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Wind energy policy and their impact on innovation - an international comparison

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1 Introduction[*]

As we now know, the dominant form of technological development is currently associated with substantial intervention in the natural world and the progressive exhaustion of natural resources. Sustainable development, guaranteeing the long-term availability of natural resources and preservation of environmental quality, would therefore seem to require fundamental changes in existing production methods and consumer behaviour. The political and scientific debate has stressed above all the importance of progress in environmental technology with respect to exploiting resources, to production, consumption and disposal. (cf. Enquete-Commission 1994:65ff., SRU 1996:82, EG-Commission 1993).

During the past 20 years, innovation has taken place primarily in end-of-pipe technologies, which has already resulted in considerable reductions in environmental pressure (cf. Walz et al. 1992:7). However, the demanding criteria for sustainable development cannot be met by this alone. In future it will therefore be crucial to work towards additional fundamental technological change and a shift in the direction taken by progress up to now, through the development and application of new, sustainable manufacturing techniques and products. Thus the polity is now faced with a question: with which environmental policy measures can this shift in private-sector innovation towards more environmental innovation be achieved?

Support for wind energy offers a good example of innovation-oriented environmental policy. Since 1989, with the help of various environmental policy measures, a wind-powered generation capacity of over 2,000 Megawatts has been installed in Germany and the wind-generated electricity component of net electricity consumption in the coastal states of northern Germany has reached over 4.4%. The environmental policy instruments applied here include not only environmental regulations and charges, or informational instruments, but above all funding and state support. Considerable capacity growth can also be seen in Denmark and Great Britain, due to environmental policy measures.

The following will therefore examine the influence of environmental policy instruments on technological progress and the implementation of technologies, using wind energy as an example. The paper is based on study which is related to a research project on the “Innovation impacts of environmental policy instruments” supported by the German Ministry for Research and Technology (BMBF). The method of the study is based on a detailled analysis of the latest literature on the wind energy development. In addition structured personal interviews with key players from producer and user of wind turbines, ministries as well as wind energy associations in Germany and an analysis of statistical data, inter alia from the German Wind Energy Institute, were made.

Up to now, the innovation effects of environmental policy instruments has been studied mainly with a more or less mechanistic approach based on a neo-classical model of the environmental economy (cf. Hemmelskamp 1997b). The traditional neo-classical debate on economic instruments for the environment has, however, some weaknesses as regards its relevance in practice. The ideal assumptions of the model do not exist in reality. Thus, for example, the influence of the behaviour of innovators on supply and demand, and its effect on the use of environmental policy instruments are broadly ignored. Nor is there frequently a distinction drawn between suppliers and developers of environmental technologies. This excludes significant innovation on the part of suppliers, which is not directly induced by environmental policy measures. The benefit for suppliers of technology is not a reduction in pollution costs, but an increase in turnover. Taking this into account, the specific influences of

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environmental innovation by suppliers of technology and by businesses complying with regulations must be analysed separately (cf. Hemmelskamp 1997a).

Therefore, the study in hand used a methodological approach of the framework-conditions of environmental innovation which is developed as a part of the German Research Consortium (FIU) supported by the Ministry of Research and Technology (BMBF) on the innovation impacts of environmental policy instruments (see Hemmelskamp 1997a).

Besides results of environmental economics the approach used also results of newer approaches of innovation research. Innovation research offers some additional approaches to explain this. The economic debate on factors influencing innovation was for a long time dominated by the question of whether available technical expertise or existing market opportunities exert the strongest influence on the innovation behaviour of companies. However, there is now a consensus among researchers, that both supply and demand-side factors influence technological innovation (cf. e.g. Becher et al. 1993:34). The increasing importance of environmental innovation is breathing new life into the debate. The special nature of environmental innovation means that the returns on innovation are often uncertain, lie in the distant future and/or are garnered by third parties, and the stimulus for innovation is therefore to a great extent dependent on the use of environmental policy instruments. Despite this, innovation models up to now have scarcely paid any attention to environmental policy instruments as such, registering them as further "technology push" or "demand pull" factors (for more details of this discussion see inter alia Kemp 1996 or 1998).

In the following, the use of environmental policy instruments is viewed as only one additional factor determining the behaviour of innovating companies within a collection of framework conditions affecting innovation (cf. here Hemmelskamp 1997a). For example, these are the expected market demand and the market structure, the technological opportunities, the appropriability conditions, different company characteristics, like the risk behaviour or innovation costs, and the legal and administrative framework under which environmental policy can also be subsumed.

This approach is problematic, as Rothwell (1992:454) correctly points out: "one consequence of the multifactored nature of success and failure in innovation, of course, is that separating the impact of government regulation from that of a myriad other factors is generally extremely difficult". However, such an approach is practicable in the wind energy sector as, because of the limited number of actors and the relatively homogeneous technology, the causal relationships and influential factors can be isolated. The study poses the following specific questions:

- Can the success of wind energy be traced back to the use of environmental policy instruments?
- Which instruments were effective, and under which specific framework conditions?
- What innovations in products, processes and organisation were stimulated?
- Were developments initiated, making it possible to limit the duration of the environmental policy measures?
- What conclusions can be drawn for an innovation-oriented environmental policy?

Chapter 2 starts with an historical overview of technological development in the construction of wind energy plant, and Chapter 3 describes the environmental policy instruments applied to wind energy in Germany. In Chapter 4, the influence of these instruments is examined, in combination with the other significant determinants of the development and application of wind energy equipment. In order to analyse the effect of environmental policy instruments on innovation in the context of different national factors, Chapter 5 compares the development of wind energy in Germany, Denmark and Great Britain. Conclusions from the empirical study are presented in Chapter 6.

2 Technological development in the wind industry

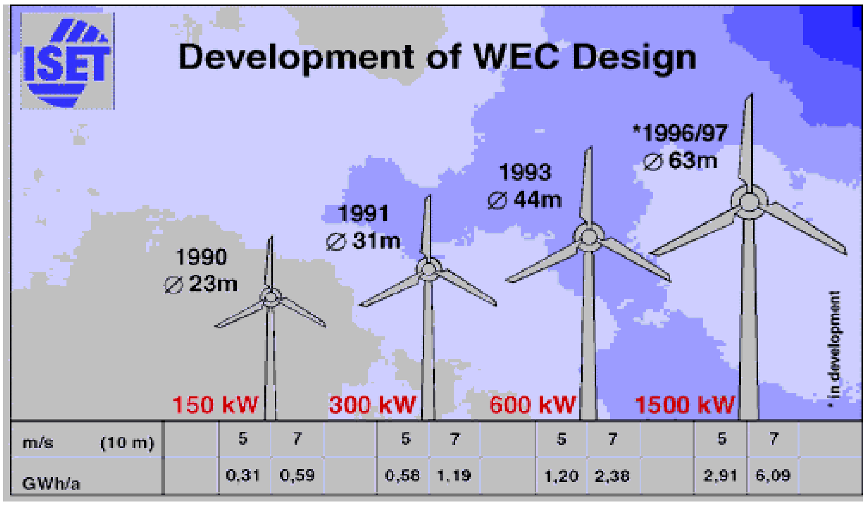
Up to the 1970s, R&D activity in the use of wind energy was directed at meeting the requirements of centralised electricity supply by large power stations with increasingly high performance and falling power generation costs. These attempts failed, however, as it proved impossible to build large wind power plants or to integrate small wind farms into the central supply structure (cf. Heymann 1995:437ff.).

Only after the energy crises of the 1970s was there a change in attitude and changes in energy law and investment help for the use of wind energy were introduced (cf. Heymann 1995:448ff.). An important milestone in the development of wind energy technology in Germany was the Growian project at the end of the 1970s. But even this project was also aimed at a technology leap, which would enable the large-scale exploitation of wind energy. Only after the failure of this project did attention in Germany turn to successful Danish plans for building smaller wind turbines, whose performance could then be increased through continuing improvements and innovation. In the beginning, a variety of variations was pursued, systems with one, two or three rotor blades. Most wind generators today have three blades. While in 1989, the available equipment generated less than 150 kW, today's models can generate over 1.5 MW. The diameter of the rotors has increased from an average 30m to a scale of up to 65m, masts have grown from 30m to 98m (cf. Figure 1).

Two designs are now emerging as dominant: in smaller models, a three-phase generator powered by a turbine with fixed rpm is coupled to a main circuit. The rotor blades are fixed to the hub and their pitch cannot be altered. Power generation is controlled by a cut-out, which is switched when a particular wind speed is reached. This technology has the advantage of lower manufacturing and maintenance costs. Larger wind farms appear to be settling for technologically more complex configurations where the pitch of the rotor blades can be adjusted and the rpm is variable. This system makes it possible to compensate for short-term changes in load or fluctuations in power, and thereby optimises the plant's suitability for connection to the grid (cf. Heier 1997:95ff.). Another trend can be seen in large wind farms towards a gearless cord system with multi-polar generators.

In future, less fundamental technological change can be expected, and rather more improvements of detail, aimed at increasing the product lifespan, improving efficiency and the quality of the electricity generated, and at reducing operating noise. Opinion is divided as to further developments of scale. On the one hand it is argued that best ratio of costs to performance has already been exceeded in 1.5 MW equipment, while others argue that, particularly with respect to exploiting offshore locations, further growth up to and over 2 MW should be expected. Manufacturing processes should become more automated and manufacturers will produce in larger batches.

Figure 1: Development of WEC Design



m/s (10 m)	5	7	5	7	5	7	5	7
GWh/a	0,31	0,59	0,58	1,19	1,20	2,38	2,91	6,09

Source: ISET (1997b)

3 Environmental policy measures: regulatory framework for energy use

Wind energy has been encouraged in Germany since the 1970s with various environmental policy instruments supporting research, development and demonstration, as well as the launching and spread of wind energy turbines.

3.1 Support for research, development and demonstration

The BMBF has been supporting the use of wind energy since 1974 by supporting research aimed at raising the economic feasibility of this form of energy use (BMBF 1995:11f.). After hearing the views of experts, the ministry commissioned the development and setting up of the GROWIAN project. The project was characterised by an ambitious technical plan from the BMBF and the critical response from the participating energy supply companies (cf. Heymann 1995:374,382). The energy suppliers only agreed to participate on the basis of contracts which freed them from any risk, as they were convinced that the project would fail from the very beginning (cf. Heymann 1995:370-373). It was therefore not surprising that the project was closed down in 1987 after technical problems, and the plant torn down one year later.

Development of a second generation of large wind turbines has been taking place with the support of the BMBF since the mid-1980s. In 1989, a Monopterus turbine with a capacity of 640 kW, and in 1990 and 1991, two WKA-60 turbines with 1.2 MW each were built. In 1993, an Aelus II with performance data of 3 MW was erected by an energy supply company. The projects conducted by large companies never progressed beyond the prototype stage, while some of the prototypes set up by smaller turbine manufacturers were later launched onto the market in modified form. Various demonstration projects in the 1980s also supported the development and use of a total of 214 small wind turbines (cf. Hoppe-Kilper et al. 1995: 42ff.).

The European Community and, subsequently, the European Union has been supporting R&D and demonstration projects since 1979, with the aim of improving the economic viability and reliability of equipment and gaining public acceptance for the use of wind power. By 1992, a total of over 180 projects had been supported with funding of ca. $75 million.

3.2 Measures for market introduction

The aim of the 100/250 MW programme, which ran from June 1990 to December 1995, was to test the use of wind energy on a major economic scale, gain experience over the long term and to provide a stimulus for the installation of a large number of wind turbines by different companies at suitable locations (cf. Li et al. 1995:1617ff.). Key factors in approval of wind power projects were the technological maturity of the equipment type, the need for demonstration projects at the relevant location, the management structure and the potential for innovation. Approved projects were granted a subsidy of ca. 4.5 cents/kwh at first and, after the introduction of the Feed-in-law (Stromeinspeisungsgesetz), a contribution towards operating costs of ca, 3.5 cents/kWh. Investment subsidies were only available under certain conditions. Participation in a wind energy measurement programme (WEMP) is compulsory for those receiving funding from the 100/250 MW programme. Over a period of 10 years, the performance data of the wind turbines, information on maintenance and repair work, the economic efficiency of the equipment and meteorological conditions must be handed over to the Institute for Solar Energy Supply Technology (ISET), to provide information on the quality and efficiency of the various technological options. These data are published annually by ISET and can also be evaluated to answer specific questions (cf. e.g. ISET 1997a)

The federal states of Germany have supported market launches with non-repayable investment subsidies and interest relief. After the introduction of the 250 MW programme there was a short transition period, during which it was possible to receive cumulative funding. In recent years, subsidies from the states have been successively reduced.

3.3 Support for the diffusion of wind energy plant

3.3.1 The Electricity Suppliers Act

The Feed-in-law (Stromeinspeisungsgesetz) regulates purchase of and payment for electricity from renewable sources by the public energy supply companies. The companies are obliged by the Act to pay for the wind energy from their catchment area at least 90% of the average sum gained from electricity supplies to end consumers in the previous year. In 1997, the price was at ca. 10 cents/kWh. The Feed-in-law opened up the electricity market for private providers of renewable electricity, something which had earlier been obstructed by the infrastructure and supply monopoly in the energy market.

The Act has been heavily criticised by electricity suppliers, the German Chamber of Trade and Industry and the German Industrial Association as inappropriate from a micro- and macroeconomic perspective (cf. BMU 1997:11). The main point of contention is the high cost of generating wind energy in comparison to the costs of conventional power generation from fossil or nuclear fuels. However, attempts by energy suppliers to cast doubt on the constitutional validity of the Electricitiy Suppliers Act have, up to now, failed (cf. BMWi 1995:5; Bergmann 1996:24ff.), although a final judgement on the constitutionality of electricity supply payments has not yet been given.

In 1997, the German Parliament (Bundestag) passed law to reform the Electricity Suppliers Act. The rate of payments for renewable energy remains untouched, but the existing hardship clause has been amended through the addition of a 5 percent ceiling. Now, if the wind energy component from any supplier rises to above 5 percent of its total turnover in kilowatt hours, the manager of the grid upstream is obliged to reimburse additionally incurred costs (Deutscher Bundestag 1997:37). This 5% ceiling has already been exceeded by the North German energy supplier Schleswag, and Preussen-Elektra, the grid manager upstream must reimburse the additional costs. However, if Preussen-Elektra's renewable energy component also exceeds 5 percent, not only is there no further requirement to reimburse the costs for new wind turbines under the Act, but the obligation to purchase the electricity also becomes null and void (cf. Johnsen 1997:8).

The debate over the Feed-in-law is superimposed with the liberalisation of the electricity and gas markets and the associated amendments to the Energy Act (Energiewirtschaftsgesetz). The existing obligation to purchase electricity from renewable sources could not be maintained if the closed catchment areas were to disappear, as provided in a government proposal towards implementing the EU guideline (cf. Bergmann 1997). It is therefore unclear how the Feed-in-law can harmonise with the Energy Act.

3.3.2 Support for the use of renewable energy from the BMWi

In 1994, the BMWi (Federal Ministry of Economics - sic.) supported four areas in renewable energy, in 1995 this number rose to seven. Ca. $850,000 was made available for wind energy in 1994, and a total of some $3.4 million was set aside for the four subsequent years. (cf. Johnsen 1996:17). Demand for funding has considerably exceeded the available funds, as the dynamism in technological development has meant that a great number of wind energy projects now meet the criteria of the funding programme (Reinhard 25.8.1997; BMWi 1997a).

3.3.3 Credit financing

As part of the ERP environmental and energy conservation programmes, as well as its own environmental programme, the state-owned German Compensation Bank (Deutsche Ausgleichsbank, DtA) is charged by the Federal Ministry of Economics with guaranteeing long-term low-interest loans at fixed rates, some 1-2% below the market rate, and with the possibility of a two-year grace period. According to the DtA, between 80% and 90% of wind energy projects in Germany are financed with these low-interest loans for environmental projects. By combining the ERP programme and the DtA's environmental programme, it is possible to finance up to 75% of the total investment in this way. Since 1990, over 80% of the ERP and DtA environmental programmes' funding, ca. $1,650 million, has flowed into wind energy projects. The term of the credits is generally between 12 and 15 years (cf. Koch 1995; Stein 1995:45ff.). DtA and ERP loans are purely refinancing programmes, where credit arrangements are made by the borrower's own bank. This bank carries the credit risk and therefore determines the necessary securities on a case-by-case basis.

3.3.4 Depreciation under tax law

Since the Feed-in-law came into force, tax authorities recognise that wind energy projects aim to make a profit. This assumes that wind power plants are operated in such a way as to gain economic advantages and so that expenditure is, over the entire period of the project, exceeded by income (cf. Tipke/Lang 1996:368; Seeger 1993:42ff.). The framework taxation conditions for investment in wind energy projects have thereby changed in two essential respects.

Depreciation of wind energy plant can, under §7.1 of the Act, be written off against tax as capital or operating stock, either linearly or in decreasing instalments. Original costs are distributed over the usual service life of 10 or, since June 1997, 12 years (cf. Behnke 1997:18).

Moreover, losses accrued during the start-up period can be set against future profits from wind energy projects, in order to guarantee that performance is taxed over the entire period of operation, and not according to certain parts thereof. Thus general partnerships have the opportunity to include start-up losses directly in tax returns. For example, high allocations of loss during the early years offer advantages to independent entrepreneurs with high marginal tax rates if their pension plan is not based on annuity equity but on capital life insurance, which is paid periodically and whose returns are not subject to tax. Such people, when in retirement, will have a marginal tax rate of only 20-30%. Diversification of marginal tax rates means that allocation of losses is based on the high marginal rate, while the returns expected later are based on only a low marginal tax rate.

3.3.5 3.3.5 Support for export

Under the BMBF's Eldorado programme, demonstration projects by German manufacturers of wind energy equipment in selected countries in different climate zones were supported between 1991 and 1995. The level of funding was determine according to the rotor diameter and the height of the hub, and could amount to up to 70% of the equipment costs (cf. Bräuer 1996:99). The idea behind the programme was to translate the 250 MW programme onto projects abroad. However, due to budget shortages, the desired funding could not be made available for the project. With the support of the state of Schleswig-Holstein, the German Renewable Energy Enterprises (GREE) team was set up to reduce the costs of canvassing for international projects with presentations at trade fairs, and thereby to open up new market perspectives especially for small to medium-size businesses. Alongside these direct measures, training for foreign staff at wind energy courses, such as the DEWI,is an attempt to improve the framework conditions for export abroad (cf. Molly 1997:81f.; Rave 1995:111).

3.3.6 Improvements in legal and administrative framework conditions

Setting up a wind farm requires planning permission. Planning law regulates permitted use of the plant's location (cf. §§ 29 to 35 of the Building Statutes, Baugesetzbuch). If preferred sites for wind energy land use are already provided for in the local development plan, the construction of a wind farm is relatively unproblematic. If, on the other hand, there is no such determination, only small plants, serving single estates or development areas are possible. Wind farms can also be permitted without being mentioned in a development plan if the electricity generated is partially or wholly fed into the public power grid. The regulations in the Development Land USe Ordinance (Baunutzungsverordnung) nevertheless restrict the construction of wind parks in urban areas to large industrial areas. In developed urban areas for which there is no plan, wind farms may be permissible as auxiliary plant, if the new development harmonises with existing buildings and the local landscape is not harmed. But here also, the permissibility of wind parks is also limited primarily to industrial or commercial areas. (cf. Frerichs/Viebrock 1995:6f). Most wind farms are erected in rural areas where, under §35 of the Building Statute Book, this should actually be forbidden. Until 1996, an exception was made only for plants which provided energy for existing agricultural or forestry businesses. However, wind farms were mostly granted planning permission, as it was assumed that their construction was in the public interest. Since 20th June 1996, wind and hydroelectric power facilities are considered privileged building projects, permission for which lies finally with the relevant local authorities. A community can therefore exclude protected landscapes or areas which are important for tourism or residents, for example.

Building law regulates requirements for the construction, design, alteration, use, maintenance and decommissioning of constructed facilities. Permissibility under building law has not, however, proved to be a serious obstacle to the erection of wind farms in recent years. (cf. Niedersberg 1996:69). It should nonetheless be remembered that the use of wind energy is certainly associated with potential risks and environmental impact in the immediate vicinity, and these are taken into account in the permissions procedure. For example, mechanical noise emissions are produced by the generator and the gearing, or from fast-moving rotor blades. Permissions decisions are offered some points of reference in the TA-Lärm, the Technical Guidelines on Noise Abatement, under which various maximum noise levels are laid down for various land use structures, such as residential or industrial areas (cf. Niedersberg 1996:71ff.).

Furthermore, nature conservation standards must be observed for the construction of wind power facilities, as this is viewed in principle as intervention in the natural environment (cf. Niedersberg 1996:74). Permission depends on whether the intervention is avoidable. Factors which are examined include the effects on migration and hatching of birds, the influence on areas of ornithological interest or the landscape Building a wind farm generally assumes an unavoidable negatiove impact on the natural environment (cf. Niedersberg 1996:76). However, this intervention must be compensated for by measures to protect the landscape or payment of a charge. Examination under the regulations on intervention provided for in conservation law took place during the planning permissions procedure until 1993, which meant that the designation of replacement areas necessary for the required compensation was often no longer possible. Since April 1993, designating replacement areas is simpler, since the regulations on intervention provided for in conservation law are applied when the local development plan is produced (cf. Niedersberg 1996:78f.).

4 Determinants of innovation in wind energy

4.1 Determinants of the development of wind farms

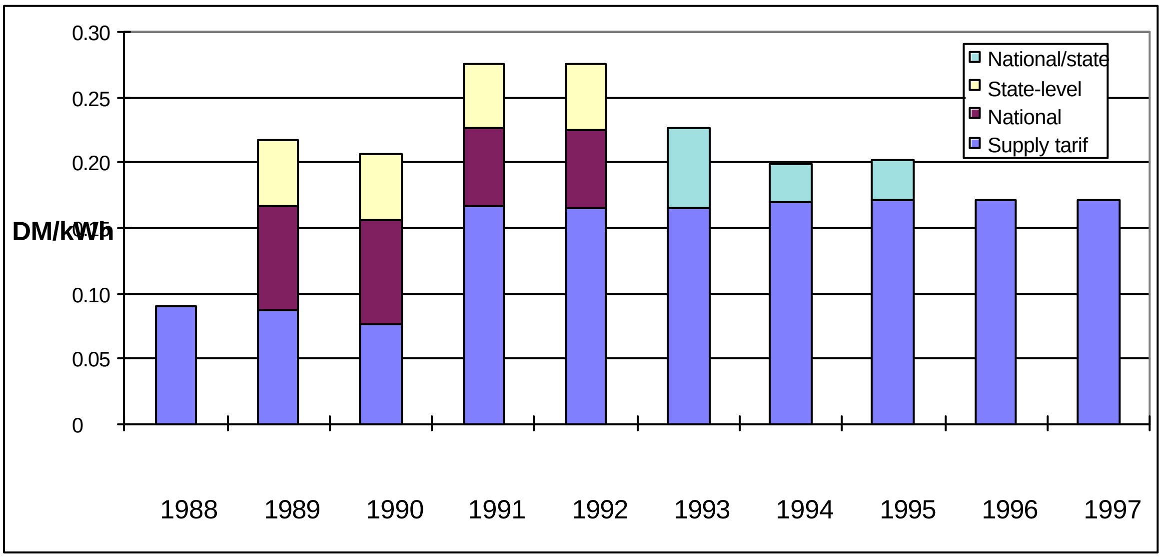
The following discusses the effects of environmental and technology policy on the development of wind energy equipment, in the context of influences from demand and market structure, the chances for securing returns on innovation and the technological preconditions.

4.1.1 Demand in domestic and foreign markets

4.1.1.1 Domestic demand

A significant rise in domestic demand was triggered at the end of the 1980s with the BMBF's 100/250 MW programme, as well as the Electricity Suppliers Act, tax breaks and the provision of low-interest loans. The highest level of subsidies, about 15 cents/kWh, was reached between 1991 and 1992 with the various national and state-level programmes and the Feed-in-law (cf. Figure 2). Since 1993, the average subsidy on wind energy has been gradually reduced, so that only payment under the Feed-in-law and the low-interest loans from the DtA are now generally important for the economic viability of wind farms (cf. Rehfeldt/Schwenk 1997:68f.; BMWi 1995).

Figure 2: Subsidies for wind energy



Note: The investment cost subsidies have been translated into operating cost subsidies. Tax advantages have not been included.
Source: Rehfeldt/Schwenk (1997:55); Li et al. (1997)

Returns-dependent subsidies in particular stimulated demand oriented around cost-efficiency and indirectly triggered the corresponding innovation from manufacturers. Every improvement in the performance and value for money of the equipment increased the subsidised component.In this way, a powerful incentive for further development of wind energy equipment was created. It is therefore not surprising that performance improvements after the introduction of the programme were found predominantly in coastal areas with strong wind conditions. However, because of the increased efficiency which has been achieved, locations with less strong wind conditions are also becoming increasing interesting to investors. If the framework conditions remain unchanged, experts believe that demand will probably develop well for the next five years. Nonetheless, further development is held to depend essentially on the outcome of the debate on the future of the Feed-in-law. This positive assessment is given more weight by plans in the federal states and the available potential for wind energy use. Current studies show that there is still considerable potential for growth. Kaltschmidt and Wiese (1993:83ff.) estimate that the potential land cover could amount to 7% of land in Germany. Nor should the potential for offshore wind farms in coastal waters be forgotten. At depths of up to 40 m, an area of some 17,000 km2 with a generating potential of 237 TWh/a would in theory be available for wind energy use. (cf. Matthies/Nath 1995:181ff.). However, the exploitation of offshore potential has to date been hindered by marginal political issues. Only in the amended Feed-in-law of 28th November 1997 is the company nearest to an offshore wind farm required to purchase the electricity generated (cf. Anonymous 1997:10).

4.1.1.2 Foreign demand

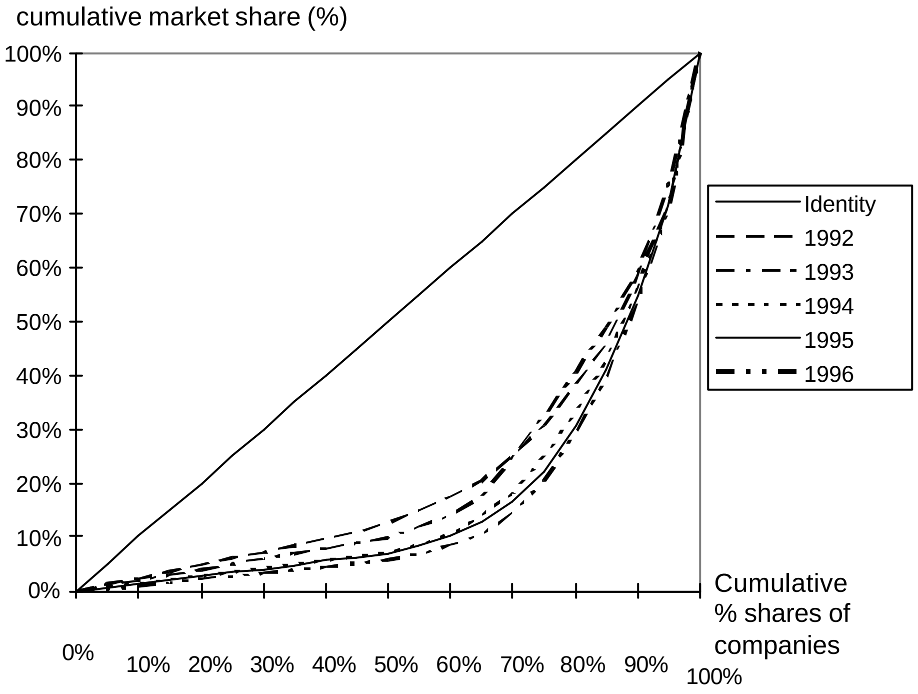
In some industrialised countries, and in many borderline and developing countries, there are significantly more favourable framework conditions for renewable energy. DEWI is assuming further expansion of wind energy use world-wide up to around 17,500 MW by 2001, and the German government's Office for Technology Assessment (TAB) estimates the global market volume for the wind energy sector at ca. $3.5 billion per annum (cf. Rehfeldt 1997b:25; Fleischer 1996:39). The major growth markets are principally in North America, Western Europe and Southeast Asia, including China (cf. Fleischer 1996:71; Rehfeldt 1997c:24f.). China, for example, plans to expand its generating capacity by 13,000 MW per year until the year 2010 (cf. Rösch/Bräuer 1997:55ff), and providers of wind energy technology do not therefore need to compete with already existing (and amortised) conventional power stations. The installation of wind farms can rather contribute to filling supply gaps, and exports are thus seldom hindered by sunk costs. Despite these positive market predictions, German manufacturers of wind energy technology have had virtually no presence on the export market in past years (cf. Lauritzen et al. 1996:70; Rehfeldt 1997b:27). The export share of German manufacturers is, compared to that of their Danish counterparts, small. The decisive factors here are difficult hurdles to entering foreign markets. These barriers are due partly to high transaction costs in canvassing for new business and providing customer service and partly to the first mover advantages of Danish manufacturers, who already have large market shares abroad and good sales and service infrastructures. Nonetheless, a growing commitment to the export market has been evident on the part of German firms since 1996. It is expected that export rates will, in the long term, increase to Danish levels of some 50-80%. The German market is increasingly becoming something of a reference market, where the practicability of new equipment designs is tested. Exports of complete wind farms will also remain the exception, with companies rather entering into joint ventures with foreign partners.

4.1.2 Market structure of the wind energy industry in Germany

The most significant innovation to date in the wind energy sector has been on the part of a large number of small to medium-sized companies. These companies were supported by the BMBF, e.g. through its Special Demonstrations Project (Sonderdemonstrationsvorhaben), which enabled manufacturers to develop and set up the first wind energy plants. Spreading funding among many manufacturers also promoted competition between equipment manufacturers and encouraged the development of a variety of designs.

The structure of the market has changed, however, since the start of the 1990s. In 1997, some 40% of equipment installed was manufactured by Enercon. Two Danish companies, Micon and Vestas, also have high market shares. The market presence of danish firms, and thereby the transfer of expertise through spill-over effects was encouraged to some extent by a funding strategy which also made it possible to support foreign companies. Although new suppliers are continually entering the market, this has not influenced the market shares of the five leading suppliers in recent years. This trend towards concentration is also reflected in the Gini coefficient. The level of concentration, with respect to cumulative plant number and installed capacity, as well as to new installations and newly installed capacity, has risen since 1992. Figure 3 shows clearly that the Lorenz curve for cumulative installed capacity increasingly sags from year to year, indicating an increasing market concentration. Further market concentration can be expected in future.

Figure 3: Lorenz curves for cumulative installed capacity [1992-1996]



Source: DEWI (various years)

Increasing market concentration is partly a consequence of returns-oriented supplier subsidies and depreciation for tax, which have meant an increasing shift in the focus of competition from quality to price. This forces manufacturers to exploit existing potential for cost reduction, in order to improve the ratio of price to annual energy production. However, the potential in product innovation for improving efficiency and increasing performance is limited. It is correspondingly difficult for manufacturers to differentiate themselves from the competition through their products. Thus it can be seen that innovation is shifting from products to processes.

There is still considerable potential for cost savings in the production process, through rationalising production and increasing batch sizes. Companies can be seen to be following two different strategies. Some companies are using more series production, such as standard gearing systems, in order to benefit from economies of scale and process innovations on the part of suppliers. The disadvantage in this strategy is the heavy dependence on suppliers. The production depth of other manufacturers is relatively high, including internal research and development. In contrast, companies with little production depth generally conduct no R&D of their own, and are therefore dependent on innovation by their suppliers. For most suppliers, however, wind energy is generally a niche segment, and the technical requirements from products are determined to a great extent by companies from other branches. The strategy of production depth therefore seems to offer advantages with respect to innovation intensity, because of the opportunities for feedback between the separate phases of innovation.

4.1.3 Protection of returns from innovation

Even if patenting is the option for certain product innovations, stealing a march on the competition in marketing new wind energy equipment has proved to be the decisive instrument for protecting returns within the wind industry. For example, the major producers such as Tacke, Enercon or Vestas all vied to be the first to develop and bring large 1 MW equipment onto the market. Most producers now have such equipment in their product palette.

4.1.4 The technological state of manufacturers

As far as wind energy goes, there was no well-founded store of experience in the 1970s and 80s on which the ambitious BMBF projects could call. Subsidies policy concentrated itself sensibly enough on generating a store of technical solutions. Thus the support of the WMEP in the 100/250 MW programme was also a significant measure, which made it possible to analyse data on performance and wind speeds, as well as the reliability and economic viability of the equipment (cf. ISET 1995:3).

The large companies participating in subsidised projects made use of calculation and design processes and computer simulations, exploiting their existing knowledge from aerospace research and vehicle manufacture (cf. Heymann 1995: 452ff.). This is reflected in the direction taken by development activities. The extent to which these first large-scale projects led to an accumulation of useful technological experience is a matter for debate. The participants argue that important discoveries about parallel connections, handling vibrations and controlling the equipment were made (cf. Heymann 1995:381). On the other hand, critical voices have been raised, pointing to mistakes made during development of the major projects and the slight influence they had on the technological development of wind energy use.

R&D subsidies of gradual performance improvements through trial and error by smaller manufacturers was more successful, but even here, the influence of different technological backgrounds on the direction of innovation is clear. Tacke Windtechnik, for example, grew out of a machinery manufacturer and both Husum shipyards and Jacobs-Energie are using their wind energy equipment construction activities to diversify their production, which used to be concentrated around shipbuilding. The equipment produced by these companies is characterised by traditional engineering design with little innovation. In contrast, Enercon's equipment reflects the background of the company’s founder in electrical engineering, which made possible a leap to more technologically ambitious designs, where electronic control of the equipment has a key function..

To an increasing extent, however, a trend can be seen in the wind industry whereby individual manufacturers are no longer able to keep pace with technological development, because of their limited staffing and financial capacities. This is expressed in limited concentration on innovation and increased use of outside expertise. This raises the importance of specialist producers of technology, but at the same time reduces the variety of innovative work and increases the influence of individual technology producers on the direction of further technological development. Only a few manufacturers still conduct their own research and development.

4.2 Determinants of the use of wind farms

The factors influencing the use of wind energy equipment are examined in four categories. The influence of the structure of the energy supply network is discussed first, followed by the effects of economic viability, the risk associated with investment in wind energy and finally the environmental aspects.

4.2.1 Structure of the German electricity supply network

Electricity supply in Germany is predominantly public. Closed catchment areas have arisen through licensing agreements between electricity suppliers and local authorities and through demarcation agreed among suppliers (cf. Mez 1997:233). Due to this structure, feeding wind energy from independent wind power generators into the network was, until the start of the 1990s, only possible on the basis of a cooperation agreement between suppliers_ (cf. BMWi 1995:15). The framework conditions for an obligatory take-up of electricity from renewable sources and a fixed rate of payment was created only with the introduction of the Electricity Suppliers Act.

Interest in wind energy use on the part of energy suppliers has been low up to now. Since 1990, the share of installed wind capacity among energy suppliers has fallen steadily and is now at around 8% (cf. ISET 1991:15, 1997a:28). Instead, the proportion of private limited companies or cooperatives has risen to 44%. Experts on the wind energy sector assume, however, that in future, alongside the increasing significance of private limited companies, energy suppliers will also build their commitment to wind energy and, in the log term, achieve a 30% share of installed capacity. Suppliers justify their lack of interest with the excessive costs of wind-generated electricity, for example, and point to the fluctuating nature of wind as an energy source, which means, according to them, that expansion of wind energy can only increase capacity to a limited extent, and is therefore no substitute for existing fossil or nuclear power stations (cf. Palic 1996:53f.). The electricity sector therefore generates power predominantly with conventional coal, oil or nuclear energy technologies (cf. BMWi 1996a). There is a wealth of experience in using these technologies and much to be gained from specialisation, as the learning curve flattens out and cooperation with power station developers becomes routine. Increased use of renewable energy would bring with it a loss of these specialisation benefits for energy suppliers.

The sound infrastructure of the energy grid was a significant factor in the rapid development of wind energy use in Germany (cf. Bräuer 1996:52). Nonetheless, the limits of this supply network's tolerance are now starting to become apparent. Promising locations in windy Northern Germany possess an energy supply network which, due to the thin settlement structure, can only sustain a limited load. Since suppliers are required to provide an uninterrupted supply to the public, extending the mains grid would appear sensible. Intelligent management of wind farms could, however, reduce this capacity problem. This was underlined in the subsidy guidelines of the coastal states by taking into account corresponding grid suitability criteria, which has already provided a considerable stimulus to innovation. As capacity problems increase, wind farms with indirect mains connections via and adjustably pitched rotor blades would have significant advantages.

The planned liberalisation and deregulation of the electricity market will also change the energy supply market and thereby the further development of wind energy use. The European Commission has given exploiting renewable energy priority within the liberalised internal market The regulations in the new German Energy Act provide for the abolition of closed energy supply areas. The special importance of renewable energy was emphasised in a cabinet decision on 19th March 1997, it is nonetheless still unclear who is to be obliged to purchase electricity from renewable sources (cf. Bergmann 1997; BMWi 1997b).

4.2.2 The price of wind energy

In contrast to investment cost subsidies, the introduction of returns-dependent subsidies for companies awakened interest in functional, economic wind farms. he production costs per kWh wind energy are therefore now a central investment criterion. The crucial factors are the investment costs, the operating costs and economic life of a wind farm, as well as the availability of wind (cf. Schwenk 1994; Erdmann 1992:92).

4.2.2.1 Investment costs for a wind farm

Investment costs are made up of the costs of purchasing the plant and any additional costs. Purchasing costs account for about 2/3 of the total investment costs for a wind farm. Average prices for wind energy equipment have fallen continually in recent years, due to technical progress, such as the use of lighter materials, and economies of scale as batch sizes have increased. Thus the average turnover of a manufacturer per kW installed capacity has halved between 1988 and 1995, to ca, $1,200 (cf. Keuper 1995:28).

In the new generation of 1 to 1.5 MW equipment, this trend does not seem to be continuing (cf. Rehfeldt/Schwenk 1997:64). However, as installation increases, this class of equipment is also expected to benefit from learning effects, economies of scale and product rationalisation (cf. Allnoch 1996:656; Rehfeldt/Schwenk 1997:63ff.). On the other hand, these effects might be compensated for by e.g. increased transport costs for larger plants. Most 600 kW turbines were small enough to be transported in standard containers. 1 or 1.5 MW turbines, on the other hand, are large enough to cause problems with low bridges, for example. Nordtank calculated transport costs for 120 special transportation’s into a wind project for twelve 1.5 MW turbines (cf. Pape 1997:33). Enercon's development of its 1.5 MW equipment therefore also takes account of transport restrictions and proposes a maximum diameter for the generator.

Additional costs consist of land purchase, foundations, the connection to the network, planning, the permissions procedure and infrastructure. Costs for laying foundations vary according to the weight of the equipment and the strength of the wind, as well as the nature of the soil at the location. Infrastructure costs include expenditure on constructing roads and buildings, planning, the permissions procedure, engineering planning and a wind survey. Above all, the costs of connection to the medium tension grid have, because of increasing loads on the network, risen significantly recently and balance out to some extent the lower equipment costs and efficiency benefits from improved exploitation of the location with more powerful turbines.

4.2.2.2 Operating costs

The operating costs of wind farms cover maintenance, repair, insurance and long-distance supervision of the plant, as well as land rent, where applicable. Investors' economic feasibility studies generally assume operating costs of around 2.5% of the capital costs for the first two years, and 3% subsequently up to the tenth year (Durstewitz et al. 1995:C2-3). Some cases nevertheless calculate operating costs at a lower rate.

4.2.2.3 Capital costs

Investment costs for setting up a wind farm can be covered either by equity or borrowed capital, whereby investment cost subsidies from national or state programmes are counted as equity capital. Borrowed capital incurs interest and repayment costs. In recent years, the development of wind energy has been favoured by constantly falling interest rates. As market rates rise, the fixed, lower, interest rates available in loans from the ERP programme or the DtA's environmental programmer becoming increasingly valuable.

4.2.2.4 Wind conditions

The use of wind energy clearly makes sense above all in areas with a high average wind speed which remains as constant as possible. Wind farms at coastal locations can easily produce double the electricity available at less windy inland locations. Since returns-dependent subsidies were introduced, selecting a windy location and purchasing high-performance equipment to exploit local conditions as well as possible, as well as performance data suited to the area, have become decisive for investors (cf. Li et al. 1995:1618). These criteria are reflected in innovation by manufacturers.

4.2.2.5 The economic viability of wind farms (using 600 kW plant as an example)

The cost components listed above can be used as the basis for calculating the production costs of wind energy plant (cf. here Hoppe-Kilpper/Rehfeldt 1997:6ff.; Rehfeldt/Schwenk 1997:63ff.). The following takes a 600 kW model as example and calculates four scenarios, in order to show the influence of changes in these cost factors on the viability of wind energy projects (cf. Table 1).

Table 1: Production costs of a 600 kW wind energy plant

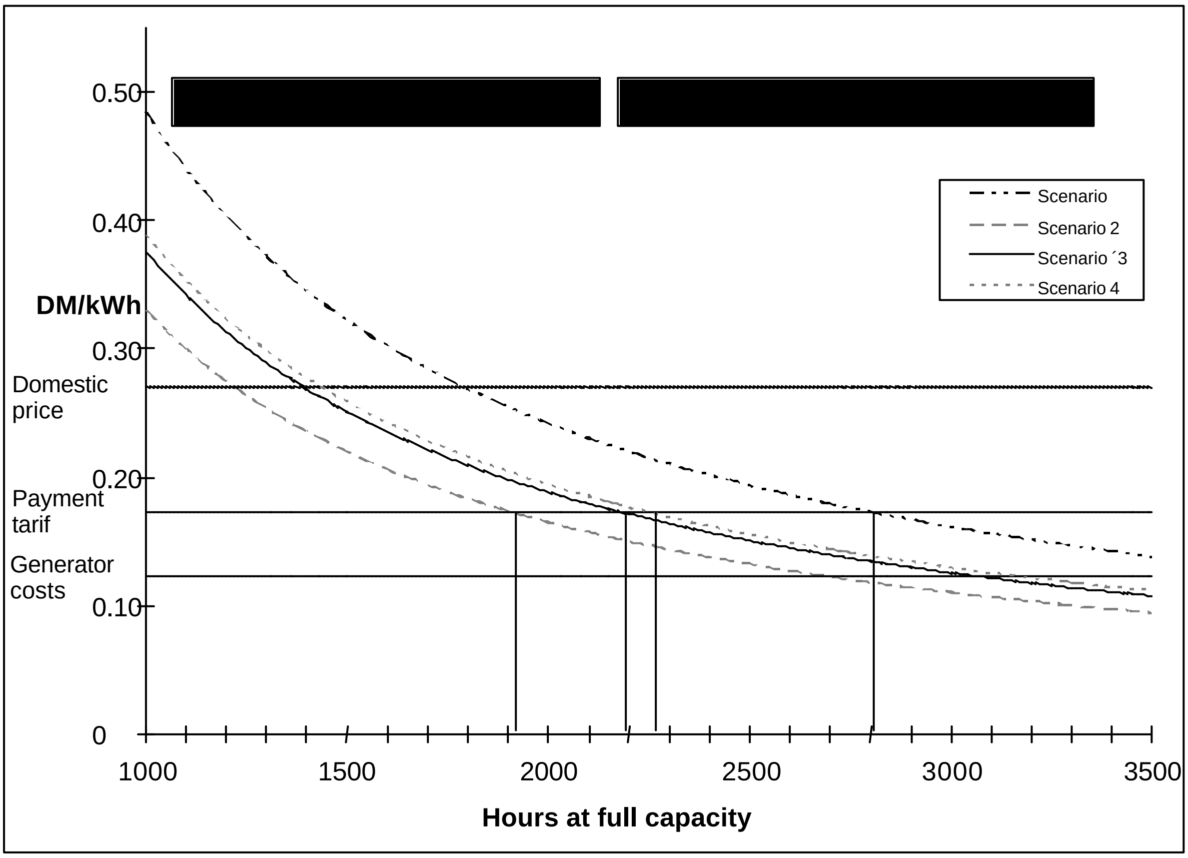
Scenario	***1***	***2***	***3***	***4***
Investment costs	2.200 DM/kW	1.500 DM/kW	1.500 DM/kW	1.500 DM/kW
Interest rate	6,5%	6,5%	10%	6,5%
Credit term period	10 Jahre	10 Jahre	10 Jahre	10 Jahre
Operwting costs	3%	3%	3%	6%
Additional investment costs	30%	30%	30%	30%

To analyse the effects of cost reductions, the calculations use figures of ca. $1,2500/kW and $850/kW with average equipment prices for 1993 and 1997 respectively. Both the current usual interest rate of 6.5% and a significantly higher rate of 10% are used, in order to examine the effects of interest rate rises. Operating costs are set at 3% and 6%, to illustrate the effects of rising repair costs, for example.

Alongside cost curves, Figure 4 takes account of payments at ca. 9.85 cents/kWh, an average electricity price for households of 15.57 cents/kWh and generating costs for electricity suppliers with new power stations of ca. 7 cents/kWh. Comparing the results of scenarios 1 and 2 chows the strong influence exerted by investment costs on the economic viability of wind energy use. Here, a 600 kW plant costing $1,250/kW in 1993 could, assuming an average income of ca. 12.5 cents/kWh from national and state-level subsidies, be operated profitably with a minimum of about 2,100 hours at maximum load. However, if the same investment costs are considered with current incomes, economic viability would be possible only with 2,800 or more hours at maximum load. Innovation in products and processes, as well as series manufacture, have made it possible to reduce investment costs to $850/kW, so that the break-even point now lies at around 1,900 hours. Thus technical progress has compensated for the reduction in subsidies between 1993 and 1997.

It is currently possible to operate a wind farm at a coastal location if the electricity is paid for as provided in the Electricity Suppliers Act. The effects of falling equipment prices can nonetheless be balanced out by higher operating costs, for example (Scenario 3), or rising interest rates (Scenario 4). These same effects could also accompany a liberalisation of the electricity market, as lower energy costs also mean lower payments for wind energy.

Figure 4: Production costs relative to capacity class and wind conditions



Should the wind energy produced be used by the generators themselves, savings on electricity costs can be calculated with the average costs for end users, ca. 15 cents/kWh. Profitability in the best-case scenario (2) is assured with around 1,200 hours at maximum load, in the worst case (Scenario 1) with 1,800. Under the current framework conditions (Scenario 2), energy suppliers could achieve the average electricity supply price of ca. 7 cents/kWh (cf. Hillebrandt 1997:22) expected from a newly built fossil power station only with 2,700 or more hours at full capacity. Analysis of the 250 MW programme at the WMEP have shown however, that such an average rate could scarcely be reached in Germany (cf. ISET 1997a:39).

Under the conditions described above, the use of wind energy, with its limited profitability, would thus scarcely be attractive to profit-oriented investors. The interest of such investors, and thereby a considerable influx of finance, was triggered only through the recognition for tax purposes that wind energy projects aim to make a profit. For example, investors whose personal tax rate is 53%, can expect returns from some projects of over 11.5% (cf. Behnke 1997:18).

4.2.3 Risks in wind power generation

Wind farm managers are exposed to technical and economic risks, including the fluctuating nature of wind energy. A variation of 4-5% in wind speed can result in a 15% loss in energy output. To reduce such risks, a wind survey of the prospective location is therefore important.

For a manager new to the market it is hard to assess the technical and economic efficiency of different equipment and designs. An important source of information is the material published by wind energy associations about the wind energy equipment available on the market. The introduction of a certification scheme, conducted by independent institutes, was also important, as it confirmed that fundamental technical requirements were being met. However, in prescribing the certification critieria, these institutes also have a string influence on technological development.

The economic risk has been significantly reduced by the determination of a minimum price and the obligation to purchase under the Electricity Suppliers Act, although the debate over the Act has removed much of this planning security. However, the growing investment costs in wind energy projects have brought economic risk. In order to limit the financial exposure of individual investors, the setting up of generator associations has proved sensible in recent years. There are high risks involved in project planning if the operating costs are calculated too low or assumed to remain fixed for the entire course of the project. Unforeseen damage to equipment when it is no longer under guarantee can rapidly endanger the profitability of a wind power project (cf. Lührs 1997:101ff.). Thus the pay-back period for a 600 kW turbine at a typical coastal location with uninsured damage of ca. $115,000 to a rotor blade increases from 10 to 14 years, at the average inland location to as much as 18 years.

The technical and economic risks are reduced by taking out personal liability, lightning, induction, fire or failure insurance. The high insurance premiums offer an incentive to develop and install technologically reliable equipment. It is nevertheless still unclear to what extent and in what way the insurance companies involved recognise damage as an unforeseen event and assume the costs for it. It can be assumed that they will assume the costs of the damage only for individual breakdowns and, should the damage repeat itself, the owner will be expected to assume the costs.

4.2.4 Environmental influence on wind energy use

Public acceptance of wind energy is shaped by its effect on the environment and thus by the conflict between benefit for the climate, the landscape and the natural environment.

With respect to global climate problems and the conservation of non-renewable resources, the use of wind energy is generally held to be an environmentally friendly energy technology, as the environmental impact of producing, operating and disposing of wind farms is relatively low, in comparison to that of other energy sources. In contrast to electricity generation from fossil fuels, emissions of atmospheric pollutants, sewage and production waste essentially occur only during the manufacturing process for wind energy plant. The energy pay-back period for a 100 kW wind energy plant at locations with ca. 6.6 m/s wind speeds is between 2 and 8 months, with wind speeds of 4.5 m/s between 6 and 20 months (cf. Kaltschmidt/Wiese 1996:170; Bräuer 1996:28f.).

Despite the positive effects on the climate and natural resources, rapid expansion of wind energy is leading to increasing conflicts with the affected local populations (cf. e.g. Brandt 1995; Fischedick/Hennincke 1996:320ff.). Erecting wind turbines affects the landscape thereby has an impact on residents and tourism. The principal factors are both the optical impression left by wind farms and the necessary additional infrastructure. The optical impact on the landscape is dependent very much on subjective judgements. Some view wind turbines as aesthetic structures which enhance the landscape, others see them as eyesores. For these reasons, today's masts are usually tubular, which gives a better appearance than girders or anchored rigging.

In addition, an operating wind farm produces machine and generator noise, as well as the whistling of the rotor blades. Reducing the noise emissions makes it possible to raise acceptance among residents, as well as an expansion of the available area, as lower noise emissions also reduce the minimum acceptable distance from settled areas. Thus manufacturers place high value on noise reduction when developing new wind power equipment. In order to push forward innovation in reducing noise emissions, corresponding criteria have also been included in funding programmes (cf. Niedersächsisches Ministerialblatt 1992). Harm to the animal world from wind farms affects birds above all. However, studies have made it clear that the risk of birds flying into single turbines or wind farms is small, compared with other technical plant such as high tension cables (cf. Miersch 1994:51). On the other hand, it is unclear whether the flight paths and choice of resting places of migrating birds is affected by optical or acoustic signals, or turbulence (cf. Brüning 1996:153).

To reduce environmental impact, Lower-Saxony has drawn up guidelines for erecting wind farms, where recommendations for minimising harm to the landscape and for compensation or replacement measures, for example, are offered (cf. Griefahn 1995). Improving local acceptance can also be expected through more intensive information campaigns about prospective projects and the operation of the plant (cf. van Erp et al. 1996:181ff.). Including local planning in state-wide planning, as in Schleswig-Holstein and elsewhere, ensures that large areas can be designated as no-go areas, for breeding birds, for example. It is nonetheless also important that more effort is made to distribute the risks and benefits of wind energy projects or to find options for compensation. The amendment to the building statute book is a contribution in this direction.

5 International comparison of environmental and subsidy policy

5.1 Development of wind energy in Germany - summary

Wind energy in Germany has been supported since the 1970s with a combination of various environmental and subsidy policy instruments. Before then, the existing framework conditions in the energy supply market had more or less prevented autonomous development of wind energy. These included lock-in from sunk costs, high costs for adapting the central electricity supply structure and the persistency of a path-dependent technological development around fossil and nuclear power stations.

A particular characteristic of support for wind technology in Germany is the use of instruments targeted at innovation, i.e. supporting both R&D as well as market launch and diffusion. The first stimuli for Wind energy were given by the BMBF in the 1970s. Despite considerable expenditure, however, the attempt to develop large-scale wind turbines failed. Employees of the participating companies tried to apply their existing expertise, in aerospace, for example. This approach confirms the theory that the direction of efforts at innovation is influenced by the existing store of experience from earlier R&D activities (cf. e.g. Dosi 1988a:1120ff.)

More successful was support for R&D projects in newly founded companies or those diversifying out of engineering or shipbuilding. In these companies, wind turbines with a low kW capacity were developed and the necessary expertise for developing larger and more efficient equipment was gathered. This brought into being a knowledge base which could be described as a "technology niche". But in the development activities of these manufacturers also, the significance of the expertise accumulated in the past for the direction of innovation is apparent. The available specialist knowledge from electrical or mechanical engineering is still being reflected in the solutions found today.

At the end of the 1980s, technically reliable wind energy plant which had already been through the prototype stage was available in Germany. As a consequence, a reorientation of subsidy policy took place, to promote the further development of a "technology niche" into a market niche. The predominant subsidising of manufacturers was significantly reduced in favour of a more or less returns-dependent operator-oriented subsidy strategy.

Operators of wind farms were therefore provided with a secure basis for their calculations and the risks in investment decisions were considerably reduced. With the integration of technical targets, incentives for innovation were offered and the minimisation of the environmental impact of wind energy use, for example, was supported. Nonetheless, because the national and state-level support measures were not harmonised with one another, the programmes overlapped and there were periodic losses of efficiency.

A central precondition for market success was the opening up of the electricity market to private generators in the Electricity Suppliers Act. The dependency on returns of the subsidies favours wind energy projects in areas with high wind conditions and the use of efficient plant. It also induces demand for wind energy equipment which responds to price fluctuations, giving manufacturers incentives to continually reduce costs. Due to this demand pull effect, the significance of process innovation in recent years has risen compared to that of product innovation, which are now predominantly distinguished by increases in the efficiency of the equipment. Process innovation serves to exploit the still considerable potential for cost reductions in the production of wind energy equipment. It is important for manufacturers to bring new equipment onto the market rapidly, in order to secure returns on their innovation.

Nonetheless, the dynamism in the growth of wind energy use can not be explained only in terms of the use of such subsidy instruments, it is also influenced by further additional state measures. While in the USA, no influence could be exerted on the quality and efficiency of wind farms through guarantees of tax and interest rate breaks (cf. Kemp et al. 1997:12), these instruments, in combination with returns-dependent subsidies, proved to be effective measures in speeding up market diffusion in Germany. The low-interest credit made available by the DtA reduces the risk of high and fluctuating interest rates on the capital markets. The recognition of profit-orientation by the tax authorities then offered investors the possibility to set investment costs against tax. The loss allocations from wind energy projects are a significant reason for interest from commercial financiers. Alteration or definition of technical standards for wind energy plant has supported technological innovation, both to improve the efficiency of and safety of plant and to increase public acceptance. Public acceptance was also an aim of the amendment to the Building Statute Book, whereby the attitudes of the local community are given more consideration during the planning process. In addition, the amendments also simplify the requirements for erecting wind farms under planning law.

By the end of 1995, a total of over $350 million had gone on subsidies for wind energy. Added to this must be payments from energy suppliers of ca. $57 million, because of the ca. 10 cents/kWh in costs avoided (cf. Langniß/Nitsch 1997:72). Although these state subsidies might be considered a relatively inefficient form of allocation (cf. Erdmann 1992:183), it has certainly proved to be an effective temporary measure to overcome existing barriers to market entry. It is nonetheless crucial from the point of view of efficiency for subsidies to be offered only for a limited period, with the maximum duration being defined in advance. With regard to wind energy, the level of subsidies has adapted flexibly to the changing framework conditions for technological and market development. It has now been possible to reduce the volume of the majority of subsidy programmes, due to cost reductions through process and product innovation, although the efficiency benefits are to some extent balanced out by bottlenecks in the electricity supply network, growing acceptance problems among local populations and the increasing scarcity of locations with favourable wind conditions.

It is currently possible to operate profitably at locations with favourable wind conditions with payments guaranteed by the Feed-in-law and financing via the DtA without taking into account the tay advantages. If operators use a lot of their own electricity, e.g. for agriculture, conditions for profitable operation are more favourable. But the provisions of the Feed-in-law are also coming under discussion. In recent months, various proposals for amendments have been debated and finally an upper limit for take-up of wind-generated electricity set at 5%.

Since the subsidies were initiated in Germany, it has been possible to build up an independent wind industry based on small businesses. Various estimates put the number of employees directly or indirectly involved in the manufacture, erection and operation of wind farms are between 5,000 and 9,000 (cf. e.g. Langniß/Nitsch 1997:73; Bräuer 1996:96). Although a great number of companies is still active in the market, an increasing market concentration is becoming apparent as subsidies are reduced. While a number of businesses was supported in R&D programmes, returns-oriented subsidies favour those companies who have built up their own R&D capacities in recent years, manufacture a relatively large proportion of their own components in something approaching series production and can therefore reap the benefits of their experience. The early technological competitive advantages of Danish businesses, gained from their pioneering role, have now been caught up by German manufacturers. In some areas, German manufacturers are even leading the way with innovative technologies. However, these technological advantages have not yet been successfully translated into the corresponding shares in growing foreign markets. Even the leading German companies are only in the early stages of building up the necessary distribution and service structures. On the other hand, Danish firms still enjoy considerable market advantages from this headstart in building up complementary assets. State support for exports has as yet been unable to achieve any notable success.

5.2 Development of wind energy in Denmark

Since the mid-1970s, the use of wind energy has gained a great deal of political importance in Denmark, as a consequence of the oil crises. In 1991, wind energy was already supplying 3% of total electricity consumption in Denmark. As development took off in Germany at the start of the 1990s, expansion in Denmark slowed, among other things because of unsolved local and permissions problems. Only after the open questions as to permissions were clarified in 1994 did development receive a new push. The Energieplan 21 foresees expansion to 1,200 MW onshore and 300 MW offshore and thereby a 10% share in electricity generation for wind energy by the year 2005. By 2030, a further increase in wind energy capacity is planned, up to 1500 MW onshore and 4000 MW offshore (cf. Meyer 1997:5).

During the 1970s, many designs at many scales were developed in Denmark on the basis of the three-wing Gadser windmill from the 1950s. Just as in Germany, large-scale plant was developed at first, and here too, they proved less than successful both technologically and economically. At the same time, the development of technically less demanding, smaller designs, with performances between 10 kW and 55 KW was successful. These small wind turbines were developed by pioneer companies and do-it-yourselfers, set up by idealistic investors for environmental reasons, in order to gather practical experience (cf. Lauritzen et al. 1996:67). Development of the small turbines was influenced to a great extent by the expertise available to developers and constructors, most of whom had no great background in mechanical engineering, but had been trained as craftspeople (cf. Heymann 1995:463). This Danish concept still shapes technological development in equipment construction, It was especially the small German wind energy companies who were able to profit from the spill-over of Daniosh expertise in building wind energy plant.

The use of wind energy was supported in Denmark through a carefully balanced combination of R&D subsidies and help with market launches. This included financial support for R&D and prototypes, or the structuring of administrative framework conditions, and are comparable with the instruments later used in Germany (cf. Hoppe-Kilpper 1995:113ff.).

A first decisive measure in the eyes of Lauritzen et al. (1996:62f.) was the constitution of the wind energy committee in 1974. The committee's function was to study and evaluate the opportunities for using and developing wind energy use in Denmark (cf. Lauritzen et al. 1996:62f.). Meyer (1997:2f.) sees rather the passing of the first alternative Danish energy plan by independent researchers in 1976 as the key milestone in the development of wind energy in Denmark.

An important role in the further technical development of small wind farms in Denmark was played by the early founding of an association of Danish wind farm operators, which evaluated all operating experience since the end of the 1970s in minute detail and gave precise requirements to manufacturers on improving their equipment.

In 1978, the test centre for wind energy equipment was set up in Risö (cf. Lauritzen et al. 1996:67). The staff of the test centre was recruited to a considerable extent from people who had already gained practical experience in the 1970s in the construction of the TWIND windmill (a private facility with a capacity of ca, 600 kW). The research centre performs an important function as a link between competing equipment manufacturers. Alongside this, testing procedures and certification guidelines based on them are developed in Risö, providing information for building safer and more reliable equipment (cf. Kemp et al. 1997:14). At present, any wind energy plant which appears on the market is tested for 3 to 6 months at the research centre in Risö.

After a feasibility study on the use of wind energy, state support measures concentrated at first on R&D and demonstration projects, as well as on determining criteria for judging quality and reliability (cf. Lauritzen et al. 1996:67). The development of efficient rotor blades, reducing noise pollution by wind turbines or constructing inexpensive offshore platforms has been supported since the early 1980s in development and demonstration projects in universities or on manufacturers' premises. Until the end of the 1980s, setting up wind farms was supported with investment subsidies. The subsidised facilities were required to give proof of certification by the test station in Risö. The level of investment subsidies varied frequently in the course of time, and the subsidies were halted in 1989 (cf. Lauritzen et al. 1996:66f.). Due to an increasing scarcity of locations, however, the substitution of smaller, technologically obsolete equipment with large, more efficient models is now being supported with state subsidies.

After reliable equipment became available in Denmark, further diffusion was supported from 1979 onwards through assistance with market introduction. This early shift in support from manufacturers to operators was an important step for the success of wind energy use in Denmark, and was later taken up in Germany. But the gradual reduction of support for market launches as technology develops is also a mark of the success of Danish wind energy policy (cf. Kemp et al 1997:14).

In addition, infrastructure projects were also financed by the Danish government, including the production of the Danish wind atlas in 1981, which provided operators with information as to suitable locations, and location assessments for onshore and offshore wind farms.

The first fundamental difference between Danish and German energy policy is the decision by the Danish government to get out of atomic energy in 1985. Producing energy plans for many years in advance with targets for expanding wind energy is also a characteristic of Danish state support policy (cf. Hoppe-Kilpper 1995:78). A further difference is the strong integration of energy supply companies in wind energy production in Denmark. Both Danish energy suppliers (ELSAM and ELKRAFT) were participating in the development of wind farms with megawatt capacity in the 1970s. In a contract with wind farm operators, the Danish energy suppliers committed themselves to purchase wind-generated electricity at 85% of the consumer price without tax. This created a guaranteed tariff, which was ca. 9 cents/kWh in 1995 (cf. Lauritzen et al. 1996:59ff.). If the operator feeds only a part of the electricity generated into the public grid, the price falls to 70% of the consumer price. The energy suppliers were also prepared to assume 35% of connection costs. Moreover, the CO2 tay and the energy tax on fossil fuels, ca. 1.4 cents/kWh is refunded to community and single operators (cf. Meyer 1997:6). A partial internalisation of the external effects of energy supply is thereby achieved in Denmark, and technology goals are linked to environmental targets. In two wind energy programmes, the energy suppliers were also required by the Danish government to install a total of 200 MW wind power capacity. While the first 100 MW was set up by suppliers by

1993, the second 100 MW could not be realised on the mainland, due to location problems. Instead, it is now intended that this 100 MW capacity be set up in coastal waters (cf. Meyer 1997:7).

Important factors in the high public acceptance for wind energy were the dissemination of information on the nature of renewable energy and institutional innovation in the form of establishing wind cooperatives (cf. Meyer 1997:5f). Today, 75% of installed wind energy capacity is organised in such cooperatives, so that large sections of the public have a financial interest in wind energy projects. This was made easier by the fact that the final distribution networks in Denmark are frequently still owned by local cooperatives. Investors must be resident in the administrative region where a project is planned and investment is tax-free if the sum invested is no more that 150% of the investor's own annual electricity consumption. There are therefore acceptance problems in Denmark only with respect to projects by energy suppliers (cf. Meyer 1997:10).

Because of these framework conditions, wind energy in development has developed into a growth sector. It is estimated that some 8,500 people were employed in the Danish wind industry in 1995 (cf. Lauritzen et al. 1996:98ff.). The export market is of major importance to the Danish industry. Current export share is around 80% of total Danish plant manufacture (cf. Lauritzen et al. 1996:98ff.). Even in 1982, Danish manufacturers of wind energy equipment had begun to export to California. When the boom in wind energy spread through other European countries, Danish manufacturers had, with the support from the Danish government, established themselves as pioneers on the world market. Since the start of the 1990s, Germany is the most significant foreign market. Danish companies are making the pace in offshore wind farms as well, having erected two already. With government support, cheap platforms, for example, were developed for offshore wind farms, which meant a clear reduction in manufacturing costs.

5.3 Development of wind energy in Great Britain

Thanks to its geographical position, Great Britain is an ideal country for exploiting wind energy. About 20% of British land experiences wind speeds of above 7 m/s. But in Great Britain also wind energy was scarcely supported until the end of the 1980s, and payment for wind-generated electricity was only 2.5 pence/kWh (ca. 4.5 cents/kWh).

Not until 1989 was support for renewable energy given strong impetus, for environmental and energy policy reasons, with the passing of the Electricity Act. The Act aims to promote forms of energy which will be competitive in the long term. The liberalisation measures laid down broke up the energy suppliers and transporters, privatised non atmoic power generators and created a generator pool, and there is an obligation to provide elctricity to customers (cf. Thomas 1997:41ff.).

The Electricity Act was supplemented in England and Wales by the Non Fossil Fuel Obligation (NFFO), and in Scotland and Northern Ireland with "renewable orders", where the British economy ministry requires regional electricity companies to accept renewable and nuclear power. To this end, the government announced, in its 1990 Environmental White Book, an expansion target of 1,000 MW renewable energy capacity by the year 2000, which was raised to 1,500 MW in 1994. NFFO 1,2 and 3, contain a take-up obligation of 1251 MW (declared net capacity) renewable energy, of which 262 MW must be wind energy (cf. Mitchell 1995:1077). In fact, the original goal of the NFFO was to secure turnover for uncompetitive nuclear energy.

The regional electricity companies have founded an agency to deal with the NFFO, concluding contracts with potential wind power operators as to the required quantities of renewable energy. Contracts are awarded in open competition on the basis of bids, with the lowest bidder being selected. Between 1990 and 1994, the NFFOs achieved an increase in installed wind energy capacity from 4.3 MW to 65.6 MW. Moreover, competitive pressures pushed the price of wind energy down by some way. In NFFO 2, payment for wind-generated electricity was still ca. 11 pence/kWh, () but prices have fallen clearly in NFFO 3 to an average of 9.54-11.65 pence/kWh. ()The reasons for falling prices are certainly falling equipment costs and experience in planning wind farms, but above all an extension of the depreciation period for taxation from 10 to 15 years. Finally, the repeated tendering has made it possible for new operators to enter the market (cf. Mitchell 1995:1085ff.). The higher costs of electricity generated from renewable sources are refunded to the regional electricity companies via a fossil fuel levy. In 1993/1994, the total volume of the levy was £1,234 million (), of which £74 millions () were used to support renewably generated electricity, while over 90% of the total went on supporting nuclear energy (cf. Baentsch 1997:245).

Implementing the NFFO has to date been less than successful. By 1996, only a quarter of the planned wind farms had come on-stream. There is no guarantee that allocated projects will actually be realised at any time, as planning permission for the plant can be applied for only after allocation. The permission procedures are complex, and obstruct the implementation of wind energy projects. There are major public acceptance problems, due to, among other things, the fact that tendering procedures virtually exclude participation by local people in wind projects, and to the negative PR campaigns about specifically wind energy which are conducted by the electricity companies. Another problem is the still inadequate experience of operators, which results in organisational difficulties. Furthermore, project planning takes little account of the needs of the environment, due to the severe pressure on costs exerted by tendering procedures. (Baentsch 1997:247). This has now led to guidelines being drawn up („Best Practice Guidelines for Wind Energy Development“), where the needs of the environmental are given more weight.

Although the goal of the British government was to develop a competitive wind energy industry (cf. Stevenson 1996:74), a corresponding manufacturing industry has not yet emerged. On the contrary, the great majority of installed wind energy equipment is supplied by Danish manufacturers. A decisive cause is the inadequate technological or institutional base which, with the selection of instruments applied in this case, had no opportunity to develop in a protected environment. British suppliers have therefore been unable to destroy the competitive advantages of their Danish counterparts.

6 Closing remarks

A fundamental problem for the development of environmental technologies is that they must generally be rapidly available for exploitation. However, the shorter the reaction time, the less chance there is to develop preventative environmental protection technologies in R&D. Instead, there is a growing incentive for minor technical improvements which will rapidly meet emissions reduction requirements and make it possible to continue using existing technologies and already available expertise, but which are, in the long term, associated with higher costs for the economy as a whole. It is therefore important to consider environmental aspects from the start of the innovation phase. During this phase, a new innovation path can be set out and a pool of environmental technology solutions can be created early on, from which solutions for reduction or avoidance of environmental stress can be selected at a later date (Adler et al. 1994:205; Vergragt und Jansen 1993:140). The transition from short term regulatory approaches in environmental policy to the definition of a reliable environmental policy framework could send important signals in this respect.

In Denmark, this policy approach to supporting the development and launch of environmentally friendly technologies has been a - successful - reality in the wind energy sector since the 1970s. Supported by a combination of various policy instruments, especially subsidies, Danish policy created firstly a technological, and then a market niche for wind technology, one which has since developed into a functioning market. The important factor was a flexible subsidies policy which could be adapted to suit the changing socioeconomic and technological framework conditions and which was able to take account of the specific requirements of invention, innovation and diffusion during the entire innovation cycle. The creation of long-term energy plans, support for R&D to create a knowledge base, the early transition from investment subsidies to returns-dependent support for diffusion, financial participation by broad sections of the public and inducing commitment to the expansion of wind energy on the part of energy suppliers are all characteristic of Danish policy, as is the linkage between wind energy policy and other policy areas, such as environmental and energy policy.

In Germany also, environmental policy instruments brought about the emergence of a market niche for wind energy use with a significant volume, where reliable and profitable wind farms were developed and institutional innovation, such as the formation of industrial associations and business networks made it possible to develop investment models. In principle, support policy in Germany is similar to than in Denmark, and in Germany also, the sequence of instruments used took account of the various phases of the innovation process. It should nonetheless be pointed out that this policy was not following any strategic plan, but rather developed gradually, and was therefore able to learn. Even if this meant the lack of a long-term perspective, it made the flexible use of instruments possible. In Great Britain, on the other hand, support for market launches under the NFFO began before British companies had been able to develop efficient wind technologies with the help of R&D subsidies. In consequence, British manufacturers were not equal to the competition, while self-supporting wind energy industries have developed in Denmark and Germany. This should be no surprise, when one considers that the NFFO are primarily aimed at ensuring the survival of nuclear power stations which have already been built. The differences between the corresponding factors influencing innovation in the development and use of wind energy technology are listed together in Table 2. This also shows up major differences between the framework conditions in Denmark, Germany and Great Britain, which affected the influence of the policy instruments used.

Table 2: Factors influencing innovation in the wind industry

	Germany	***Denmark***	***Great Britain***
Framework conditions for development			
Technological conditions	Good engineering and craft professions	Good craft professions	insignificant manufacturing industry
Market structure	increasing concentration	increasing concentration	
Market volume	Domestic: high Export: low	Domestic: medium Export: high	Domestic: medium
Market growth	Domestic: uncertain Export: high	Domestic: high (offshore) Export: high	Domestic: medium
Learning curve	First mover	First mover	
Framework conditions for use			
Energy system	centralised	centralised, in transition	centralised, in transition
Prices	falling price per kWh	falling price per kWh	falling price per kWh
Risk	high exposure	low exposure	high exposure
Environmental factors	growing problems with public acceptance	slight problems with public acceptance	high problems with public acceptance

Increasing pressure on costs, both through the type of instruments used, i.e. oriented around returns or based on tendering procedures, and through reductions in subsidies, is leading to increased competition in all three countries. It is becoming increasingly important for manufacturers to draw on their experience to reduce the specific costs of their equipment, in order to gain more room for manoeuvre in pricing. This is achieved partly through R&D to produce innovation in products and processes. There are also attempts to secure returns from innovation by being the first on the market and achieving a large market share as quickly as possible. As a consequence of this market pressure, generating costs per kWh wind power have fallen significantly in recent years. At the same time, the market concentration of German and Danish manufacturers has risen markedly. It can be expected that a global oligopoly of suppliers will emerge in the end.

Despite its improved competitive situation compared to that of fossil fuels, the future of wind energy use in Germany is considerably less certain than in Denmark or Great Britain. In contrast to Germany, Great Britain's Electricity Act provides a legal basis for further expansion of wind energy, albeit at a very low level. In Denmark, it has been possible to construct a broad consensus on further expansion of wind energy among the participating actors, i.e. energy suppliers, wind farm operators, the state and the general public. The lack of strategic planning in Germany is demonstrated by the continuing lack of agreement on how to exploit the accumulated store of technical solutions in realising environmental and energy policy goals. In the first place, there is considerable resistance to the use of wind energy among energy suppliers, who want to keep their existing monopoly and specialisation benefits and protect their own overcapacity. This is expressed in capacity planning which takes no account of expansion in wind energy. Thus the already installed wind energy capacity leads to fuel conservation, but capacity effects are scarcely realised. There is consequently a great deal of uncertainty for both the operators and manufacturers of wind technology in Germany as to the future development of the domestic market. In Great Britain and Denmark, on the other hand, the participation of energy suppliers was forced through legal measures. Moreover, steps have been taken to further decentralise energy supply. Secondly, in Germany as much as in Great Britain, acceptance among affected local residents is falling as wind energy achieves more market penetration. The response in Germany has included looking at options for involving residents financially in the operating companies, thereby learning from the Danish experience with wind cooperatives, in which the majority of the population has a stake. Due to the structure of the tendering procedure, this would appear hard to implement in Great Britain.

It is thus clear that a pool of technical solutions and a niche market can be built up by means of innovation-oriented environmental policy. It is important firstly that innovation is induced, in order to reduce the costs for a technology to a competitive level, overcome the essential technical problems and create the right conditions for exploiting past experience. Secondly, the necessary institutional framework conditions must be created. A decisive factor here is an open, flexible policy framework which uses a combination of various instruments and is able to adapt both to the specific conditions in each phase of the innovation process and to changes in the technical and socio-economic framework conditions. It is also important for the effects of using an instrument to be monitored through continual evaluation. In the wind energy sector, an instrument package which makes no attempt to trigger a technology leap, with the subsequent economic and technological uncertainty and unpredictability, has also proved advantageous. Instead, a gradual approach whereby a new technology is continually improved in small steps has proved its worth.

However, after building up a store of technologies and a market niche, further instruments must be used to create a functioning market. thus the future of wind energy use in Germany depends on environmental policy succeeding either in correcting relative prices by taking external costs into account, so that the use of wind energy becomes more profitable for business than conventional power station technologies, or in laying down now the future status of renewable energy in the energy supply system. Both measures are characteristic for the success of Danish policy. With the introduction of the energy and CO_2 taxes, Denmark achieved a partial internalisation of the external effects of power generation and significantly improved the competitiveness of renewable sources. Moreover, the long-term national energy plans, similarly to Great Britain's Electricity Act, set out concrete goals for the expansion of wind energy as substitutes for coal-fired power stations.

7 Literature

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