renewable energies recently. Most of them focus on the debate about the effects of different policy instruments (e.g. Haas et al. 2004, Markard et al. (2004), Reiche/Bechberger 2004, Lauber/Metz 2004 Mitchell/Connor 2004, Langniss/Wiser 2003, Meyer 2004, Foxon 2005, Bird 2005, Menz 2005, Szarka (2006), Alkemade et al. (2007), and Ragwitz et al. 2005 with overviews for Europe). The specific advantage of feed-in tariffs is seen in lower transaction costs and risk perception, which are extremely important especially for new entrants. The reason is that feed in tariffs give long time security on the payments for produced electricity. At the same time, the feed-in tariffs can easily be designed in a technology specific manner and even consider cost differences within one technology. The latter fact leads to a reduction of windfall profits and gives the opportunity to specifically support new and innovative technologies. Thus, it allows for greater diversity of technologies brought into the market and spurs experimentation. Both aspects work towards better fulfilling the function of diversity and variety of technical solutions. Quota obligations are often considered to be more in line with requirements for competitive policies that provide a strong incentive for short-term cost reductions. However, the perceived drawbacks of quota or bidding schemes include the lower investment security for investors, combined with higher financing costs, the complexity of the system and the risk of supporting only lower-cost technologies leading to reduced diversity of technologies in the market.

Specific details within the regulation can also influence the search process. Especially important are signals which show future requirements in cost decreases. A degression of feed-in tariffs over time, which is implemented in Germany for example, gives a strong incentive for cost reduction and technological innovation. Such additional information gives guidance within the search process and contributes to a better fulfilment of the specific functioning.

According to the paradigms described in chapter 2, the stability and long-term character of the regulation also influences the effect on innovation. Clearly the existence of long-term goals add to the legitimacy of a new technology. Indeed, missing long term targets are seen as a blocking mechanism for the functioning of an innovation system (Bergek et al. 2008a).

In addition to the numerous evaluations and case studies quoted above, the regulation in the field of renewable energy is systematically characterized in ongoing work for the OECD/IEA. For the case of wind energy, these experiences were bundled by expert opinion in a scoring indicator between 1 and 4 indicating whether the specific form of regulation has been non-supportive (1) or highly supportive (4), or in between. Thus, countries with e.g. feed-in tariffs, specific regulation details expressing future cost requirements or with reliable long term policies targets got evaluated higher and vice versa.

Clearly the resulting scoring indicator of "innovation friendliness" can only be viewed as a first attempt. Firstly, the subjective basis of the indicator values can be criticized. However, Nicoletti/Pryor 2006 in their meta analysis of indicators on regulatory regimes claim that subjective based indicators by experts familiar with the regulation need not to be less meaningful than indicators based on "objective" statistics. Secondly, the indicator does not account for all additional innovation functions which were identified in chapter 2. Nevertheless, it brings additional functions of an innovation into the empirical analysis, which are not accounted for by the rough indicators of diffusion of technology and R&D subsidies. Thirdly, it will be necessary to broaden the empirical basis of the indicator to make its results more robust.

5 Econometric analysis of relationship between regulation and innovation for wind energy

In this chapter the relevance of various determinants of innovation activity in the wind power sector is analysed empirically. The dependent variable for the econometric panel estimation is the number of international patents in country i (see chapter 3). The set of explanatory variables consists of:

- *R&D*: (real) public expenditures for research and development for wind power in country i; public R&D is a proxy for regulation at the supply side of the technology market influencing the input into the innovation process;
- *Capacity*: cumulated capacity of wind power installed in country i; *capacity* is a measure for technology diffusion and reflects the impact of domestic regulation on the functions of an innovation system which depend on the diffusion of the technology;
- *Export*: (real) export volume of wind power technologies from country i; export stands for the impact of foreign regulation on the functions of an innovation system in country i which depend on the diffusion of the technology;
- *RCA*: revealed comparative advantage index of complementary sector in country i; this variable is related to the results of Fagerberg 1995b; *RCA* is supposed to measure the relevance of spill-over effects from the mechanical engineering sector, which is the major supply sector for the wind power sector, on innovation in the wind power sector in country i; it is assumed that successful export performance indicates a high technological capability with comes hand in hand with a high potential for spillovers.
- *Policy*: policy index of “innovation friendliness"; policy is an ordinal variable which takes on the values of 1 to 4; it is supposed to supplement the capacity dimension with a qualitative component on the innovation friendliness of the instruments and the policy style in country i (see chapter 4).

The balanced panel consists of observations for 1991 to 2004 for the following ten countries: Denmark, France, Germany, Italy, Japan, the Netherlands, Spain, Sweden, the United Kingdom and the United States. In the actual implementation of the model, logs are used for the dependent variable and for *R&D*, *capacity* and *export*. To address time dependence, all variables are used in first difference form (some as lags)[3]. For the policy index we use the values of -1, 0 and +1 depending on whether innovation friendliness in country i was judged to have deteriorated, remained the same or improved from the previous year, respectively. The regression is estimated as a panel applying Feasible Generalized Least Squares using xtgls (STATA 9), allowing for different structures of the variance-covariances across countries. Since variables enter in differences, this is, in a sense very similar to a so-called "fixed effects model", but country-specific

3 Based on formal tests of stationarity for patents (augmented Dickey-Fuller and Dickey-Fuller GLS) the hypothesis of unit roots cannot be rejected.

effects are differenced out[4]. Since the number of periods (T) exceeds number of countries (N), a more general estimation procedure is feasible. In particular, we allow for three types of variance structures. Model 1 assumes homoscedasticity (i.e. identical terms on the diagonal of the estimated variance-covariance matrix and zeroes on the off-diagonals); Model 2 allows for heteroscedasticity countries (i.e. terms on diagonal of variance-covariance matrix may differ across countries). In addition Model 2 allows for correlation across countries (i.e. the off-diagonals are no longer zero in Model 3). Going from Model 1 to Model 2 improves efficiency of the estimators, but reduces the degrees of freedom (and decreases log likelihood – in absolute terms).[5] Estimation results for Model 1 to Model 3 appear in Table 3 and Table 4. For the models presented in Table 3 *policy* is not included in the set of explanatory variables.

Estimation results suggest that parameters exhibit the expected signs, but they do not turn out to be statistically significant at conventional levels in all models. If we allow for heteroscedasticity with cross-sectoral correlation, all parameter estimates are found to be statistically significant at 1 % level (except for exports in Table 4, which is statistically significant at the 10 % level). In general, the results show that innovation is highly influenced by regulation. The results are consistent with the hypotheses developed earlier, i.e. that public expenditures on R&D (regulation of the supply side), installed capacity (triggered by more favourable domestic regulation), exports (more favourable foreign regulation) and in RCA of complementary sector (spill over) increase innovation (as measured by number of patents). Likewise, the parameter estimate for our policy index for innovation friendliness is positive and statistically significant at the 10% level in model 3 only. Thus, there is some evidence that innovation activity in the wind power industry also depends on the policy environment and implementation details of the demand regulation (in addition to the effects expressed by R&D expenditures and technology diffusion). Finally, comparing results from Table 3 and Table 4 shows that they are fairly robust with respect to including the policy index, i.e. the correlation between *policy* and other explanatory variables does not significantly alter the parameter estimates for the other variables.

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4 Of course, addressing possible nonstationarity by using differences may come at a cost in terms of losing valuable information on the long-term relationship between the dependent and the explanatory variables.

5 Formal likelihood ratio tests for homoskedasticity reject the assumptions of (i) homoskedasticity in favour of simple heteroskedasticity (LR = 19.43 ; P-value = 0.02); homoskedasticity in favour of heteroskedasticity across panels (LR = 115.40; P-value = 0.00) and simple heteroskedasticity in favour of heteroskedasticity across panels (LR = 95.97; P-value = 0.00).

Table 3: Estimation results for wind power sector without indicator for policy friendliness

	Model 1		Model 2		Model 3	
	(homosk.)		(heterosk.)		(heterosk. w/ X-sect. correl.)	
R&D	0.176	**	0.228	***	0.231	***
	0.088		0.073		0.030	
Capacity (cum, t-1)	0.221		0.262	**	0.283	***
	0.184		0.146		0.067	
Export (t-1)	0.042		0.055	**	0.044	***
	0.029		0.022		0.010	
RCA compl. Sector	1.231		1.280		1.206	**
	1.812		1.646		0.560	
Constant	0.086		0.095		0.072	**
	0.081		0.065		0.032	
Sample size	120		120		120	
Log likelihood	-108.1977		-98.48499		-50.50006	

* significant at 10% level; ** significant at 5% level; *** significant at 1% level

Table 4: Estimation results for wind power sector with indicator for policy friendliness

	Model 1		Model 2		Model 3	
	(homosk.)		(heterosk.)		(heterosk. w/ X-sect. correl.)	
R&D	0.176	**	0.229	***	0.243	***
	0.088		0.073		0.031	
Capacity (cum, t-1)	0.221		0.268	*	0.278	***
	0.185		0.146		0.067	
Export (t-1)	0.042		0.057	**	0.043	***
	0.029		0.023		0.010	
RCA compl. Sector	1.251		1.455		1.520	***
	1.829		1.668		0.591	
Policy	0.014		0.095		0.096	*
	0.181		0.157		0.058	
Constant	0.085		0.085		0.066	**
	0.083		0.067		0.032	
Sample size	120		120		120	
Log likelihood	-108.1948		-98.29737		-98.29737	

* significant at 10% level; ** significant at 5% level; *** significant at 1% level

6 Conclusions

The triple regulatory challenge of R&D, public utility and environmental regulation make renewable energy an extremely important example for the influence of regulation on innovation. The functions of a system of innovation can serve as a useful heuristic. This requires that the effects of regulation on the different functions of an innovation system must be evaluated. Innovation is a process with many feedback loops between invention, development of the technology and diffusion. Therefore the diffusion for the technology becomes an important aspect which influences various functions of an innovation system. However, diffusion is highly related to regulation on the demand side. This leads to the hypothesis that regulation plays an extremely important role for shaping the innovations in renewable energy technologies.

The empirical analysis of the innovation activities has shown that the innovation dynamics of renewable energy technologies is above average. Germany and Japan (especially PV) are leading countries in the innovation. However, the results also show that leading roles can change over rather short to medium period of time. Furthermore, the differences between the competences for the various technologies within the countries indicate that the analysis must be performed on a technology specific level. Otherwise, important strengths of countries at single technologies (e.g. Denmark and India in wind energy, china in PV) are evened out.

The empirical results for the importance of regulation reveal a high level of regulation to foster diffusion of the technologies. In addition to R&D subsidies, different forms of demand regulation are used. This has led to an enormous increase in the diffusion of the technologies lately.

The econometric analysis underlines the importance of regulation for the innovations. The diffusion of the technology, which is mainly triggered by demand regulation, plus the R&D subsidies are important variables for the explanation of patent activity. Furthermore, complementary sectors as source for knowledge spillover are another factor to explain the innovations.

Finally, the paper provides a first attempt to build an indicator for innovation friendliness of regulation. This regulation indicator aims at including additional effects on the functions of an innovation system which are not covered by the “R&D subsidies” and “diffusion of technology” as proxy for the demand side regulation. The results call for additional research. It should concentrate on improvements of the construction of the policy indicator, e.g. by more formal coding, and the inclusion of additional functions of an innovation system. Furthermore, the reliability and prospect of this approach should be tested by further econometric analysis for additional sectors and technologies.

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