Reporting on dissemination activities carried out within the frame of the DESIRE project (WP8)

Name, Affiliation	Niels I. Meyer, Aalborg University
E-mail	nim@byg.dtu.dk
Title of dissemination	Learnings from Wind Energy Policy in EU, With Focus on Denmark, Sweden and Spain.
Type of activity	Article in peer-reviewed journal (submitted)
Title of forum	GIN Wind Stream Conference, Cardiff, July 2006 The article is submitted for publication in the journal *European Environment.*
Language	English
Date of dissemination	03-07-2007 (Original conference presentation)
Place of dissemination	Worldwide
Brief abstract / description of dissemination activity	The paper describes the learnings from different wind energy policies in EU and compares the Danish development to that in Sweden and Spain. It is concluded that liberalisation of the electricity market in EU has created a number of problems for the promotion of wind power and for the establishment of a sustainable energy development in general.
Audience impact assessment	The message of the paper was well received and gave rise to a broad discussion at the session.
Dissemination	Included after this form

August 17, 2006

Adjusted paper for the GIN Wind Stream Conference, Cardiff, July 2006.

LEARNINGS FROM WIND ENERGY POLICY IN EU, WITH FOCUS ON DENMARK, SWEDEN AND SPAIN.

Dr. Niels I. Meyer, Technical University of Denmark

Contact details:

NIELS I. MEYER
Department of Civil Engineering
Technical University of Denmark
Brovej building 118
Telephone: +45 45 25 19 30
Email: nim@byg.dtu.dk

Abstract:

Promotion of wind power in Europe has been pioneered by Denmark, where wind power now covers about 20% of the total electricity consumption. The paper relates this result to the early Danish development of wind turbine technologies back in the 1890s and to the continued development during the following century leading to the start of the modern phase of wind power in the 1970s.

The successful promotion of Danish wind power in the last two decades of the 20th century is related to a number of factors including individual entrepreneurs, broad public support, early official certification of wind turbines, systematic government support of various types and co-operative private ownership of wind turbines.

The development of Danish wind power since 2000 has been influenced by liberalization of electricity markets in the EU and by new market oriented policies introduced by a liberalistic-conservative Danish government since 2002.

The paper describes the learnings form different policies and compares the Danish development to that in Sweden and Spain. It is concluded that liberalization has created a number of problems for the promotion of wind power and for the establishment of a sustainable energy development in general.

INTRODUCTION

Energy has become an important political point on the agenda of most countries in the World. This is due to a number of factors including lack of long-range supply security, the approaching ”oil peak” and the consequences of global warming from emission of greenhouse gases. Strangely enough, these problems were not in focus during the negotiations leading to the liberalization of electricity markets in the EU (European Communities, 1997). The consequences and problems were not analyzed in depth before it was decided to go along with the liberalization. Instead, the main focus was on obtaining lower consumer prices through stronger market competition.

After about 10 years of experience with the liberalized electricity markets serious problems have started to appear. The long-range supply security is at stake, environmental problems and technological innovation get lower priority in the electricity sector, and the same applies to maintenance of the grids. In addition, the creation of a few dominating utilities tend to reduce effective competition.

A basic problem is that sustainable energy development requires planning horizons of 40 to 50 years while the time horizon of commercial markets typically is an order of magnitude lower. Short-sighted commercial investments will often block the introduction of supply systems which are more environmental benign, have higher supply security and are less costly in the long run. Wind power and other supply systems based on renewable energy sources are typical examples of such favorable long range solutions.

Recently the EU Commission has suggested an evaluation of the possible role of nuclear power in the future supply system. This proposal is supported by the nuclear lobby in spite of a number of unsolved security and other types of problems including safe deposit of high-radioactive waste for thousands of years and limited cheap uranium sources partly in unstable regions of the world.

The economic cost of nuclear power is claimed by the nuclear industry to be less than 3 eurocents/kWh but this is a distorted number as it does not include all externalities, e.g. full insurance cost, realistic assumptions in relation to removing of old plants, hidden state subsidies through cheap investment loans and export credits etc. Over the years the EU has subsidized nuclear power by more than 60 billion euros. The real cost of electricity from nuclear power including all externalities could well be at least 50% higher than the postulated 3 eurocents/kWh.

It should also be mentioned that it poses severe problems to combine a substantial amount of nuclear power with a substantial amount of wind power and decentralized CHP in the same system. These technologies require different system structures in order to operate in an economic and controlled way. The introduction of nuclear power e.g. in the Danish supply system would imply a phase-out of the present development of a sustainable supply system based on wind power and decentralized CHP.

The present market system where important externalities from fossil fuels and nuclear plants have not been fully internalized distorts the competition to the disadvantage of sustainable supply systems based on renewable energy. Despite of that, the EU summit in March 2006 argued for more market influence in the energy sector as a way to diminish the increasing dependence on imported fossil fuels from politically unstable regions in the World.

This paper will document that long-range governmental planning and regulation has been essential for the promotion of wind power in Europe and thus for increasing the supply security and reducing the dangers of global warming. The energy policies in Denmark, Sweden and Spain are used as case studies in relation to promotion of wind power.

DANISH WIND ENERGY POLICY

The modern Danish wind energy policy should be seen on the background of a long historical development. The leading role of Denmark in promotion of wind power from the 1970s may be traced back to the pioneering work of Poul la Cour at Askov Folkes High School in the 1890s (Grubb and Meyer, 1993; Meyer, 1995).

La Cour developed and built a wind turbine for electricity production with a rotor diameter of 22 m including mechanical speed control. He even tested a number of rotor profiles in wind tunnels and provided energy storage based on hydrogen produced by electrolysis of water. The hydrogen was subsequently used for lighting purposes. He deserves the credit of initiating modern wind power development - including hydrogen as an energy carrier based on renewable energy sources (RES).

The concepts and technologies developed by la Cour provided a basis for wind electrification in Denmark during the first two decades of the 20th century. In 1918, 120 rural wind power stations were established with rated turbine powers between 20 and 35 kW, yielding a total installed wind capacity of about 3 MW compared to a total Danish electricity capacity of about 80 MW. With the typical capacity factors of that time, this corresponds to around 3% coverage by wind of the Danish electricity demand in 1918. Even to-day only three nations (Denmark, Germany and Spain) have exceeded this coverage by wind.

During the following four decades, wind turbines were further developed and tested in Denmark and elsewhere, especially in Germany, UK and USA. This period culminated with the 200 kW Gedser Mill in Denmark, in operation from 1959 to 1967. The operation was successful, and the Gedser Mill became the mother of modern Danish wind turbines in the 1970s characterized by three blades on a horizontal axis in an upwind position.

This concept was further developed by a number of small Danish industrial entrepreneurs from the mid seventies starting with small turbines typically with rated power of about 22 kW. Most of these small firms were economically weak and only few of them survived in the long run. However, the wind power development attained early support from the Danish Academy of Technical Sciences (Danish Academy, 1975 and 1976) and from governmental support programs including a test and certification facility. The Danish utilities were also involved in a few programs in the seventies but were generally skeptical concerning the future of Danish wind power.

Energy Plans and Nuclear Debate in Denmark

The decade from the mid seventies to the mid eighties was characterized by strong debates and controversies over Danish energy policy. In the center of this debate was the question of nuclear power. The official energy policy was aiming at the introduction of nuclear power as soon as possible in the Danish supply system. This was an essential

element in the first official energy plan from the spring of 1976 (Danish Ministry of Industry and Commerce, 1976).

An alternative energy plan without nuclear power and with a higher contribution from RES was published in the fall of the same year by a group of energy experts from Danish universities (Blegaa et al., 1976). A summary in English of the alternative energy plan was published in 1977 (Blegaa et al., 1977).

The opposition to nuclear power was also taken up by two new NGOs: the Organisation against Nuclear Power (OOA) and the Organisation for Renewable Energy (OVE) that were established in the mid seventies. These organizations soon became quite professional in their arguments about safety problems and other problems related to nuclear power – and in their arguments in favor of RES. It was surprising, however, to follow the style of argumentation by some of the leading Danish engineers and physicists in favor of nuclear power. They often used discriminating personal attacks on opponents to nuclear power who were accused of planning to overthrow the democracy in Denmark and to bring the Danish society back to the stone-age (Beuse et al., 2000).

In 1979 a new Ministry of Energy was established, and the minister published a second official energy plan in 1981 (Danish Ministry of Energy, 1981). Again the introduction of nuclear power was an essential element in this plan. Two years later a group of energy experts from Danish universities published another alternative energy plan without nuclear power and with emphasis on energy conservation and RES (Hvelplund et al., 1983). This plan was based on detailed models for the potential of energy conservation and also introduced new scenario methodologies. The alternative plan got broad attention through co-operation with the two active NGOs (OOA and OVE).

The history of nuclear power in Denmark was terminated in 1985 when the Danish parliament decided that nuclear power should not be an element of Danish energy supply. It should be noted that this was one year before the Chernobyl accident. The decision was influenced by several factors, but there is no doubt that the alliance between independent university experts and competent NGOs in connection with broad information campaigns on alternative possibilities was one of the factors.

After the termination of the nuclear debate, Danish energy policy was getting ripe for more focus on RES in the electricity supply system.

Shifting Danish Energy Policies

A significant shift in the focus of Danish energy policy took place towards the end of the eighties and was confirmed by a new official energy plan in 1990. Now the overall goal of Danish energy policy was to create a sustainable energy development and to comply with commitments to reduce greenhouse gas emission in an effort towards the mitigation of climate change. This has been manifested through the two latest official Danish energy plans from 1990 and 1996 (Danish Ministry of Energy, 1990; Danish Ministry of Environment and Energy, 1996). These policy plans strongly pursued continuity in their priorities on the development of RES and the expansion of electricity generation based on renewable energy sources (RES-E). The primary focus was on increasing the share of wind and biomass in electricity production. The specific target for RES in these plans is 12-14% of primary energy by year 2005 and 35% coverage by year 2030.

Wind power was given an important role in these plans with targets for installed capacity of around 1,500 MW in 2005 and 5,500 MW in 2030, covering 10% and up to 50% of Danish electricity consumption respectively (dependent on future development of electricity demand). The 2030 target includes 4,000 MW offshore wind capacity.

The 2005 target was already exceeded by a factor of two by 2003 where the installed wind power capacity was around 3,000 MW. Since then the installed capacity has stagnated and in early 2006 the coverage by wind is about 20% with an installed capacity of about 3,100 MW.

The net increase in Danish wind capacity in the last years with overall stagnation have mainly been due to a repowering scheme from 1999. According to this scheme turbines with rated capacities less than 100 kW could be replaced by three times the discarded capacity, while turbines between 100 and 150 kW could be replaced by twice the capacity until the end of 2003. The new turbines were given a premium of 0.17 DKK/kWh (2.3 eurocents/kWh) on top of the ordinary tariff for wind electricity. Although this scheme was supposed to stop by the end of 2003, dispensation has been given for turbines installed even in 2005 in order to counteract the trend of stagnation.

A new repowering programme beginning in January 2005 is supposed to add further 350 MW wind capacity on land. Turbines of less than 450 kW capacity are entitled to take part in this programme. In addition to the market price and an environmental bonus of 1.3 eurocents/kWh, wind power producers will receive a repowering subsidy of 1.6 eurocents/kWh. So far, a number of investors seem to adopt the strategy to buy the small turbines and to let them continue their production until major repairs are needed before they take advantage of the repowering scheme.

A coverage by fluctuating wind power of more than 20% of the total electricity consumption gives rise to new regulation problems, especially in combination with a high percentage of heat-bound co-generation like in Denmark. There have already been periods in Jutland with very strong winds where the total electricity production could not be taken up by the system in West Denmark.

The simple solution is to export the surplus electricity production to Northern Germany. However, this will often result in low prices for the exported electricity as Northern Germany also has a high density of wind power and the wind blows at approximately the same speed north and south of the boarder. In a longer perspective increasing exports will require expensive expansions of the high voltage transmission lines.

The Danish Energy Authority and the system operators are presently sponsoring a number of research projects investigating alternative solutions where wind farms and decentralized CHP-plants are included in the regulation of the overall system balance.

An international pilot project is taking place in western Denmark where the system presently contains approximately 3,500 MW of centralised (large) CHP, 1,600 MW of local CHP and 2,400 MW of wind power capacity. The project involves the development of a “Cell Architecture” for decentralized grid management of semi-autonomous cells with well-defined local functions and system-wide coordination capabilities (Lund et al., 2006).

A cell is defined as the part of a distribution system below a 150/60 kV substation typically consisting of 20-100 MW of conventional loads and a mix of CHP and wind turbine generators. The ambition is to develop a cell structure, where the cell disconnects itself from the high voltage grid and transfers to controlled island operation in case of a

regional emergency situation reaching the point of no return. A less ambitious goal of the project is to secure that the cell black-starts itself to a state of controlled island operation after a total system collapse.

A distribution company in western Denmark has agreed to be part of the pilot project and a suitable 60 kV cell of that company has been selected as the pilot cell. The actual pilot implementation and testing of the cell controller in a selected part of the pilot cell is expected to be accomplished during 2006 and 2007 (Lund et al., 2006).

Danish Strategies for Wind Power Promotion

The Danish strategy for promotion of wind power in the period from the mid seventies to the mid nineties has combined a number of different elements:

- long-term government support for research, development and demonstration;
- national tests and certification of wind turbines;
- government sponsored wind energy resource surveys (wind atlases);
- subsidies, feed-in tariffs and regulations;
- local ownership of wind turbines and careful selection of sites.

These element will be discussed in more detail in the following.

Research, development and demonstration

In 1982 a government committee was established for promoting energy systems based on RES, including wind, solar and biomass. The members of the RES-Committee were experienced experts within these fields. After a few years of introductory work, the committee has had an annual budget of about 4.6 million euros where an appreciable part has been spent on development and demonstration of wind technologies. In the late eighties, the committee promoted new programs of offshore wind farms in order to overcome the foreseen obstacles for land based turbines and Denmark has been first in the world to establish large offshore wind farms.

The Danish development has followed a safe technical path, with a gradual increase in turbine size based on improvements of the same basic design. This development is illustrated in Table 1.

Year	1978	1983	1985	1988	1991	1995	1999	2005
Typical rated power of new turbines, kW	20-40	55-75	100-150	200-250	300-450	500-700	1000-1500	2000-3000

Table 1. Development of rated power for commercial Danish wind turbines. Numbers refer to the typical capacity range installed in a given year.

In addition to wind technology the committee was supporting development and demonstration of biogas systems based on animal manure, new processes for gasification of straw, efficient solar collectors and a number of other RES systems. Support was also

given to market penetration in the form of information campaigns and the establishment of a number of local energy offices for promotion of RES.

The work of the committee was discontinued in 1991 in connection with a restructuring of the government committees in the field of RES. The total funding for RES from the committee during its nine years of operation amounted to about 30 million euros.

National Tests and Certification of Wind Turbines

It is important for a new and vulnerable industry as wind turbine manufacture in the late seventies and early eighties to acquire a credible market reputation from the beginning. For this reason a machine-testing program was established at Risø National Laboratory in 1978. About a year later, a formal certification procedure was added. This program has been essential in preventing sub-standard technologies from being marketed both at home and abroad.

A contrasting experience was reported from California in the early eighties, where generous federal tax credits combined with state incentives, provided large subsidies for wind installations. Entrepreneurs responded rapidly by constructing small-scale wind farms with 50 to 200 kW turbines, bringing California into the forefront with respect to the quantity of installed wind power. Unfortunately, many of the early machines installed in California were of poor quality and broke down during the first season of operation. The Danish turbines in California, however, distinguished themselves by credible operation due to the testing procedure at Risø National Laboratory.

Wind energy resource surveys

Wind resources are complex, and meteorological data on wind speeds are generally too inadequate to identify the potential wind power production with the necessary accuracy at a given site. It is important in this context to keep in mind that wind power varies as the cube of the wind velocity. As a consequence, national resource studies are crucial to wind energy penetration.

In 1981, a wind atlas for Denmark was published, based on the pioneering work of E. L. Petersen and co-workers at Risø National Laboratories (Petersen et al., 1981). Computational procedures described in the atlas make it possible to estimate the wind distribution over inhomogeneous terrain, taking into account topographical and shelter effects. The atlas may be used in wind power assessments at specific sites, and the methodology has been refined and computerized so that customers may have detailed information concerning expected electricity production for a specific turbine at their site.

An extensive national assessment study on sites for wind turbines was carried out in the period from 1981 to 1986 by Danish energy and environmental authorities (Danish Energy Authority, 1986). The assessment was based on turbines with a rated capacity of 2.5 MW each and led to a total production of 3 TWh per year from wind power if the potential was to be fully utilized. This would correspond to about 10% of the total electricity consumption at that time.

The assessment was obviously on the pessimistic side due to the questionable assumption of using only 2.5 MW turbines on land-based sites. The actual development has shown how misleading such assessments may be. The production from land-based

wind power in year 2005 was about 7 TWh covering around 20 % of the total Danish electricity consumption.

Subsidies, feed-in tariffs and regulations

From 1979, private citizens who installed wind turbines were reimbursed 30% of the turbine's purchase price by the Danish government. Only turbines tested and certified by the Wind Test Station at Risø National Laboratory were eligible for this subsidy.

As wind power economy was improving during the eighties, the investment subsidy was gradually reduced to 10%. In 1989 it was finally eliminated after a total investment subsidy of about 280 million DKK (38 million euros) contributing to the installation of about 300 MW rated wind power.

Danish utilities had little experience in handling dispersed, small-scale electricity systems such as wind turbines when the modern phase of wind power was developing in the late seventies and early eighties. The utilities had been focusing on large-scale conventional power generating systems. As a consequence, most Danish electric utilities were highly skeptical about wind power, and they were not interested in offering favorable feed-in (pay-back) prices for wind electricity.

On this background the promotion of wind power would need either government regulations including favorable feed-in tariffs or voluntary agreements between utilities and wind power producers. In accordance with Danish traditions, the process started out by relying on voluntary agreements.

Already in the late seventies the first agreement was set up between the Association of Danish Electric Utilities on the one side, and the Danish Wind Power Association together with Danish wind turbine producers on the other side. This agreement was renegotiated several times during the period up to 1992 due to pressure from the wind power producers.

After a number of disagreements, especially over conditions for grid connections of wind power, the Danish government in 1992 introduced regulations for these conditions and for the feed-in tariff, which was fixed at 85% of the utility production and distribution costs. On top of the feed-in tariff from the utilities, the private wind power producers would receive a "tax refund" of 0.27 DKK per kWh (3.7 eurocents per kWh). This may be regarded as a premium due to the environmental benign nature of wind power.

As an example, a typical remuneration for wind power in the years after 1992 would amount to about 0.60 DKK per kWh (8 eurocents per kWh), which corresponds to a return on the investment of 10 to 15% (after tax). This remuneration was high enough to yield a strong growth in land-based wind capacity in the rest of the nineties as illustrated in Fig. 1.

Fig. 1. Development of installed Danish wind capacity from 1980 to 2002 (Danish Energy Authority).

Local Ownership of Wind Turbines and Careful Planning of Sites

The problem of visual pollution is hard to tackle because it is a matter of taste. Most people are quite happy to look at wind turbines, but a few people hate the turbines and have organized themselves to fight wind power. Public attitude surveys of wind power in the nineties have generally shown that around 80% of the Danish population supports wind power (Danish Wind Industry, 1993; Damborg, 2003).

The high acceptance of wind turbines in Denmark is to a large extent due to the fact that the majority of the Danish turbines are owned by private households based on neighborhood co-operatives. About 150,000 Danish households were registered as owners of shares in wind turbines in 2001. It is much easier to accept some extra noise and the view of a turbine if it reminds you of the fact that the turbine gives you money when the wind blows. The noise problem is, however, of minor importance for modern turbines when combined with regulations of minimum distances from dwellings.

There is no simple rule to indicate the optimum density of wind turbines when taking into account the environmental concerns of the population. The Danish experience seems to indicate that it depends both on the type and size of turbines, the organization of ownership and the rate of penetration. In addition, the acceptance is increased when the turbines are placed with consideration of the landscape and when aesthetical turbine designs are used.

In the early nineties, politicians in local communities were increasingly influenced by loud speaking groups opposing wind energy. This resulted in rather restrictive local policies towards sites for wind turbines, and the annual increase in wind capacity dropped from about 80 MW during the period 1990-92 to about 30 MW in 1993 and 1994.

In order to counteract this development, the Ministry of Environment and Energy ordered all Danish municipalities to estimate their potential for wind turbine sites and to report the results by June 1995. Not all municipalities were meeting the deadline, but the initiative by the Ministry did make an impact as may be seen from Fig. 1.

Wind Turbines as an Export Industry

In 2005, Danish wind turbine producers had a turnover of about 22 billion DKK (3 billion euro) with more than 90% of this coming from export covering nearly 40% of the world market for wind turbines. The direct employment in Danish wind industry is 6,600 people. Including sub-suppliers, the total employment related to wind industry is estimated at around 21,000 people.

Today, wind turbines are the third largest Danish export industry with significant contributions both to the balance of pay and to the global environment. This is in striking contrast to the pessimistic evaluation of the wind industry potential by engineers from Danish utilities and the nuclear establishment 20 years ago (Beuse et al., 2000).

Offshore Wind Farms in Danish Waters

Offshore wind farms are considered as a promising solution in relation to site constraints on land for countries with long coastlines and shallow waters like the UK, Ireland, Denmark, Sweden and Finland. Other countries with long coastlines like France, Portugal, Italy and Greece may have problems with deep waters close to the shore.

The first offshore wind farm in the World was made operational in September 1991 at a site northwest of the island of Lolland in the Baltic Sea. The wind farm consists of eleven 450 kW turbines positioned in two rows at water depths between 2 and 6 meters. The distance from shore varies from 1.2 km to 2.4 km, while the distance between turbines is about 300 meters.

The second offshore wind park was made operational in October 1995. It is sited at Tunø Knob in the sea between Jutland and the island of Samsø. The total capacity is 5 MW based on ten 500 kW turbines. A special investigation concerning the impact on bird habitats has been carried out in connection with the Tunø Knob project. This problem has turned out to be negligible.

Since that a number of Danish offshore wind farms have been installed as indicated in Table 2.

Year	**Place**	**Rated capacity**	**Number of turbines**	**Total capacity**
1991	Vindeby	450 kW	11	5 MW
1995	Tunø Knob	500 kW	10	5 MW
2001	Middelgrunden	2 MW	20	40 MW
2002	Horns Reef	2 MW	80	160 MW
2003	Rødsand	2.3 MW	72	165.6 MW
2003	Paludans Flak	2.3 MW	10	23 MW
2003	Rønland	2/2.3 MW	8	17.2 MW
2003	Frederikshavn	2.3/3 MW	4	10.6 MW
2003	Grenaa Harbour	2.75 MW	3	8.25 MW

Table 2. Offshore and near-coast Danish wind farms.

There was an agreement between the previous Danish social-democratic government and Danish utilities that they shall establish five wind farms each with a capacity of 150 MW before year 2008.

The sites for these five offshore farms have been decided and the first farm was in operation in late 2002 at Horns Reef in the North Sea. With its installed capacity of 160 MW it was the largest offshore wind farm in the world. The farm is expected to produce at least 0.6 TWh in an average wind year corresponding to at least 3750 hours at rated capacity. The salty environment in the North Sea has, however, given rise to a number of technological problems for the offshore farm at Horns Reef. After replacement of sensitive parts and extra precautions against corrosion these problems seem to have been solved – but at a high cost.

In 2003 number two of the planned large offshore wind farm was installed in the Baltic Sea at Rødsand 10 km south of Nysted city on the island of Lolland. This wind farm has not had the same technological problems as the Horns Reef farm.

After the change of government in Denmark in December 2001 the fate of the last three of the planned offshore farms has been uncertain. This has subsequently been resolved by an agreement in the Danish parliament in March 2004 including the large majority of the

political parties. According to this agreement two new offshore wind farms each of 200 MW total rated capacity shall be installed before 2007 based on a tender procedure. The tender is supposed to include favourable conditions in relation to grid connections and guaranteed tariffs. The first tender for a new 200 MW wind farm at Horns Reaf in the North Sea has resulted in a tariff of 0.53 DKK/kWh (7.1 eurocents/kWh).

Conservative evaluations have concluded that there exists a total potential for offshore wind electricity production in Danish waters of at least 20 TWh per year, corresponding to nearly two thirds of the electricity consumption foreseen in year 2030. Thus, the technical wind resources do not constrain the fulfilment of the target for wind power in Denmark.

Shift in Economic Support Scheme

A new Danish energy act was confirmed in June 1999 which introduced a shift from the previous feed-in scheme to a proposed special market for trade in green certificates in combination with consumer quotas for green electricity specified by the government. In this model RES-E producers would receive a tariff consisting of the market price for electricity plus the selling price of the green certificate. The Danish government was inspired to make this shift by an expectation that the feed-in scheme would not be accepted by the EU Commission in the long run where the Commission would prefer a scheme with more market features (Danish Energy Authority, 2001). Decisions by the EU Commission in December 2005 have, however, postponed a harmonization of national support schemes, until more experience has been obtained in practice in relation to the different schemes. Thus, the Danish policy decision in 1999 was premature and based on wrong assumptions in this context.

The trading of green certificates was originally planned to start in January 2000, but owing to a number of complications related to the operational principles of the system including high transaction costs at a small national market, the Danish government has postponed the starting date of trading several times. It now appears that the trading of green certificates in Denmark is postponed into an uncertain future. As a consequence of this, a complicated set of transitional rules for RES-E has been introduced in the Danish system (Danish Ministry of Economy and Trade, 2003; Meyer and Koefoed, 2003).

The Danish transition from the original feed-in scheme to the planned certificates trading model has introduced so much uncertainty for private wind power investors that installation of new land-based capacity dropped from above 600 MW in 2000 to about 100 MW in 2001. This down-word trend has continued in the following years except in 2002 where a 160 MW offshore wind farm was installed at Horns Reef in the North Sea. The stagnation has been reinforced by the market oriented energy policy of the incoming conservative-liberalistic government in 2001 as illustrated in Fig. 2. Danish wind energy producers are now receiving the lowest price among the old 15 Member States of EU.

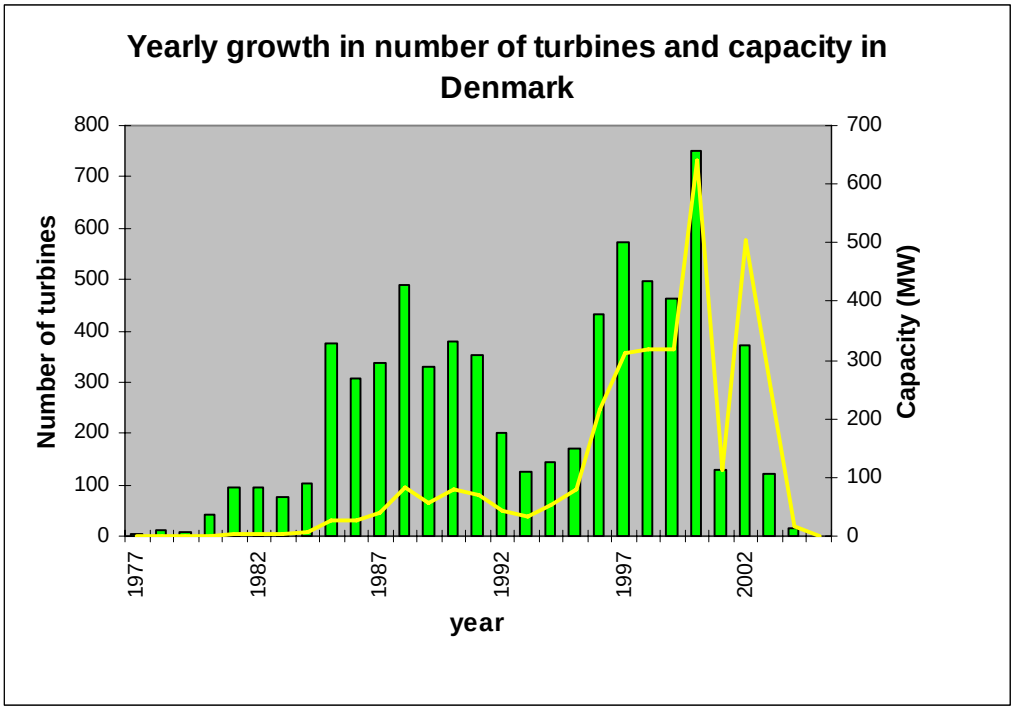

Figure 2. Yearly growth in number of turbines in Denmark (columns) and annual installed capacity (curve) from 1977 to 2004.

The net increase of wind capacity in 2005 and the first three months of 2006 has been close to zero. This is a striking illustration of the influence of national energy policy.

SWEDISH WIND ENERGY POLICY

The Swedish energy policy has been very different from the Danish policy both in relation to choice of technology and in relation to organisation and funding principles. From the seventies the Swedish government and Swedish turbine manufacturers have focused on large machines (larger than 1 MW) with two blades. At the same time the governmental wind energy policy has been expressed in vague terms with no precise indications of the operational tools.

The economic government support in Sweden was mainly used to develop and demonstrate two large turbines with a rated capacity of 2 MW and 3 MW owned by the utilities Vattenfall and Sydkraft. These machines never reached the state of mass production. The Swedish government tried to place the responsibility for the national wind power expansion in the eighties with some of the large utilities but they were not committed to this job at that time and the total installed wind capacity in Sweden was less than 7 MW in 1988. In contrast to this policy, the Danish development was based on a relatively large number of private entrepreneurs marketing small turbines and systematically increasing the turbine size as learning experience was gained.

Another barrier for the Swedish development has been the complicated, slow and bureaucratic local permit procedures. The Swedish legal system does not allow legally

binding national or regional plans for wind power expansion. Instead general guidelines have been used with the first one from 1995 and with subsequent improvements in 2002 and 2003.

As a result of the different policies the market development for wind came much later in Sweden than in Denmark and the installed wind capacity in Sweden is still much smaller than in Denmark as illustrated in Fig. 3 – despite comparable wind potentials in the two countries. In the spring of 2006, however, Mona Sahlin, Swedish Minister for Sustainable Development has announced that the Swedish government's aim is to free the nation's economy of fossil fuel use by 2020. This ambitious goal would involve a rapid implementation of more RES such as wind and biomass.

A detailed analysis of the Swedish development from 1975 to 2000 has been given by Åstrand and Neij (2006). A summary of the main points of Swedish wind development is given in the following.

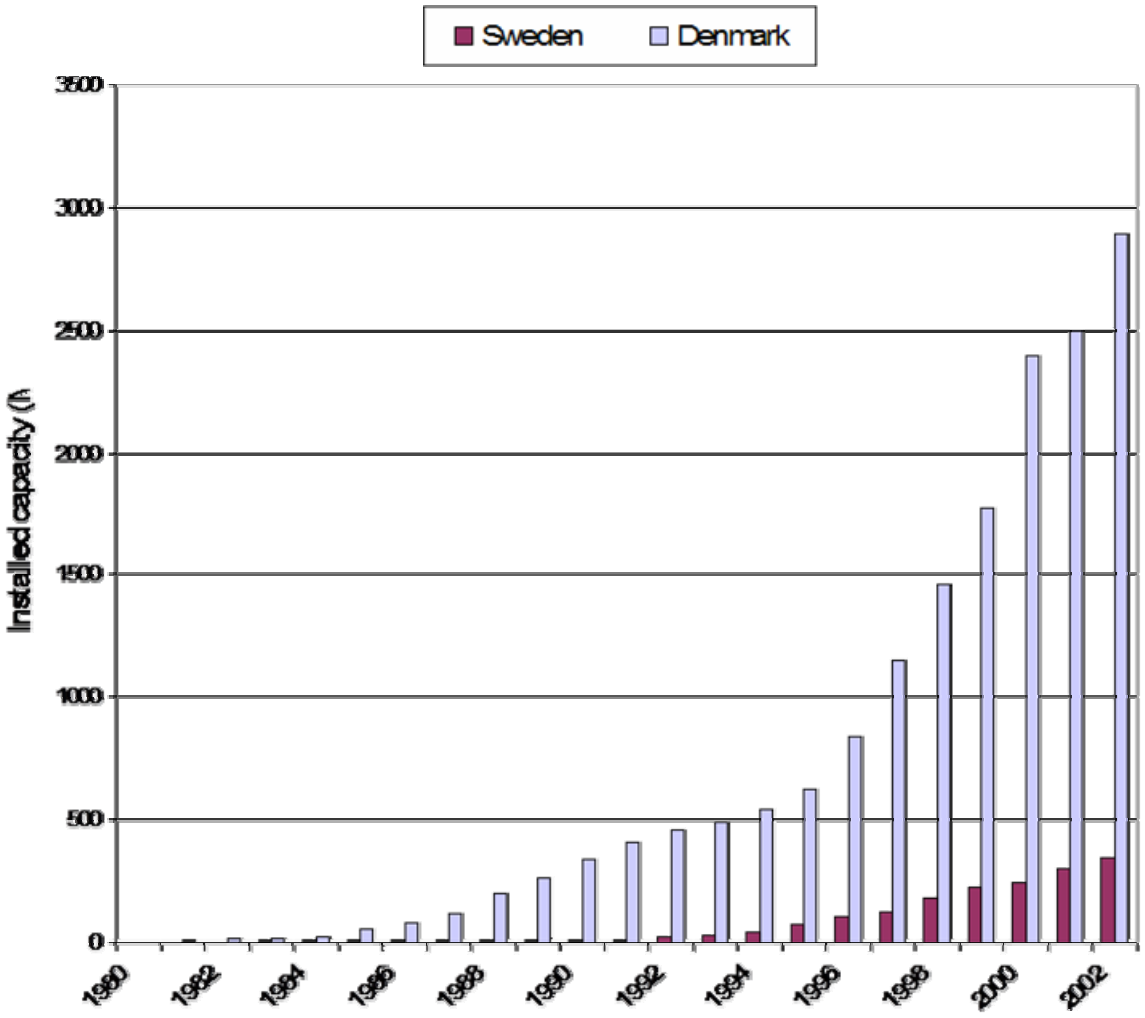

Figure 3. Development of installed wind capacity in Sweden and Denmark from 1975 to 2000 (from Astrand and Neij, 2006).

Economic Support Schemes

In 1991 an investment subsidy of 25 % was introduced which was increased to 35 % in 1993. At the end of the first period of this scheme in 1996 a capacity of 110 MW (350 wind turbines) had been installed.

A second period with an investment subsidy of 15 % was introduced from 1998 to 2002 with the goal of creating an annual increase of 0.5 TWh of wind electricity. In 2002 the installed capacity had increased by 290 MW (374 turbines) and the Swedish government confirmed the same year a goal of a yearly production from wind power of 10 TWh by 2015.

A new support scheme for wind power and other RES was introduced in 2003 based on trading of green certificates. The official goal was to increase the yearly electricity production from RES to 10 TWh in 2010. The first experiences with this scheme, however, did not fulfil the expectations. This has mainly been due to lack of stable and long-range framework conditions for the scheme.

The responsibility of promoting Swedish wind power has been divided between a number of different institutions until 2005 when support for research, development and demonstration was centralized at the Swedish Energy Authority STEM. The support includes a special budget for offshore wind power and for wind power in mountain areas.

A modified certificate trading scheme will be introduced in 2006 in order to accelerate the promotion of electricity based on RES. The new scheme will be running until 2030 and the RES plants are given 15 years contracts for their certificates.

In order to increase the market for trading of green certificates, negotiations between Sweden and Norway concerning a common certificate market have taken place in recent years. The common market was planned to start in January 2007. The new Norwegian government has, however, decided in the spring of 2006 to discontinue these negotiations and to go for another type of support scheme for RES in Norway. This may imply a certain set-back for the Swedish certificate system.

At the end of 2005 the total installed wind capacity in Sweden was about 500 MW and Swedish wind power produced nearly 1 TWh of electricity during 2005 which is less than 1 % of the total electricity consumption. It is estimated by the Swedish government that 4,000 MW of installed wind capacity will be needed in order to fulfil the goal of 10 TWh of electricity from wind by 2015 (Swedish Government Proposition, 2006). The government also proposes that the goal for the total contribution from RES is increased to 17 TWh by 2016 which may require more than 4,000 MW of wind power.

SPANISH WIND ENERGY POLICY

The first state support for wind power in Spain was connected to a law for energy conservation from December 1980. This law regulated the principles for grid connection of wind turbines and introduced an investment support for RES of up to 30%. It also established a tariff for wind electricity to be regulated on an annual basis.

The first grid connected wind farm in Spain consisting of five 120 kW turbines was installed in 1984 by the Spanish utility ENDESA.

A specific plan for the promotion of renewable energy systems in Spain was implemented in 1986. This plan focused on R&D and did not define any national RES targets. It was not until 1991 that such targets were set up in the "Energy Savings and Efficiency Plan 1991-2000" (PAEE) together with earmarked public funding for RES. As a result the total installed wind power capacity in Spain was less than 7 MW by 1990. At the end of 1995 this number had only increased to a little over 100 MW.

However, in the following decade Spain experienced one of the highest growth rates in the world and at the end of 2005 Spain has an installed capacity of over 10,000 MW, only surpassed by Germany. The development of accumulated wind capacity in Spain from 1990 to 2005 is illustrated in Fig. 4.

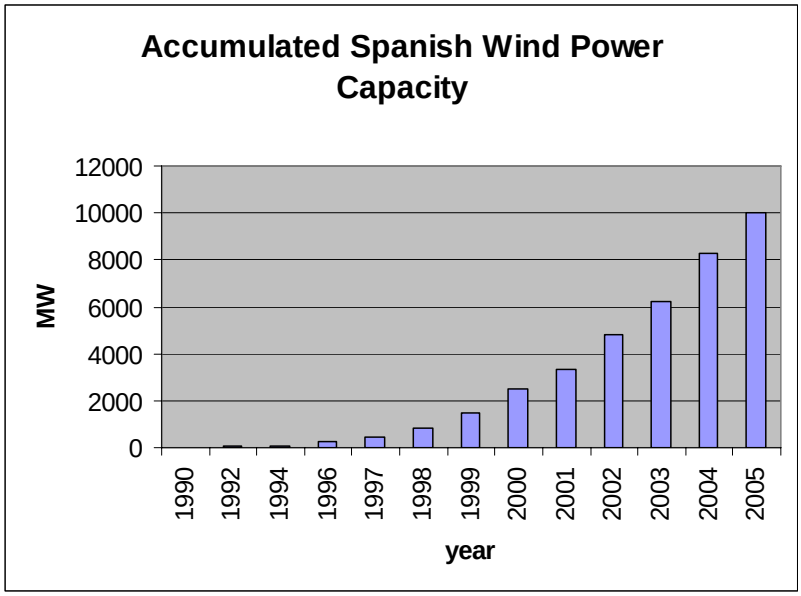

Fig. 4. Development of accumulated wind power capacity in Spain from 1990 to 2005.

Details of the Spanish promotional schemes for wind energy are given by Bechberger (2006). The main points are summarized in the following.

Key Actors in Promotion of Spanish Wind Power

The two main governmental actors in promotion of wind power in Spain have been the *Institute for Energy Diversification and Saving* (IDAE, established in 1984) and the *National Energy Regulatory Authority* (CNE, established in 1998).

IDAE as a governmental agency has had financial autonomy to implement a number of economic support schemes for RES including investment subsidies, soft loans and through capital participation in RES companies. IDAE has prepared the national "1999 Policy Plan for the Promotion of Renewable Energy" (PFER) and an updated version of the plan in 2005 (PER).

The main goal of CNE is to ensure effective competition between energy providers and to protect consumer interests.

In addition, the regional governments of some of the Autonomous Communities (ACs) have played an important role. They have the authority to decide the administrative procedures for RES plants below 50 MW and a number of the ACs have very favourable wind regimes.

The promotion of RES has also been supported by associations representing developers of RES plants. The largest one is the "Association of Renewable Energy Producers" (APPA, established in 1987) which now has about 300 company members. APPA has played an important role through political lobbying and media campaigns for improved economic support for RES.

A special association for the wind energy interests of large corporations was established in 2002 and now operates under the name of "Wind Energy Enterprise Association" (AEE). The second largest Spanish power utility, Iberdrola, has recently invested strongly in wind energy and now owns about 3,000 MW of wind capacity.

Another driving force for wind power has been the Spanish equipment manufactures, where Gamesa Eólica is the most important one with 15 production sites in Spain. In 2004 the company recorded sales of about 1.6 GW of wind power which made it the second largest manufacture of wind turbines on the world market with about 18 % share of installed wind capacity in 2004.

Planning of Wind Power Development in Spain

As mentioned above the first comprehensive energy plan including targets and funding for RES was the PAEE from 1991. The wind target for year 2000 was a total installed capacity of 175 MW. The actual installed capacity by year 2000 turned out to be about 2,500 MW! This may be a world record in underestimation of the possibilities. As the underestimation became obvious during the nineties new and more ambitious plans were set up.

In 1999 the Spanish parliament approved a special "Policy Plan for the Promotion of Renewable Energy" (PFER) with a target which would almost double the share of RES in primary energy consumption from 6.3 % in 1998 to 12 % in 2010. PFER was the first Spanish planning document solely for the promotion of RES. It included technology-specific targets and incentives for the market diffusion of each RES technology, e.g. fiscal instruments as reduction of corporate taxes. For wind energy the target for installed capacity was about 9 GW in 2010 as compared to 835 MW in 1998.

Again the rate of annual wind power installation turned out to be higher than expected and the 2010 target was surpassed already in 2005. At the same time, the total energy consumption in Spain was increasing at a higher rate than expected. As a consequence the wind target for 2010 was updated in September 2002 from 9 GW to 13 GW by 2011.

However, the target increases have not ended by that. At the end of August 2005, the Spanish government has approved a new RES promotion plan named "RES Plan 2005-2010" (PER). According to this plan wind capacity should increase to 20 GW by 2010 corresponding to about a doubling compared to 2005. This target is supported by favourable economic schemes as described in the following. There are interests in the wind power industry to increase this target further, but in order to accept that, the System

Operator will likely demand strong technical requirements for wind turbines in relation to overcoming voltage dips on the grid and to entering into a delegated dispatch center.

Support Schemes for Wind Power

Since 1980, the development of electricity from renewables (RES-E) in Spain has been supported by different schemes including guarantees of grid connection and purchase contracts with utilities at a certain guaranteed price. These concepts were first introduced through the 1980 Energy Conservation Law. The price was not specified in the law but was set annually by Order of the Ministry of Energy and Industry and there was no regulation on the length of contracts. These uncertainties for the investors may be an essential part of the explanation of the slow rate of increase in Spanish wind capacity in the eighties.

A new electricity law was adopted in 1994 (Ley 40/1994) which reduced some of these uncertainties. The new law introduced a minimum period of five years for the purchase contracts and the price were to be set my means of a governmental Royal Decree (2366/1994) which reduces the uncertainty compared to a price set by Ministerial Order. In the period from 1995 -1998 the tariff has been between 6.5 and 6.9 eurocents/kWh.

After the adoption of the EU directive in 1996 on liberalisation of electricity markets new market features were introduced in the Spanish electricity laws. Electricity producers based on RES could choose between three different schemes:

1) The electricity could be sold through a pool system. This was obligatory for all generators with plant capacities above 50 MW. The payment in this system was regulated by the so-called “ordinary regime”.
2) RES generators with plants below 50 MW have a second trade option under the so-called “independent system” where the generators are free to set up bilateral contracts with a distributor, supplier or qualified consumer. However, this system does not offer government guarantees on grid connection, purchase contracts and price.
3) A third trade system is referred to as the “special regime”. This regime guarantees the right to grid connection, a standard five years purchase contract and a defined (revisable) price per delivered kWh. Under the special regime the producers can choose between a “market-based option” and a “revisable tariff option”.

In the market-based option producers are paid the pool price plus an environmental bonus.

A Royal Decree from the end of 1998 (2818/1998) introduced different tariffs and environmental premiums for different green technologies. For wind power the basic tariff has varied between 6.2 and 6.6 eurocents/kWh in the period from 1999 to 2004, while the environmental premium varied between 2.7 and 3.2 eurocents/kWh during the same period.

The combination of favourable feed-in tariffs and the ambitious official goals for the coverage of electricity demand by wind power have given potential investors a high degree of security. This is a significant factor in the high growth rate of Spanish wind capacity from the end of the nineties. The installed wind capacity of about 830 MW by the end of 1998 had grown by nearly a factor of 10 by the end of 2004. By the end of

2005, the installed capacity has exceeded 10,000 MW covering 7.8 % of Spanish electricity demand.

Since 2004 the Spanish energy policy in relation to RES has been increasingly market oriented. This is manifested by a Royal Decree from 2004 (436/2004) by its incentives for RES producers to join the national energy pool. According to this Royal Decree those producers that choose the market option will receive an economic "market bonus" on top of the market price and the green bonus. The green bonus is 40% and the market bonus 10 % of the average consumer price.

The Royal Decree also introduces an element of disincentive in the form of a penalty for missing the announced production by more than 20%. This applies to plants with a capacity above 10 MW. At the end of 2005 about 90 % of the Spanish wind power producers had chosen to join the pool system. This may be explained by the fact that the market bonus is expected to more than compensate for possible penalties. In addition, the high pool price in 2005 has resulted in clearly higher total income per kWh for producers in the market system than for producers with a fixed feed-in tariff.

With increasing penetration of wind power in the Spanish supply system there is a need to include wind power plants in the stabilization of the grid system. New regulations are in preparation which will require wind power plants to ride through abrupt voltage drops in the grid. Another requirement planned for wind power plants larger than 10 MW obliges these plants to join a regional pool of producers which will supply the grid operator with frequent information about the regional wind electricity production. The regional pool administrator shall also inform the grid operator about the regional production prognoses. This is expected to reduce the need for reserve capacity.

A special proposal for support of offshore wind farms has been published in February 2006 based on a tender system. This proposal has been criticised by governmental institutions and organisations of wind producers with reference to less successful experiences in other European countries (e.g. the UK) and to a restrictive cap for the total tariff for the offshore wind farm.

It should be mentioned that a similar tender system has been used in Denmark in 2005 in connection with the 200 MW offshore farm at Horns Reef in the North Sea. But this tender was operating without a cap requirement in contrast to the Spanish proposal.

COMPARISON OF WIND ENERGY DEVELOPMENT IN DENMARK, SWEDEN AND SPAIN

Denmark, Sweden and Spain have had quite different energy policies in relation to wind power. In a short statement Denmark has pioneered the modern phase of wind power based on technological traditions going back to the 1890s, Sweden has only shown a modest interest in wind power until the last few years, while Spain has experienced a slow growth in installed wind capacity until the late nineties where the growth in capacity took off with exceptional high rates. The factors influencing these striking differences are discussed in the following.

Driving Factors in Denmark

In addition to the long historical tradition for wind power in Denmark, the following factors are assumed to have had significant influence on the Danish development in the modern phase of wind power:

- A technological strategy based on a step-by-step increase in turbine capacity starting from the low end (around 20 kW). This permitted a low-cost learning curve in contrast to the case in countries like Sweden and Germany with early emphasis on turbines at MW level.
- Broad public support based on alliances between NGOs and independent energy experts at Danish universities.
- Support in the mid-seventies from official institutions like the Danish Academy of Technical Sciences. This promoted the credibility of wind power resulting in early state support for research, development, demonstration and marketing, especially from the beginning of the eighties.
- Establishment in the late seventies of a test and certification facility at Risø National Laboratories, which included pioneering work on wind atlases.
- Local ownership of turbines, frequently organized in co-operatives. This eliminated most local resistance against wind turbines.
- Establishment of a strong industrial section for production of wind turbines. This started with many small producers in the seventies and eventually stabilized the industrial development with a few large production plants in the nineties.
- Far-sighted official energy plans from the early nineties with emphasis on sustainable energy development and with targets for wind power. Together with favourable economic feed-in schemes this has accelerated the penetration of land-based wind power in the nineties.
- State support for offshore wind power resulted in the world's first large offshore wind farms in the early nineties.

The combination of these driving forces can explain that Denmark in spite of its small population has had a central role for the development of global wind power from the seventies to the end of the century. During this period both the absolute amount of installed wind power capacity and the relatively coverage of national electricity consumption by wind have placed Denmark among the leading countries in the world.

This is changing after the introduction of the liberalised electricity market in the EU and the change of Danish government in 2001. The incoming conservative-liberalistic government has changed the Danish energy policy radically. The development of RES is now mainly left with the commercial market and most of the previous government funding for RES has been abolished. As a result the penetration of wind power in Denmark has stagnated in the last few years.

In 2005 new capacity of only 22 MW was installed, while 18 MW of capacity was taken out of production. This trend has continued during the first three months of 2006 with no new installed capacity and deployment of 1.9 MW of wind capacity.

The ups and downs of Danish wind power development clearly illustrates the central importance of the official national energy policy.

Barriers for wind power in Sweden

In contrast to the Danish case, the Swedish energy policy from the seventies on has focused on development of large turbines at MW scale, and the promotional responsibility was left with the large utilities. Neither of these choices has been favourable to the penetration of wind power in Sweden. The market was not ripe for MW turbines before the end of the nineties and the large utilities were not especially interested in wind power.

The background for the Swedish energy policy may be found in the industrial structure where Sweden, in contrast to Denmark, is characterized by large industrial units producing large scale technologies like cars, airplanes and nuclear plants.

The main factors explaining the relatively slow Swedish implementation of wind power may be summed up as follows:

- Questionable choice of turbine technology from the outset.
- No strong driving forces for wind power.
- No successful national production of wind turbines.
- Bureaucratic procedures for instalment of wind power.
- More focus on biomass than on wind.

Those barriers for the penetration of wind power in Sweden may, however, be reduced by recent initiatives from the Swedish government, including streamlining of the certificate trading system and increased economic support for the promotion of RES. The budget for the Swedish Energy Authority (STEM) has thus been increased by about 80% from 2005 to 2006. STEM also administrates a special budget of about 9 million euros for promotion of offshore wind parks. In addition, the Swedish utility Vattenfall is planning large investments in wind power in the coming years.

Barriers and Driving Forces for Wind Power in Spain

The Spanish energy policy has been characterized by many changes in the support schemes for RES. The resulting uncertainty for investors may be part of the explanation for the late take-off of Spanish wind power. Other factors are needed, however, in order to explain the exceptional high growth in installed capacity since the late nineties. The following summary is an attempt to explain this special development:

- Short-range and varying support schemes have created uncertainties for potential investors and have delayed the exploitation of Spanish wind potential until the late nineties.
- There were no significant national production of wind turbines in Spain until the late nineties. This was changed especially by Spanish Gamesa Eólica which is now one of the largest turbine producers in the world.

Gamesa now covers the whole chain including manufacturing of turbines, ownership and operation of wind farms and trading in the pool.

- The favourable Spanish feed-in system introduced in the late nineties has given strong incentives for potential investors and developers.
- A number of the governments of Autonomous Communities have supported the implementation of wind power.
- One of the largest Spanish utilities, Iberdrola, has invested heavily in wind power and has a close co-operation with Gamesa Eólica.
- The increasing electricity consumption in Spain has made more room for wind power than e.g. in Denmark and Sweden with less growth in electricity demand. As a consequence Spanish utilities have been less sceptical concerning the penetration of wind power.
- The increasing dependence on imported fuels and problems with fulfilling the Kyoto commitments have prompted the Spanish government to promote renewables and especially wind power.

CONCLUSIONS

Although Denmark, Sweden and Spain all have good wind power potentials, the exploitation and development of this potential have been quite different in the three countries. One important factor in this connection is the official energy policy of the country involved. This is clearly illustrated by the Danish development where a recent shift in government and energy policy has discontinued the successful penetration of wind power in Denmark. Reference to a possible saturation of acceptable land based sites in Denmark can only partly explain the stagnation of Danish wind power.

Concern about global warming, an approaching oil peak and energy supply security in general has prompted many European governments and a number of European utilities to give high priority to renewables and especially wind. As an example, recent Danish utility scenarios support a coverage of electricity demand by wind of up to 50 % before the middle of this century. This will require new system thinking where wind turbines actively support the overall system balance and are able to ride through voltage drops in the grid and other irregularities. The development of such wind power technologies is presently taking place and demonstration on large scale systems should be supported by governments.

ACKNOWLEDGEMENTS

Thanks are due to support from the DESIRE project sponsored by the EU Commission. Special thanks are due to Dr. Carlos Madina for personal information in relation to the Spanish energy development.

REFERENCES

Bechberger M. 2006. Why renewables are not enough: Spain's discrepancy between renewables growth and energy (in)efficiency. Forthcoming in: Lutz Mez (ed.) Green Power Markets: Case Studies and Perspectives. Multi-Science Publishing. Brentwood, UK.

Beuse E, Boldt J, Maegaard P, Meyer NI, Windeleff J and Østergaard I. 2000. Renewable Energy in Denmark – History of 25 Years of Growth 1975 to 2000 (in Danish). OVE Publishers. Aarhus, Denmark.

Blegaa S, Hvelplund F, Jensen J, Josephsen L, Linderoth H, Meyer NI, Balling N. and Sørensen B. 1976. Sketch of Alternative Danish Energy Plan (in Danish). OVE Publishers. Copenhagen, Denmark.

Blegaa S, Josephsen L, Meyer NI and Sørensen B. 1977. Alternative Danish Energy Planning. *Energy Policy*: 87-94.

Damborg S. 2003. Public Attitudes Towards Wind Power (in Danish). Danish Wind Industry Association. www.windpower.dk

Danish Academy of Technical Sciences. 1975. Wind Power (in Danish). Copenhagen. Denmark.

Danish Academy of Technical Sciences. 1976. Wind Power 2 – Proposal for an Action Programme (in Danish). Copenhagen. Denmark.

Danish Energy Authority. 1986. Large Windmills in Denmark. Copenhagen, Denmark.
Danish Energy Authority. 2001. Status of Green Certificate Market Development. Copenhagen, Denmark.

Danish Ministry of Economy and Trade. 2003. Announcement on Law Concerning Electricity Supply. Law No. 151, March 10, 2003. Copenhagen, Denmark.

Danish Ministry of Energy.1981. Energy Plan 81. Copenhagen, Denmark.

Danish Ministry of Energy. 1990. Energy 2000 – A Plan of Action for Sustainable Development. Copenhagen, Denmark.

Danish Ministry of Environment and Energy. 1996. Energy 21 – The Danish Government's Action Plan for Energy. Copenhagen. Denmark.

Danish Ministry of Industry and Commerce. 1976. Danish Energy Policy 1976 (in Danish), Copenhagen, Denmark.

Danish Wind Industry Association. 1993. Attitudes on Wind Power (in Danish). Ringkøbing, Denmark.

European Communities. 1997. Directive 96/92/EC of the European Parliament and of the Council of 19. December 1996 conerning common rules for the internal market in electricity. *Official Journal of the European Communities.* January 30.

Grubb MJ and Meyer NI. 1993. Wind Energy: Resources, Systems, and Regional Strategies. In *Renewable Energy: Sources for Fuels and Electricity*, edited by T.B. Johansson, H. Kelly, A.K.N Reddy and R.H. Williams. Washington D.C. Island Press: 157-212.

Hvelplund F, Illum K, Meyer NI, Nørgård JS and Sørensen B. 1983. Energy for the Future (in Danish). Borgen Publishers. Copenhagen, Denmark.

Lund P, Cherian S and Ackermann T. A Cell Controller for Autonomous Operation of a 60 kV Distribution Area. 2006. *International Journal of Distributed Energy Resources* 2: 83-100.

Meyer NI and Koefoed AL. 2003. Danish Energy Reform: Policy Implications for Renewables. *Energy Policy* 31: 597-607.

Meyer NI. 1995. Danish Wind Power Development. *Energy for Sustainable Development* 2: 18-25.

Petersen EL, Troen I, Frandsen S and Hedegaard K. 1981. Wind Atlas for Denmark. Risø National Laboratory. Roskilde, Denmark.

Swedish Government Proposition. 2006. Environmental Benign Electricity with Wind Power – Means for a Sustainable Wind Energy System (in Swedish), Proposition 2005/06:143. Stockholm, Sweden.

Åstrand K and Neij L. 2006. An assessment of governmental wind power programmes in Sweden – using a systems approach. *Energy Policy* 34: 277-296.