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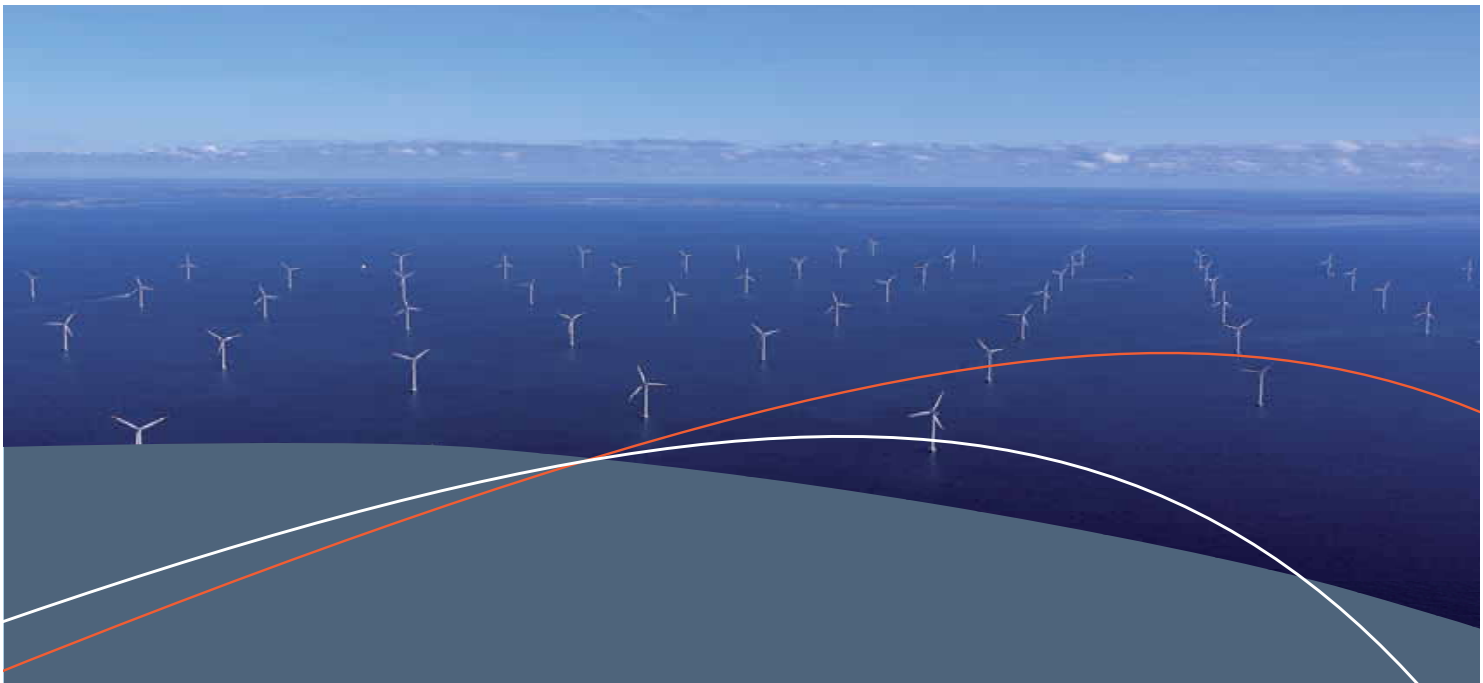

Offshore Wind Power

Danish Experiences and Solutions

DANISH ENERGY AUTHORITY

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- Danish Experiences and Solutions
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The photo on the first page shows the world's largest offshore wind farm, Nysted, with an installed capacity of approximately 165 MW.

The photo from 2001 on the last page is of the centre of Copenhagen with the Middelgrunden Wind Farm in the background.

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PREFACE

FROM WINDMILLS TO WIND POWER PLANTS

Denmark has come a long way since the 1980s, when most electricity consumption was based on coal and when the acidification of forests and bodies of water was the predominant theme in the environmental debate. Today, renewable energy provides 28% of Danish electricity, including 19% from wind power. Wind turbines are produced by large industrial companies that have created growth and jobs in Denmark.

It is the Government's intention that expansion of wind power in Denmark, to the greatest possible extent, shall take place according to market-based framework conditions. Expansion of wind power according to market demand will be by far the most effective means of ensuring long-term conversion of the supply system to renewable energy use. It will also provide the best leverage for our wind power industry to excel in export markets.

Wind power is increasingly competitive vis-à-vis traditional generating technologies. With higher oil prices and high CO_2 allowance prices, the amount of renewable energy in Danish electricity supply could reach 80% by 2025. A significant part of the expansion will occur in the form of large, offshore wind farms. In the offshore environment, wind resources are better; offshore, it is also easier to set up wind turbines in harmony with the surrounding environment.

When the wind blows, wind power naturally produces electricity. Ensuring that our electricity system is able to accommodate the expected increasing quantities of wind power is a major challenge to system operation. The Government intends to develop the electricity system and to establish flexible management of electricity production and consumption so that the increasing quantities of wind power are best exploited.

Target-oriented regional planning and identification of potential locations for offshore wind farms must ensure a role for new wind power.

This publication describes Danish experiences with offshore wind power and discusses the challenges and problems in relationship to the grid, to the economy and to the environmental issues that Denmark has dealt with in the last twenty-five years.

Flemming Hansen
Minister of Transport and Energy

SCENARIOS FOR RENEWABLE ENERGY IN THE SUPPLY OF ELECTRICITY

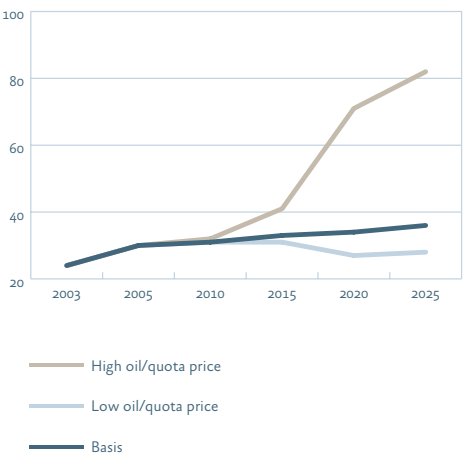


Figure 0.1: The Danish Energy Authority's alternative scenarios, developed for Energy Strategy 2025, show that market strength can give rise to a very high percentage of renewable energy in electricity supply if oil prices and CO_2 allowance prices rise to a high level.

OFFSHORE WIND POWER POLICY IN DENMARK

Photo: Energi E2

Nysted Offshore Wind Farm south of Lolland will have a neighbour at 200 MW at Rødsand within the next five years.

The Danish Energy Authority implements the government's offshore wind power policy. The basis is that the best way to ensure a role for renewable energy in the future is an effective market system. Market-oriented production can result in a better correlation between supply and demand and producers will be better able to make use of system capacity.

To the greatest extent possible, continued expansion with offshore wind power must therefore take place according to market conditions. The guiding principle for Danish offshore wind power policy is thus to ensure stable, clear frameworks for future investors in offshore wind farms. With respect to supply security, economic growth and the environment, it is essential that Danish knowledge concerning offshore wind power remains a position of strength for Denmark.

The positive experience gained in Denmark with introducing large quantities of wind power to the grid must be improved and barriers to market access must be eliminated. We must ensure that our invaluable experience of the environmental impact of offshore wind power is operationalised so that other countries are able to benefit from it. Finally, it is essential that locations can be found for future offshore wind farms in a maritime environment that is under continual increasing pressure.

Ensuring that the electricity system is able to handle the expected large new quantities of wind power is a major challenge. The fulcrum for continued successful development with new offshore wind farms will therefore be the integration of the electricity produced into the electricity-supply system.

A precondition for the establishment of future offshore wind farms is the existence of viable locations. The Minister of Transport and Energy has requested the Danish Energy Authority to elaborate an overview of such possible future new locations. A clear overview of the situation will encourage future investors and proprietors to initiate new offshore wind power projects.

Developments in the wind power industry indicate that the global market will continue to grow, creating major potential for Danish industry. The Government has emphasised that this potential must be exploited and converted to economic activity.

A focused initiative in research, development, demonstration and training is fundamental to creating the right framework for innovation and growth. The Advisory Council for Energy Research and the Danish Energy Authority have proposed the drafting of an all-encompassing, cross-disciplinary energy research strategy. Particular weight must be given to the relationship between research and development efforts, energy-sector enterprises and financial institutions, along the entire chain from research to trade.

FACT BOX

POLITICAL AGREEMENT ON WIND ENERGY AND DECENTRALISED HEAT AND POWER, ETC.

On 29 March 2004, the Government entered into energy-policy agreements with a large majority in Parliament. One of these agreements concerns wind energy and decentralised heat and power, and was entered into with the Social Democrats, the Socialist People's Party, the Social Liberals and the Christian Democrats. The agreement concerns, among other things, future expansion of Denmark's offshore wind farms.

"With a view to promoting the long-term security of energy supply and a continued diversification of supply to several sources of energy and to promote the continued development of wind power technology the partners have agreed to secure the basis for the installation of two offshore wind farms of 200 MW each. Establishment will be implemented through tender procedures aimed at exploiting areas at Horns Rev and on Omø Stålgrunde" (subsequently it was decided to locate the second wind farm at Rødsand – ed.).

The two new parks, with a total construction investment of DKK 4.5 billion (EUR 600 million), will be capable of supplying electricity to 350,000-400,000 households, equivalent to approx. 4 per cent of the total Danish electricity consumption.

STATUS OF WIND POWER EXPANSION IN DENMARK

When the first energy crisis struck in the middle of the 1970s, exploitation of renewable energy as a replacement for fossil fuels to produce energy became very attractive. Ambitious wind-power development programmes were therefore launched in several countries. In the USA, Japan, Germany and Sweden in particular, the aeronautical and turbine industries were encouraged by means of public research and development grants to come up with effective, MW-capacity wind turbines.

DOUBLE-EDGED DEVELOPMENT STRATEGY

In Denmark, on the other hand, a double-edged development strategy was adopted.

At the end of the 1970s, with support from the Danish Energy Authority's Energy Research Programme (ERP), power plants focused on developing MW-wind turbines. Although this approach did not lead to direct, industrial mass production of larger wind turbines, the development programme yielded technological knowledge which became available to wind turbine manufacturers through the Risø Research Centre, Denmark's Technical University and the electricity producers.

Concurrently, as of the beginning of the 1980s, support given to installations and advantageous feed-in tariffs for electricity produced by wind turbines led to the creation of a bottom-up market for small, 25-55 kW wind turbines. Gradually growing demand in the domestic market made it possible for a number of relatively small engineering companies to develop industrial mass production of increasingly larger wind turbines, based to a large extent on the technological competence acquired through the power plants' development programme for large wind turbines. The synergy between these two lines of development is an essential background to Danish success with wind turbines. >

Offshore wind farms in operation

1 Vindeby
2 Tunø Knob
3 Middelgrunden
4 Horns Rev I
5 Samsø
6 Rønland
7 Frederikshavn
8 Nysted/Rødsand I

Offshore wind farms in calls for tender

9 Horns Rev II
10 Rødsand II

Figure 2.1: By the end of 2005, eight offshore wind farms are in operation in Denmark and two calls for tender have been made for two new wind farms on each 200 MW. See the table on page 4 for more detailed information about the wind farms already in operation. The map was prepared by the Danish Energy Authority.

Photo: Jan Kofod Winther/SEAS

Vindeby, west of Lolland, was the world's first offshore wind farm. It has 11 450 kW-wind turbines. It provided Danish electricity companies with invaluable experience.

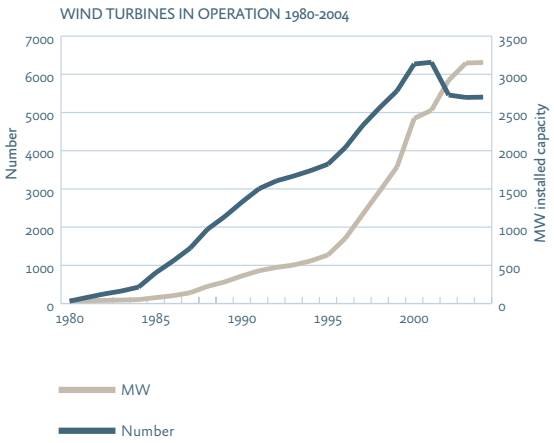


Figure 2.2: Total installed capacity and number of wind turbines 1980-2004, calculated on the basis of the Danish Energy Authority's basic data registry.

Today, wind turbines are produced at an industrial level and the electricity is sold on the market in competition with electricity produced from other types of fuels. With the upscaling to large MW-wind turbines, it soon became attractive to investigate the possibilities for locating wind turbines offshore. Two offshore wind farms at approximately 160 MW were built off the Danish coast. In 2005, a project at Horns Rev was tendered out, with operations expected to begin in 2009. The Danish State has issued a call for tenders for another offshore wind farm, to be built at Rødsand.

RE IN DENMARK AND IN THE EU

Since 1980, more than 6000 wind turbines have been established onshore. During the 2001-2003 period, a re-powering programme scheme led to approximately 1500 smaller wind turbines being replaced by approximately 300 new and larger wind turbines, which together have tripled the capacity. The total number of wind turbines is currently approximately 5300, with a total installed capacity of 3100 MW (see Figure 2.2).

The percentage of renewable energy in Danish electricity supply has increased enormously since the mid-1990s and, in 2004, accounted for approximately 28% of electricity produced, of which wind contributed the largest share (approximately 19%), although waste and biomass also made significant contributions (see Figure 2.3).

In the EU as well, wind turbines account for the relatively strong increase in the production of RE. The installed capacity in EU15 increased by 23% in 2003 to a total of over 28 GW. In an average wind power year, this capacity can generate 60 TWh of electricity, that is, approximately 2.4% of European electricity consumption.

It is particularly in Germany, Spain and Denmark that there has been major growth in the use of wind power and these three countries together account for 84% of EU15's wind power capacity (see Figure 2.4).

Existing Danish wind farms - status as of autumn 2005
More detailed information on calculation procedures can be found on pages 22-23

Name of wind farm	Start-up year	Turbine capacity	Total capacity	Estimated annual production	Owner
Vindeby, Falster	1991	11 450-kW units	5 MW	approx 10 GWh	Energi E2
Tunø Knob, Odder	1995	10 500-kW units	5 MW	approx 15 GWh	Elsam
Middelgrunden, Copenhagen	2001	20 2 MW units	40 MW	approx 95 GWh	Energi E2 + private shareholders
Horns Rev I	2002	80 2 MW units	160 MW	approx 600 GWh	Elsam
Samsø	2003	10 2.3 MW units	23 MW	approx 80 GWh	Samsø municipality and private shareholders
Rønland, Harboøre	2003	4 2 MW units 4 2.3 MW units	17 MW	approx 70 GWh	Private shareholders
Frederikshavn	2003	2 2.3 MW units 1 3 MW units	8 MW	approx 20 GWh	Elsam
Nysted/Rødsand I	2003	72 2.3 MW units	165 MW	approx 600 GWh	Energi E2

MEANS

Since 1980, the Danish framework conditions for expansion with renewable energy have been characterised by a broad political understanding that RE technologies, being new on the market, require special support in order to gain a foothold. Up until 1990, subsidies were provided for 30% of the installation costs. A fixed electricity production feed-in tariff was also introduced and made available until the electricity reform was implemented (part of the liberalisation of the electricity market in 1999), when the fixed feed-in tariff was replaced by a feed-in tariff paid by electricity consumers. The support was provided equally across the country, irrespective of wind conditions, and it was therefore economically advantageous for the private sector to establish wind turbines at the best onshore locations.

Policy goals were set for future expansion with renewable energy. At the political level, it was emphasised that expansion of the country's wind power system had to be well supported at the local level and authorisation was only given to set up privately owned wind turbines if the owners were from the local area concerned. Until the mid-1990s, the main form of ownership was shareholding. Local electricity companies were obliged to carry out the necessary grid expansion, and electricity production from wind turbines was given prioritised access to the electricity grid.

Both regional and local planning authorities were involved in the process of identifying suitable locations and developing wide political support for proposed projects. As of the mid-1990s, thanks to the advantageous conditions, wind power was greatly expanded and the cost to the State for production subsidies increased more or less proportionately. In 1999, this expense was assumed by electricity consumers.

OFFSHORE WIND POWER STRATEGY

Denmark is a small, densely populated country with a relatively long coastline, and its far-reaching ambitions for expanding its electricity system with wind power quickly awoke interest in studying the possibilities for locating wind turbines offshore. The first pilot projects with offshore wind turbines were carried out in the 1990s. They demonstrated that the economy of wind power operation was better than expected and that the environmental impacts were less than feared. >

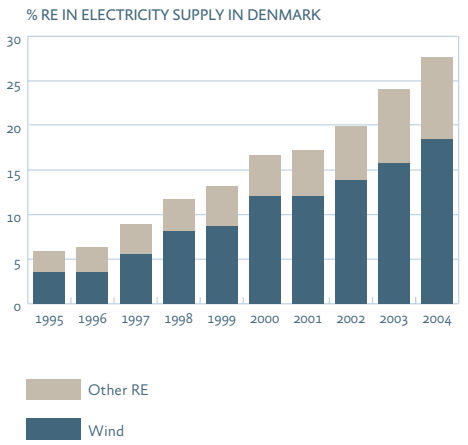


Figure 2.3: Over the last 10 years, wind power has played an increasingly important role in Danish electricity supply and reached 19% in 2004.
Source: The Danish Energy Authority

FACT BOX

WINDMILLS: AN HISTORICAL PERSPECTIVE

Utilisation of wind is a very old energy technology. There have been windmills in Denmark since the 13th century. They have developed from post mills to Dutch mills to Poul La Cours' test mills at the end of the 1800s.

Wind has been used to produce electricity since around 1900. But wind power could not compete with thermal power plants, which used coal and oil, and were used to only a limited extent during the two world wars.

After the Second World War, there was a certain amount of research activity, such as that conducted by Johannes Juul who, in 1951, had a stable, three-winged windmill (the Gedser Mill) built. This was the basis for today's Danish wind turbine design. But wind power could still not compete with coal- and oil-fired thermal power plants, which took advantage of continual technological development and of the relatively low international fuel prices up until 1973.

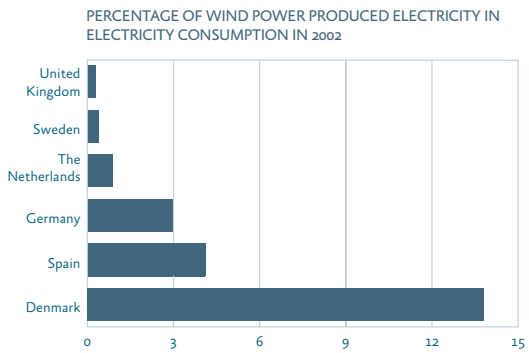


Figure 2.4: shows the percentage of wind power produced electricity in the 5 EU countries in which wind power was most used in 2002. Source: EU Commission

Against this background, the public authorities and electricity companies worked together to analyse the possibilities for large-scale expansion with offshore wind turbines. An action plan (described on page 7) recommended concentrated expansion in a few main areas. The Government then entered into an agreement with the electricity utilities to set up an extensive demonstration programme. The result was the offshore wind farms at Horns Rev and Nysted/Rødsand.

In addition to these two demonstration projects, three near-shore projects have been carried out since 2000.

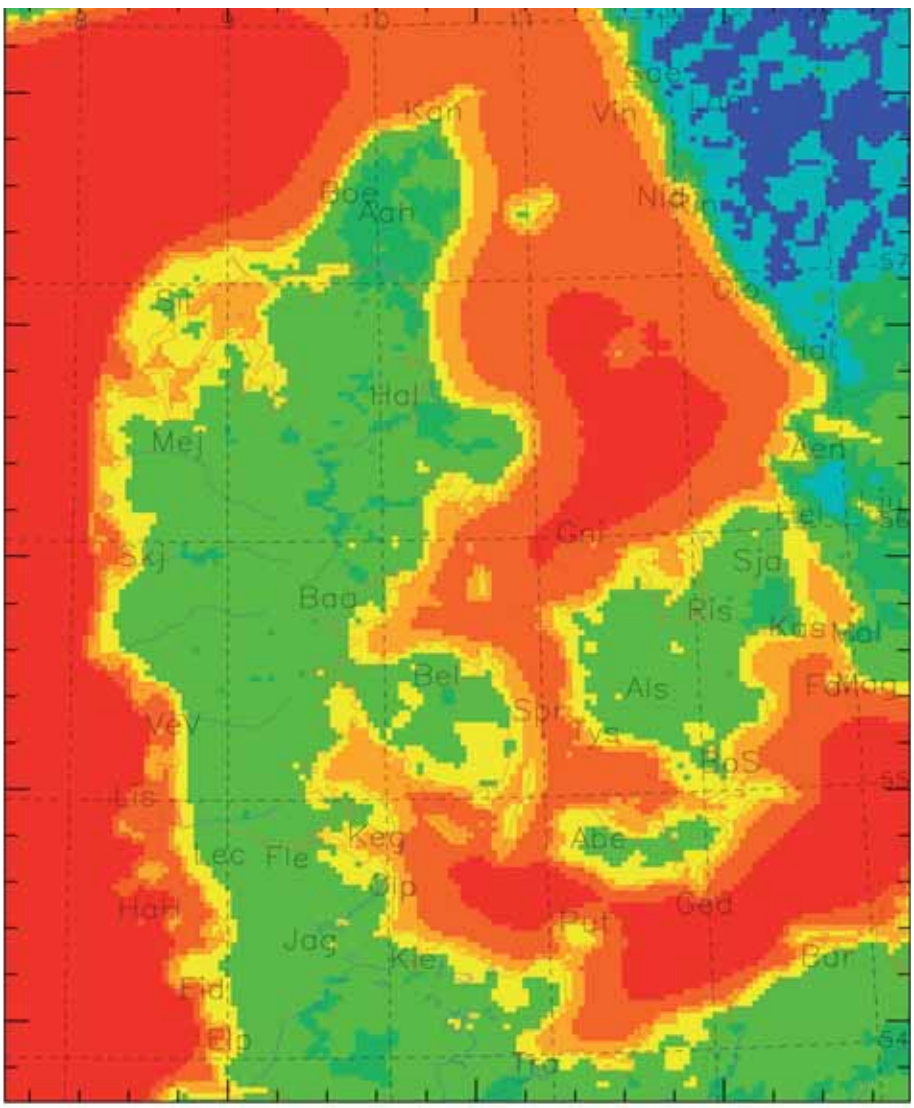


Figure 2.5: This map of Denmark shows wind speeds measured as an average in a normal wind year, both on land and offshore. The wind speeds are calculated at an altitude of 50 meters using WAsP software (see pages 28-29). This model clearly shows the extremely large electricity generating potential of offshore wind power. The red colours show wind speeds of 8-9 m/sec, yellow/orange 7-8 m/sec, green 6-7 m/sec and the blue less than 6 m/sec.
The map is drawn up by Risø.

MARKET-BASED PROCEDURES FOR NEW OFFSHORE WIND FARMS IN DENMARK

In 2004, Denmark issued its first ever call for tenders for the setting up of an offshore wind farm. The two large, approximately 160-megawatt demonstration farms already in operation had been built subsequent to a government order in 1997, while other, smaller offshore wind farms had been built after applications had been submitted but without any competition among potential applicants.

TENDERING OF OFFSHORE WIND FARMS

In the summer and autumn of 2004, the Danish Energy Authority called for tenders for two offshore wind farms, one at Horns Rev and one at Rødsand. The farms were offered for tender after a large political majority in Parliament in March had entered into an energy-policy agreement that ensured, among other things, the basis for the establishment of two 200 MW offshore wind farms.

The calls for tender were issued as EU tenders, according to the following procedures.

As a step in the tender process, the Danish Energy Authority invited interested applicants to request to be pre-qualified. On the basis of an assessment of applicants' financial, legal and technical qualifications, a number of pre-qualified applicants were then asked to submit tenders on the basis of the Danish Energy Authority's tender conditions. When tenders are decided on, the Danish Energy Authority handles negotiations with the applicants. The principal criterion determining allocation of the undertaking is the amount of the feed-in price per kWh of electricity produced that applicants request in order to carry out a project. The specific location proposed for the farm and a credible schedule for its establishment are other criteria used in choosing the successful applicant.

The winner of the tender process is given the right to undertake preliminary studies, establish a generating installation and exploit offshore wind energy but must adhere to the same planning process as applies to all offshore wind power projects, including environmental impact assessment (EIA) procedures (cf. pages 10-11). >

Photo: NOE

With 8 wind turbines, the Rønland offshore wind farm in western Jutland is one of the privately financed offshore wind power projects in Denmark.

FACT BOX

ACTION PLAN ON OFFSHORE WIND POWER

On 1 July 1997, a working group with representatives from the Danish Energy Authority, the Forestry and Nature Agency and electricity companies presented the Government with an action plan outlining the conditions for large-scale expansion of wind power in areas at a distance of 7-40 km from the coast.

The working group concluded that wind turbines would be so far advanced technologically and in terms of economies of scale by the beginning of a demonstration programme in 2000 that offshore wind turbines would be able to produce electricity at essentially the same cost as medium-sized land-based wind turbines.

The working group recommended locating the first 4000 MW offshore wind turbines up to 2030 in 4 main areas: Horns Rev in the North Sea, an area south of the island Læsø in the Kattegat, Omø Stålgrunde in the Langeland Belt and Rødsand/Gedser Rev in the Baltic Sea.

It recommended that the expansion should be made as flexible as possible, with a monitoring phase after each demonstration project, so that the experience gained could be used to adjust the environmental impact, the action plan itself, the design of wind farms, the areas used, installation techniques, etc.

Photo: Elsam

After having been pre-qualified, Energi E2 won an open call for tenders and was awarded the contract to set up an offshore wind farm as a neighbouring installation to Horns Rev I.

In June 2005, Energi E2 A/S, which had submitted the tender with the lowest feed-in price, was chosen as the winner of the tender for a 200 MW offshore wind farm at Horns Rev. The price has been fixed at approx. EUR 0.069 /kWh (not index regulated) for 50,000 full-load hours, which corresponds to approximately twelve years' electricity production. It has been agreed that the farm will be set in operation during 2009.

The Danish Energy Authority expects to be able to conclude the tender process for a second offshore wind farm (at Rødsand) in early 2006.

SCREENING OF OFFSHORE AREAS

In preparation of the call for tenders for two offshore wind farms with a total of 400 MW new production capacity, the Danish Energy Authority also screened potential farm locations at sea.

The objective with the screenings was to assess the suitability of various areas for the establishment of wind turbines, including offshore wind farms' possible impact on other activities in the related areas. The general public and the authorities concerned were consulted on environmental conditions, navigational safety and landscape-related interests. The consultation responses influenced the tender conditions concerning requirements and terms for the wind farms' locations and design, the nature of the studies and analyses that the EIA reports must contain and regarding the construction, operation, etc., of the farms.

A number of marine areas were screened, starting with the potential areas that had been identified in the Action Plan on Offshore Wind Power from 1997. Other potential areas were also screened, including an area at Kriegers Flak,

FACT BOX

FUTURE OFFSHORE WIND POWER EXPANSION

As a follow-up to the Energy Strategy 2025, the Government has decided that the Action Plan on Offshore Wind Power from 1997 is to be updated. The objective with the updating is to carry out a new assessment of where future expansion of offshore wind power can take place. The Minister of Transport and Energy therefore requested the Danish Energy Authority to establish a committee with relative reference group, of which the task is to assess the possibilities for future offshore wind turbine expansion.

The committee will also consider possibilities for the grid connection of larger offshore wind farms and new technological possibilities for establishing wind turbines in deeper water. The possible introduction of offshore wind turbines in relationship to other area interests such as environmental protection, navigation, the military, the fishery and visual consequences, etc., are to be newly assessed. In order to maintain and further develop peak competencies in the wind power sector in Denmark, the committee will also assess where it might be possible to locate offshore test-sites for wind turbines.

The process will build further on the Action Plan on Offshore Wind Power from 1997 and the relative mapping material from 1995, as well as on experience from the demonstration offshore wind farms and on the results of the screenings carried out.

approximately thirty kilometres east of Møns Klint. The result was that Rødsand and Horns Rev, where large-scale farms have already been set up, will be expanded. Work was also begun on a new action plan for future expansion of offshore wind power.

OPEN DOOR

According to the regulations laid down in the Act on Electricity Supply regarding generating installations at sea, permission for preliminary studies and for exploitation of wind energy at sea may only be given either after applications have been requested in connection with a call for tenders or after an application has been made public and other interested parties have been given the opportunity to apply.

The latter procedure is known as an open-door procedure, since applicants may at any time seek authorisation to carry out preliminary studies, establish installations and exploit wind energy.

On the basis of a specific application and according to objective criteria, the Danish Energy Authority may decide that expansion is to be carried out in a given area as requested. Other interests in the maritime area concerned will be taken into consideration when the decision is made as to whether the area in question is to be expanded.

If the Danish Energy Authority decides that no major societal interests are compromised by the expansion of an offshore wind farm, it has the authority to invite other interested parties to apply to develop a given project, thus ensuring competition regarding the relative conditions.

The Danish Energy Authority has not, however, yet implemented the open-door procedure for offshore wind farms.

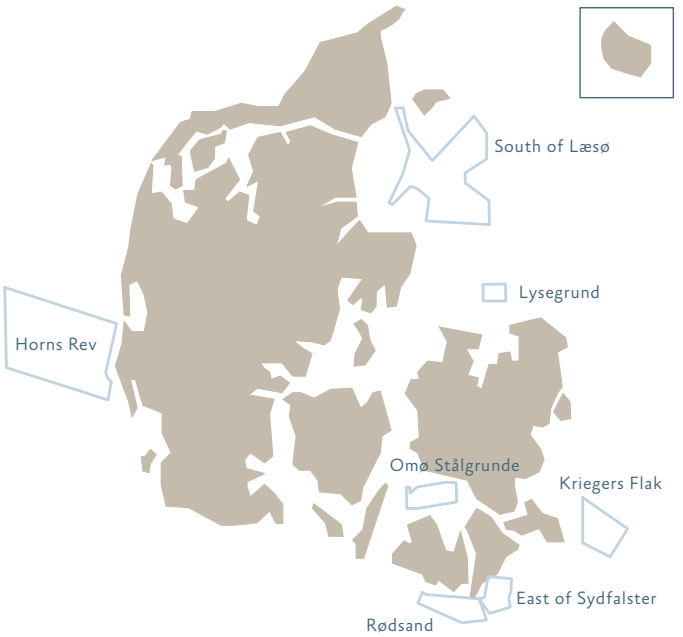


Figure 3.1: Up until the most recent call for tenders regarding large wind farms (Horns Rev and Nysted), screenings have covered two areas in addition to the four so-called main areas identified in the 1997 Action Plan: Lysegrund and Kriegers Flak, for which expansion is also planned in the Swedish and German section.
The map is prepared by the Danish Energy Authority.

FACT BOX

SCREENING

A screening assesses and provides information about a given area in relationship to crucial area interests. The objective with the screenings carried out has been to assess and provide information about potential areas prior to the issuing of a call for tender for the establishment of an offshore wind farm. Part of the process therefore involved the call for ideas and proposals for the contents of a future Environmental Impact Assessment (EIA). Possible investors are therefore given an indication of which studies will be necessary in order to carry out a project and are informed as to the conditions that will likely be set for the subsequent EIA process. As well, the general public has the opportunity, in the early stages of the decision-making process, to express its opinion on a new offshore wind farm.

FROM PLAN TO PROJECT

FACT BOX

Photo: Gunnar Britse/Energi E2

EIA REPORT

The rules governing EIA reports are described in Executive Order no. 815 of 28 August 2000 on assessment of the environmental impact of offshore electricity-producing installations.

Any party applying to establish an offshore wind farm must prepare an environmental report in order to ensure

- that the environmental conditions within defined installation, impact and reference areas are studied and described,
- that all known environmental impacts in connection with the establishment and operation of the wind turbine installation have been previously considered and assessed, and
- that the authorities and the general public have a basis for assessing and deciding on the project.

The procedure for establishing offshore wind farms has been gradually developed as experience has been gained during the first eight Danish offshore wind power projects. The Danish Energy Authority functions as the central fulcrum in relationship to the many, often opposing, interests connected to the establishment of offshore wind power projects. In practice, this means that investors only need to receive authorisation from the Danish Energy Authority when an offshore wind power project has to be realized.

PRELIMINARY STUDIES AND THE EIA PROCEDURE

Projects that can be assumed to impact significantly on the environment may only be carried out on the basis of assessment of the environmental consequences (an EIA report) and after the general public and the authorities and organisations concerned have had an opportunity to express their opinions.

An applicant will therefore not only be required to study the wind-, current- and bottom conditions that must be known in order to plan an offshore wind power installation. Environmental studies must also be done that illustrate how the installation will affect nature in the area.

When the Danish Energy Authority issued its call for tenders relative to Horns Rev, the tender conditions contained, in addition to general requirements, a series of location-specific requirements for the studies that had to be part of the EIA report. This was the result of remarks and proposals made in connection with the Danish Energy Authority's screening (more information on this is given on page 9).

It is expected that a similar process will be followed for the call for tenders for Rødsand.

When, on the basis of these preliminary studies, an application (including an EIA report) has been submitted regarding an offshore wind power project, the Danish Energy Authority sends this material for public consultation with an appeal deadline of at least eight weeks.

AUTHORISATION TO ESTABLISH AN OFFSHORE WIND FARM

Once the EIA procedure has been completed, the Danish Energy Authority prepares the final authorisation for the establishment of the offshore wind farm in question. This is done according to detailed conditions that reflect both the EIA report's conclusions and consultation responses from the general public and the authorities concerned. Public consultation of the EIA report is an open and flexible process that makes it possible for the Danish Energy Authority to clarify and prioritise the various - and often opposing - interests associated with the establishment of an offshore wind farm.

The authorisation issued by the Danish Energy Authority is made public. Any party with justified and individual interest in the decision has the right to register a complaint with the Energy Appeal Board regarding the decision's environmental aspects. The authorisation may not be acted upon before the appeal deadline has expired. Once authorised to carry out a project, the permit holder must provide the Danish Energy Authority with documentation proving that the conditions in the permit issued have been fulfilled. This must be done in the form of a detailed project for the installation works. The permit holder may begin to install the offshore wind farm only after the Danish Energy Authority has determined that the documentation submitted is sufficient.

PRODUCTION PERMIT

When an installation is ready to produce electricity for the grid, the permit holder applies to the Danish Energy Authority for a permit to exploit the wind energy. Electricity production may not begin before the permit has been issued. The permit holder must first be able to document that all of the conditions in the permit have either been fulfilled or that they will be fulfilled.

In addition to authorisation to establish and use an offshore wind power installation, the wind farm owner must also obtain a licence to produce electricity if the overall project has a capacity of more than 25 MW and if the wind farm owner does not already hold such a licence.

Nysted Offshore Wind Farm, which was built as a second, large demonstration project and which began operation in 2003, was planned on the basis of an extensive analysis of environmental consequences that was included in an EIA report.

Photo: Jan Kofod Winther

THE ENVIRONMENTAL IMPACT OF OFFSHORE WIND POWER

The flying patterns of migratory birds were studied as part of the environmental monitoring programme for Horns Rev. It was experienced that the birds are able to find their way around wind farm by means of various routes, as is shown in this illustration from Elsam Engineering.

Wind power, as a renewable source of energy, produces no emissions and is an excellent alternative in environmental terms to conventional electricity production based on fuels such as oil, coal or natural gas. But wind turbines do have an impact on their surroundings both visually and in terms of sound and, especially with the development of increasingly larger wind turbines, it has proven difficult to find appropriate, sufficient locations in such a densely built-up country as Denmark.

While expansion with offshore wind farms is an attractive alternative, such activity at sea must respect the vulnerable marine environment and thorough studies of offshore wind farms' environmental impact are therefore required before the Danish Energy Authority authorises a project.

EIA REPORT

According to regulations in force (cf. pages 10-11), it is the Danish Energy Authority that decides whether a special EIA report must be prepared before an application to set up an offshore wind farm can be processed. An EIA report must provide an exhaustive assessment of the project's environmental consequences and must include a description of workable alternatives.

The description of the environmental consequences must assess the fauna and flora, the sea bottom, the water and air, climatic conditions, any archaeological deposits, impact on the landscape and coastal safety. The applicant must also demonstrate how any damaging environmental impacts can be reduced or neutralised.

Experience gained during the first EIA procedures for offshore wind farms has shown that the authorities concerned, interest organisations and citizens all take advantage of the public consultation of EIA reports in order to make comments that contribute to the final definition of the projects.

EXPERIENCE FROM PILOT PROJECTS

The experience gained over time from projects carried out have been of great value to Danish politicians and authorities in the period leading up to more extensive expansion of wind power at sea. The first two pilot projects, at Vindeby in 1991 and Tunø Knob in 1995, showed that the projects had limited visual consequences and that very few complaints were made once operations began.

Even before the two pilot projects, Danish studies of wind turbines on land showed that they did not constitute a serious threat to fowl or other animals. The environmental studies done of the Vindeby project showed that offshore wind farms actually lead to an increase in fish stocks.

The Tunø Knob project was followed up by an extensive study of the consequences to bird life. The study showed that there were no negative impacts on the area's eider. They were not frightened away when the offshore wind farm was set up and it was learned that the availability of food plays a much greater role in the existence of eider than does the presence of wind turbines. This does not, however, mean that the specific study done of eider justifies the drawing of general conclusions regarding other marine birds, given that eider are only disturbed to a limited extent by human activity.

The next pilot project was done (in 2000) at Middelgrunden, outside of Copenhagen. The public consultation of the project led to the number of wind turbines being reduced from 27 to 20 in order to limit the visual impact. The EIA report submitted prior to project implementation referred to the possible risks of heavy-metal pollution from previous dumping in the area, to the sound impact, to effects on water currents, to the risk of collisions and to the impact on fauna and flora. The experience gained during the first years of operation confirmed that the offshore wind farm did not in fact have significant environmental consequences.

REQUIREMENTS REGARDING OFFSHORE WIND FARMS

In recent years, the Danish Energy Authority has approved three near-shore projects: at Rønland (2003), Frederikshavn (2003) and Samsø (2003). In each of these cases, a series of specific requirements were made regarding the authorisations in order to protect the marine environment.

The Rønland project was approved as a near-shore project with eight 2-2.3 MW wind turbines on the condition that the risk of spreading chemicals and heavy metals was to be reduced and that particular care was to be taken during installation works with regard to the seals in the area. In the operational phase, the owners must regularly study the consequences to bird species (as had been referred to in the EIA report) and must also study the offshore wind farm's effect on the spread of eelgrass.

According to the EIA report, the Frederikshavn project, approved as a near-shore project with three 2.3-3 MW wind turbines built by three different companies for the purposes of research and development, would not have a significant negative impact on bird life, even though the offshore wind farm was located relatively close to several international nature-protection areas. The EIA report's conclusions were confirmed by an independent study done by the Danish National Environmental Research Institute.

The Samsø project, consisting of ten 2.3 MW wind turbines, is part of a major initiative that will make the island self-sufficient with renewable energy. The project was approved with a few minor changes. On the basis of the experience gained with the nearby Tunø Knob installation, it was decided that seals and porpoises would benefit from an expected increase in the food basis. >

Photo: DMU

Together with porpoises, the seal population is an area of particular importance in the environmental monitoring programme. This seal puppet was born at Nysted after the commissioning of the offshore wind farm.

Photo: Samsø Energy and Environmental Office

Samsø offshore wind farm at Paludan Flak is a part of the island's ambitious project to supply all of its energy needs from sustainable sources.

Photo (on the left): The environmental monitoring programme focused on the offshore wind farms' impact on fish- and bird life. When the large foundations under the Nysted Offshore Wind Farm were set in place, they proved not to be a deterrent to the wildlife in the area.

Photo (on the right): Special efforts have been made to develop the light markings for offshore wind turbines. The wind turbines must be visible to air traffic without being a visual disturbance to the local area. On the basis of experience gained at Nysted Offshore Wind Farm and other installations, new marking requirements were set for large wind turbines in order to reduce the visual impact of future offshore wind farms.

MONITORING PROGRAMME

The Action Plan on Offshore Wind Power from 1997 underlined the need to concentrate wind power expansion in a few, relatively large areas. This conclusion was later confirmed by visualisations and analyses of the main areas identified. On this basis, in 1998 the government at the time entered into an agreement with Danish power plants to carry out a large-scale demonstration programme. One of the objectives with the programme was to clarify the environmental consequences of an extensive expansion of such farms.

Since the two offshore wind farms are demonstration projects, a detailed measurement and monitoring programme was established in order to chart the environmental conditions before, during and after the two farms were set up. The environmental studies will be done during the 1999-2006 period and are being financed, with a budget of DKK 84 million (approx. EUR 11 million), by Danish electricity consumers as a Public Service Obligation (PSO).

In 2005, the reference studies and monitoring of the installation works were completed and the ongoing studies of the operational phase's consequences for the environment continue. The programme is regularly monitored by The International Advisory Panel of Experts on Marine Ecology (IAPEME), which assesses the environmental analyses each year.

According to IAPEME, this is a pioneering research programme that makes Denmark an international leader in research into this aspect of the marine environment. There is also considerable international interest in the programme results, since numerous wind power projects in both Europe and the rest of the world expect to benefit from the Danish research.

The results of the monitoring programme are considered to be very representative because Horns Rev is located in a severe marine environment with powerful westerly winds and heavy seas, while Rødsand/Nysted is in calmer inland waters.

PRELIMINARY RESULTS

The preliminary results show that large marine mammals, such as seals and porpoises, did leave the areas when noisy and disturbing installation works were going on but that they later returned. Migratory birds alter their routes so that they

Photo: Gunnar Britse/Energi E2

do not fly into the offshore wind farms, which reduce the risk that the birds could collide with the farms. Overwintering and resting birds have, to a large extent, avoided the farms but studies are being carried out to monitor the birds' behaviour over a longer operational period.

The preliminary assessment is that wind turbine foundations can have a positive effect on fish life because the man-made constructions create new places where fish can conceal themselves and lead to an increase in the fishes' food base.

The research programme also covers study of the general public's opinion of offshore wind farms. During the planning phase, there was widespread concern in the local area that the visual disturbance would create problems for the tourist industry. This has not, however, proven to be the case so far. The visual disturbance is greatest at night when the safety lighting on the nacelles is clearly visible from land, especially under good visibility conditions.

The Danish Civil Aviation Administration, which is responsible for air-traffic marking, has set new marking requirements for both wind turbines with a total height between 100 and 150 m and for wind turbines over 150 m. The new marking requirements are expected to reduce the overall negative visual impact, which for instance has been identified at the Nysted Offshore Wind Farm.

Popular scepticism during the planning phase has apparently not carried on into the operational phase. Studies of the local residents' attitudes show increasing acceptance of the offshore wind farms, although the desire has been identified to have future wind farms located further from the coastline.

The final results of the Danish monitoring programme is to be presented at the Offshore Wind Farms and the Environment Conference 27-29 November 2006 in Denmark.

FACT BOX

Photo: Elsam Engineering

ENVIRONMENTAL MONITORING PROGRAMME

Between 1999 and 2001, as the basis for the Horns Rev and Nysted environmental monitoring programme, basic studies were undertaken in order to establish a reference for later analyses. The programme has an overall economic framework amounting to DKK 84 million (approx. EUR 11 million) for the 2001-2006 period. The Environmental Group, consisting of the Forestry and Nature Agency, the Danish Energy Authority, Elsam and Energi E2, is responsible for the programme. The Environmental Group's activity is evaluated by The International Advisory Panel of Experts on Marine Ecology (IAPEME).

The Transmission System Operator (TSO), Energinet.dk, administers the programme and submits projects for the Danish Energy Authority's approval.
An NGO reference group, consisting of the World Wildlife Fund, the Danish Nature Conservation Association, the Open-Air Council, Greenpeace, the Danish Ornithological Association and the Organisation for Renewable Energy, monitors the programme on behalf of Danish NGOs.

Up to the present time, studies and analyses have dealt with

- bottom fauna and flora, including the food basis for fish, with particular focus on the consequences of the introduction of a hard-bottom habitat
- Studies of stopover-, foraging and migrating birds, including study of the risks of collision between birds and wind turbines, bird counting from aircraft and the recording of birds' flying heights.
- The reaction of waterfowl, including the scoter's food base
- Marine mammals' possible modified behaviour, particularly that of porpoises and seals
- The impact of electromagnetic fields on fish
- Sociological and environmental-economic studies.

Status reports are published annually, including the IAPEME's assessments and recommendations and will soon be transferred to the Danish Energy Authority's website www.ens.dk; until that time, the reports can be found at www.hornsrev.dk/Engelsk/default_ie.htm and http://uk.nystedhavmoellepark.dk/frames.asp

GRID CONNECTION, GRID ACCESS AND SYSTEM INTEGRATION

FACT BOX

CONNECTION RULES FOR OFFSHORE WIND FARMS

The Danish Transmission System Operator's rules for the connection of offshore wind farms (Technical Guidelines TG 3.2.5: Connected wind turbines with a voltage of more than 100 kW) can be find via www.energinet.dk (only in Danish).

Major developments in the use of wind power in Denmark have posed new challenges for the transmission system operator (TSO) because, in a market-based system, large, varying and, to a certain extent, unpredictable quantities of electricity must be accommodated. Substantial pressure is put on producers' ability to deliver system services.

GRID CONNECTION

Traditionally, onshore wind turbines have been connected to the electricity system through distribution grids less than 100 kV. This applies to both individual wind turbines and wind farms.

In 1998, it was decided to connect large offshore wind farms directly to the transmission grid over 100 kV. This is because these farms are so large that it is not possible to convey large power volumes of 150-200 MW in the existing, low-voltage grid. These large wind farms must therefore be connected at a strong point in the electricity grid. With extensive expansion in the use of wind power, it also became necessary to make increased requirements regarding the connection of wind turbines and their system characteristics (such as voltage, power and frequency control), which had previously been delivered from thermal power plants onshore.

Large offshore wind farms are set up with an internal grid system that leads to a connection point on a transformer platform. The grid connection consists of this transformer platform, a cable transmitting the power to shore and the land cable from the arrival point to the place where the grid connection is linked to the overall transmission grid onshore.

Grid connection is done by means of cables stretching the entire way from the offshore wind farm to the connection point onshore. Under normal conditions, electricity cables do not have an impact on the environment, which means that basically it is not necessary to prepare an EIA report for this part of the overall facility operation.

INTERFACES FOR GRID CONNECTION

The interface between the producer and the transmission company has remained the same for many years. A wind farm including its own internal grid is owned and operated by the producer, as is the case with power plants onshore,

while the transformer platform and the grid connection transmitting the power to shore is owned and operated by the transmission company. The transmission company is also responsible for carrying out any necessary reinforcement of the underlying grid. The responsibilities are divided in this way to promote wind power by making the necessary grid available without costs to the producer.

SYSTEM SERVICES

Connection of an offshore wind farm must fulfil the connection rules set by the TSO Energinet.dk (Technical Guidelines TG 3.2.5). The Danish Energy Authority must be kept informed of these rules.

The rules cover, among other things, the technical requirements that a wind farm must meet at the offshore connection point (at the transformer platform). These requirements deal with control capabilities, the output of reactive power, the ability to remain operational and to continue production when there is a grid outage, gradient limitation and the contents of operation agreements.

By means of this process, the two large offshore wind farms at Horns Rev and Nysted are technically prepared to provide various system services. This will also be the case for future offshore wind farms.

GRID REINFORCEMENT

Large offshore wind farms are usually located far from major centres of consumption and are connected to the transmission grid in sparsely populated areas. The transmission grid must therefore be able to transport the power from the offshore wind farms over long distances. Up to the present time, it has been basically sufficient to use the existing transmission grid, originally built to transport power in the opposite direction, from centralised power plants to consumers. It has therefore been possible to grid connect the first offshore wind farms without major investments in grid reinforcement.

This will presumably also be possible in some countries with an extensive electricity infrastructure and, in certain cases, it will therefore be possible to grid connect one or more large offshore wind farms without extensive investments in grid reinforcement. >

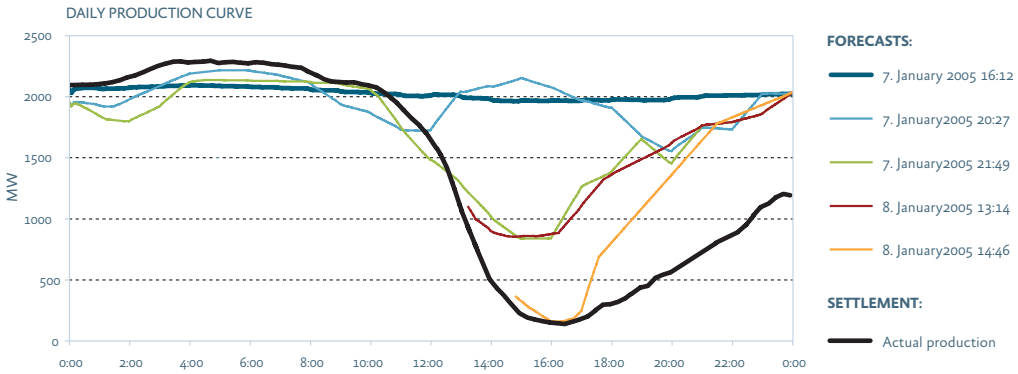
Thanks to a well-developed electricity infrastructure, it was possible to connect the 160 MW offshore wind farm at Horns Rev without extra grid reinforcement because the wind farm was connected directly to the transmission grid.

Photo: Elsam

Photo: Jan Kofod Winther

The transformer platform at the Nysted Offshore Wind Farm is owned by SEAS Transmission.

Figure 6.1: The curves show the short-term forecasts (up to 21.5 hours) for the severe storm that struck western Denmark on 8 January 2005. According to the first forecasts, production capacity of approximately 2000 MW wind power was expected in the period between noon and 6 pm. The actual production around 4 pm reached no more than 200 MW, that is, a tenth of the estimate, because most of the wind turbines shut down, given that the wind speed was greater than 15 m/second. The system operator had to provide the remainder from up-regulated power. Source: Energinet.dk



In Denmark, the transmission grid's capacity has been reached with the wind farms set up at Horns Rev and Rødsand. If the grid is not reinforced, bottlenecks will be created in this part of the transmission grid when new offshore wind farms are grid connected in these areas in 2009-2010. Such bottlenecks can limit the possibilities for fully exploiting wind power. Depending on the location, it is therefore to be expected that future Danish expansion of wind power will necessitate correspondingly significant expansion of the transmission grid if it is to make full use of the wind power.

PRIORITISED ACCESS

According to Danish legislation, renewable energy has prioritised access to the grid. In practice, this means that wind power has access to grid capacity before all other electricity produced. This also applies to electricity produced by offshore wind farms. However, special rules apply to the two offshore wind farms tendered out at Horns Rev and Rødsand since, in the case of grid limitations, their production may be reduced with financial compensation.

The system operator, Energinet.dk, has the task of co-ordinating the prioritised access with general system operation, during which production and consumption are constantly adapted to market conditions.

SYSTEM INTEGRATION

The nature of wind power is that it is produced when the wind blows and not in correlation to ongoing electricity consumption. Wind at sea has a considerably higher energy content than wind onshore. Offshore wind farms located in the North Sea, for example, produce around 4000 full-load hours/year, approximately twice as much as the average quantity of wind power onshore.

Even though offshore wind farms are designed to deliver a part of the system services that an electricity system requires, services must be acquired from the other units in the electricity system so that the overall operation functions optimally. Expansion with wind power therefore results in a change in the role of onshore power plants so that they will supply system services to a greater extent and function as system reserves.

The unpredictability of wind power makes it necessary to have the capability to regulate both up and down so as to accommodate deviations in wind power forecasts. In western Denmark in 2005, up to 1700 MW up-regulation and 1000 MW down-regulation will be necessary. In addition, there must be both appropriate access to primary reserves for voltage and frequency regulation and automatic and manual reserves.

As the percentage of wind power in overall production gradually increases, its unpredictability may become a growing problem for the electricity system, both operationally and economically. The extent of the problem will depend on the accuracy of wind-power forecasts and the possibilities for adapting electricity consumption and production from other plants on short notice. Inaccurate wind forecasts are a major reason for the need for up- and down regulation capacity in the system and there is therefore a need for systems and instruments that can provide accurate forecasts for production from wind turbines.

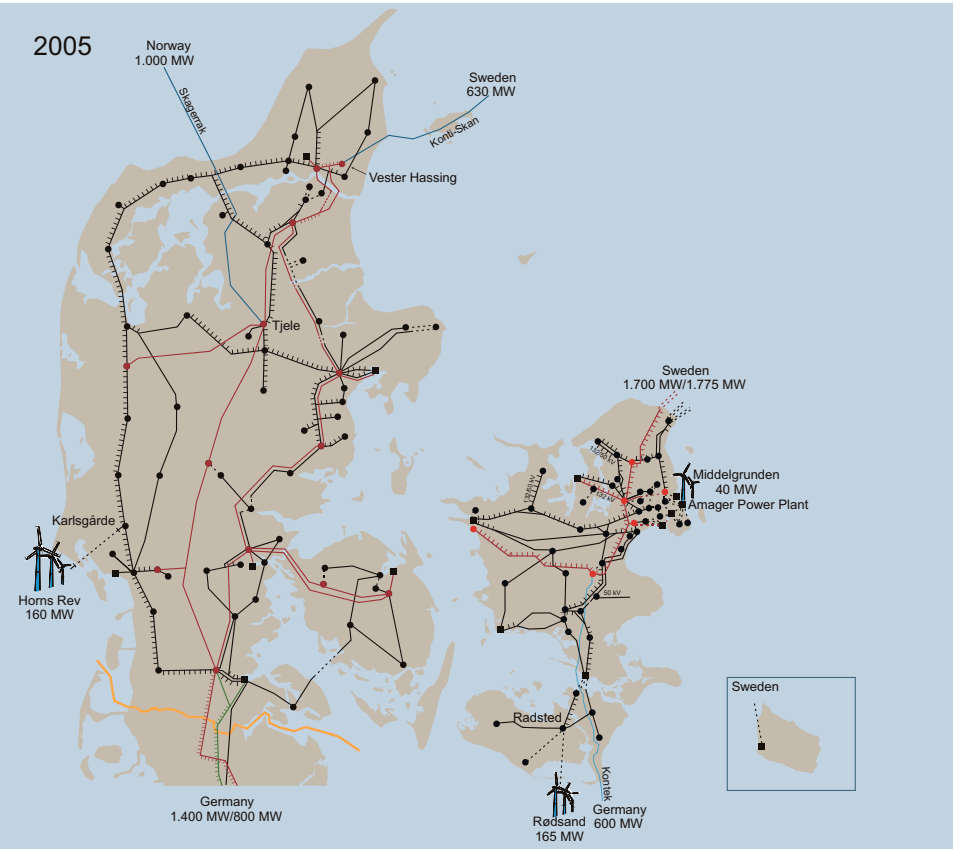
Another important issue is the extent of the costs of regulating power that can be expected in the future. The market mechanism indicates that the

price of regulated power will increase in a future electricity system in which large quantities of wind power will increase imbalances and hence demand for regulating power. On the other hand, the technology used to regulate the electricity system is being further developed and regulated power prices will also depend on the extent to which the rest of the electricity system gradually adapts to an increased expansion of wind power.

MARKET INFLUENCE

Large quantities of wind power means that the price pattern in the electricity market will be much more volatile with low prices when wind power production is high and with high prices when wind power production is low. This will give market players the incentive to activate new resources in the electricity system. When large quantities of wind power are produced and hence prices are low, flexible consumption, such as large heat pumps and heating elements at decentralised heat and power plants, can play a constructive, price equalising role. In situations in which there is less output and therefore higher prices, new initiatives will be necessary. They include condensation operation at large CHPs, new peak-load installations, emergency power installations, more flexible heat production at CHPs and price elastic consumption in the form of advanced agreements with consumers on the temporary interruption of electricity supply. Electricity storage and interconnections lines to countries outside Denmark can also have a price equalising effect on the market under conditions of both low and high prices.

In itself, the production of power from wind will lower prices and thereby reduce incentives to invest in new thermal power plants. Flexible electricity consumption can counteract the effect by positively contributing to stabilising electricity prices and hence stimulating market players to invest in new CHP capacity.



- 400/150-kV or 400/132-kV transformer station or 400-kV distribution substation
- 150/60 -kV or 432/50-kV transformer station or 150-kV distribution substation or 132-kV distribution substation
- Power plant
- 150-kV or 132-kV one-system line
- 150-kV or 132-kV two-system line
- 150-kV or 132-kV cable
- 400-kV cable
- 400-kV one-system line
- 400-kV two-system line
- 400/150-kV or 400/132-kV combined line
- 220-kV two-system line
- 220/150-kV combined line
- 250-kV, 350-kV or 400-kV HVDC
  Independent of the number of systems

Figure 6.2: Map of the electricity transmission grid in Denmark, showing the location of the three largest Danish offshore wind farms currently in operation and interconnection lines to Norway, Sweden and Germany. Source: Energinet.dk

WIND POWER ECONOMY AND PRICE SETTING

FACT BOX

FULL-LOAD HOURS

A full-load hour is an hour in which a wind turbine produces at full capacity. An annual number of full-load hours is the time it will take a given wind turbine to yield its annual production if it is able to produce with its installed capacity all of the time. Depending on the placement of the wind turbine with respect to the wind, the annual average full-load hours onshore is between 1500 and 3000, with an average for all land-based wind turbines of approximately 2000 hours. At sea, 3500-4000 full-load hours are calculated.

The payment received by wind turbine owners for the electricity they produce has evolved over the last twenty-five years in step with the development of wind-power technology and with the establishment of the liberalised electricity market. Generally speaking, production costs have steadily fallen as wind turbines have been upscaled and society's payment for electricity production has decreased even more. Today, Danish electricity consumers cover all of the increased costs associated with electricity production from wind turbines in Denmark.

ELECTRICITY PRODUCTION FROM WIND POWER

In a normal year, which means with an average wind content, the annual production from a wind turbine depends partly on its installed capacity, i.e. on its size, and partly on its location, that is, how much wind there is in the area where it has been installed.

Annual production is often declared as corresponding to a number of full-load hours (see definition on the left page).

At sea, an annual production of approximately 4000 full-load hours can be expected in the best areas in terms of wind, such as in the North Sea where Horns Rev has been set up. For a 2 MW wind turbine, this corresponds to the electricity consumed by approximately 2000 single-family households. In inland Danish waters, such as at Rødsand, Omø Stålgrunde, etc., approximately 3500 full-load hours are calculated. For the 2.3 MW wind turbines at the Nysted offshore wind farm, this corresponds to the electricity consumed by approximately 1900 single-family households.

Corresponding production from wind turbines onshore varies between approximately 1500 full-load hours and approximately 3000 full-load

hours at the best locations which, in Denmark, are on coasts facing westward.

ECONOMY OF WIND POWER OPERATION

The economy of wind power operation depends partly on the total amount of electricity produced by the wind turbines and partly on the feed-in price and on installation and operating costs. Wind turbines are expensive generating installation investments. Hence, the production costs are highly dependent on installation costs and their financing.

For onshore wind turbines, installation expenses, including financing, typically account for 75-85% of production costs while ongoing operational costs account for the remainder. For offshore wind turbines, installation expenses make up 70% of production costs and operational costs are somewhat higher than on land, primarily because there is greater stress on wind turbines at sea and ongoing maintenance is therefore more costly and more complicated.

In addition to the actual cost of the wind turbine itself, installation costs arise from construction of the foundation, from the internal collection-grid, planning, etc. For offshore wind turbines, the planning and the foundation generally account for a relatively higher percentage of costs than for wind turbines onshore for which the cost of the wind turbine itself accounts for considerably more than half of the total costs involved (cf. Figure 7.1, which shows the typical distribution of installation costs in a Danish offshore wind farm. >

TYPICAL BREAKDOWN OF INSTALLATION COSTS FOR AN OFFSHORE WIND FARM IN DENMARK

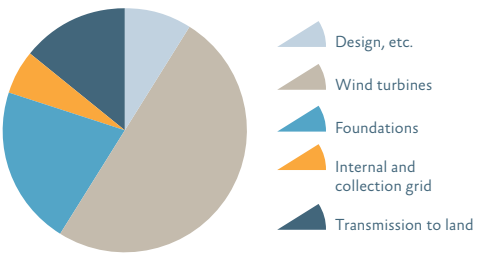


Figure 7.1: Design and foundation costs are generally a relatively large part of the overall installation costs for an offshore wind farm. Source: Danish Energy Authority

Photo: Mads Eskesen/Earth-Vision

3 MW offshore wind turbine	**MWh**
Manufacture	12,300
Transport and installation	500
Operation and maintenance for 20 years	100
Removal	-4,800
Total	**8,100**

Figure 7.2: Life-cycle analysis of a 3 MW offshore wind turbine. A life-cycle analysis charts and assesses the environmental impact of the wind turbine throughout its entire life – from manufacture to disposal. Given an expected electricity production output of approx. 12,000 MWh per year, the wind turbine will in eight months generate the total energy consumption that is needed for manufacture, transport and operation of the wind turbine. Source: Vestas Wind System

The offshore wind farm at Middelgrunden outside of Copenhagen is an example of joint ownership between the local electricity-grid company, Københavns Energi, and local electricity consumers organised into a co-operative society.

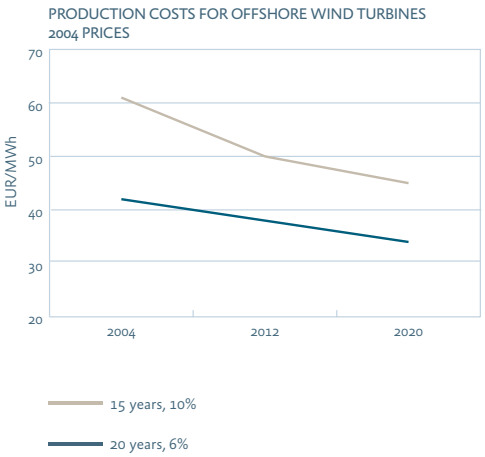


Figure 7.3: Production costs for offshore wind turbines at locations that result in average annual production of approximately 4000 full-load hours. Source: The Danish Energy Authority's Technology Catalogue 2004

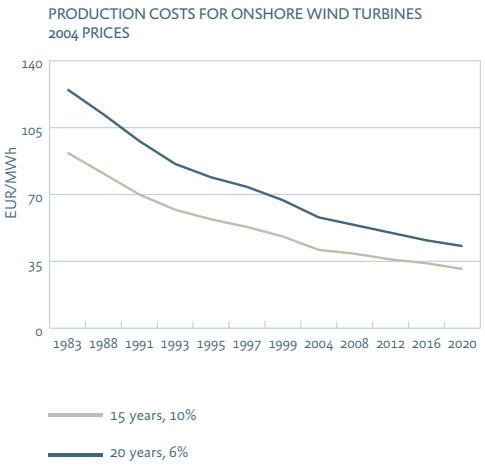


Figure 7.4: Production costs for a land-based wind turbine with an annual average electricity production of 2200 full-load hours in the 1980-2000 period, on the basis of results from the Risø Research Centre's study of representative accounts. According to the Danish Energy Authority's Technology Catalogue, annual production in the 2000-2020 period will amount to 2400 full-load hours.

Ongoing operational costs, in addition to repairs and servicing, arise from research, administration, etc.

Figure 7.3 shows, in the form of a forecast up to 2020, the evolution in production costs for offshore wind farms on the basis of assessments in the Danish Energy Authority's most recent Technology Catalogue (2004).

Figure 7.4 provides corresponding figures for onshore wind turbines, beginning from 1980, when the first mass-produced wind turbines were installed in Denmark.

Costs related to power transmission to land, grid connection and possible grid reinforcement are sustained by the system operator, Energinet.dk, or by the local grid company and, ultimately, by electricity consumers in the form of grid tariffs. These expenses are therefore not included in calculating owners' production costs. Investments in transformer platforms and sea-to-land cable depend on where the offshore wind farm is located. Based on the first farms in Denmark, these costs amount to approximately EUR 0.006/kWh of an offshore wind farm's electricity production.

FEED-IN TARIFFS FOR WIND POWER

Originally, wind power were given a fixed feed-in tariff that was the same irrespective of wind conditions. The level was set so that the private sector was offered a financial incentive to establish wind turbines at less than optimal wind locations. Projects in favourable wind locations were therefore particularly profitable for investors. Until 1999, additional costs associated with wind turbines (both on- and offshore) and financed by electricity utilities were spread out on the total electricity production from the electricity utilities as part of the non-profit system then in effect, and according to wich the electricity production should not result in neither surplus nor deficit.

Photo: Jan Kofod Winther

The cost of producing electricity at Elsam's pilot project at Tunø Knob, where 10 500 kW wind turbines had been installed, proved in practice to be somewhat lower than expected.

During a four-year transition phase after liberalisation of the electricity market, the by then commercially producing power-plant owners were guaranteed a price of EUR 0.08/kWh. After 2004, no feed-in tariff for wind turbines financed by the electricity utilities connected to the grid before 1 January 2000 was made available. Newer wind turbines receive a feed-in tariff phased out within the first 20 years of operation.

Transition schemes were also set in place for privately-owned wind turbines. These schemes gave private owners a reasonable safety net for the investments originally made on the strength of the expectation that electricity production from wind turbines could be calculated at fixed prices during the wind turbines' expected lifetime.

The transition scheme guarantees owners of wind turbines, which were grid connected before 2000, EUR 0.08/kWh for a number of full-load hours, which depends on the size of the wind turbine. This feed-in tariff is gradually being phased out. Newer wind turbines receive a lower feed-in tariff in the first years of operation.

The majority of the wind power projects implemented in Denmark since the 1999 electricity reform have been covered by a re-powering programme. According to the programme, owners who dismantled wind turbines with a capacity of up to 150 kW received a decommissioning certificate. The certificate gave the holder the right to an extra feed-in tariff of EUR 0.023/kWh during 12,000 full-load hours in a new wind turbine grid connected before 31 December 2003.

A new re-powering programme was introduced as part of a broad energy policy agreement in Parliament on 29 March 2004. Decommissioning certificates are issued until 15 December 2009 for dismantled wind turbines with a capacity up to and including 450 kW.

The decommissioning certificate gives the holder the right to an extra feed-in tariff of EUR 0.016/kWh during 12,000 full-load hours at a new wind turbine.

All additional costs arising from feed-in tariffs are covered by electricity consumers as a PSO administered by Energinet.dk. Figure 7.5 shows the evolution of these costs. In 2004, in which electricity production from wind turbines accounted for approximately 19% of domestic electricity supply, consumers paid approximately EUR 0.007/kWh in subsidies to wind power generated electricity. On the other hand, electricity from wind power contributes to put pressure on the market price of electricity from all Nordic power generation facilities.

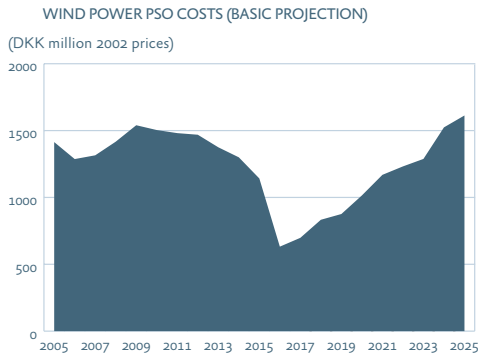


Figure 7.5: On the basis of the Danish Energy Authority's basic projections in Energy Strategy 2025, the costs to electricity consumers of the feed-in tariff for wind power produced electricity (both offshore and onshore) are given here. Source: The Danish Energy Authority

FACT BOX

FEED-IN TARIFFS FOR OFFSHORE WIND POWER

Wind turbines grid connected as of 1 January 2005
Generally speaking, a feed-in tariff of 10 øre/kWh (EUR 0.013/kWh) is paid for 20 years as well as a rebate of 2.3 øre/kWh (EUR 0.003/kWh) for equalisation costs, etc. In connection with the tendering out of an offshore wind farm at Horns Rev II, a feed-in tariff was agreed to that, with the market price, ensures a transfer price of 51.8 øre/kWh (EUR 0.069/kWh) during 50,000 full-load hours. Compensation is paid for any network tariff required by production. Once the full-load hours have been reached, the feed-in tariff is no longer paid. The transfer price at Nysted/Rødsand II will be set at the basis of the call for tenders which it is expected will be decided upon in early 2006.

Wind turbines grid connected 2000-2002
A feed-in tariff is paid that, with the market price, ensures a transfer price of 43 øre/kWh (EUR 0.057/kWh) for 10 years, after which a feed-in tariff of up to 10 øre/kWh (EUR 0.013/kWh) is paid until the wind turbine has been in operation for 20 years. This feed-in tariff is regulated in relationship to the market price, given that the sum of the feed-in tariff and the market price may not exceed 36 øre/kWh (EUR 0.048/kWh). In addition, a rebate of 2.3 øre/kWh (EUR 0.003/kWh) is paid for equalisation costs, etc.

Wind turbines financed by electricity utilities 2002-2003
Wind turbines financed by the electricity utilities are wind turbines set up by electricity generating companies subsequent to an order or a particular agreement. The offshore wind farms at Horns Rev and Nysted fall within this category. A feed-in tariff is paid that, with the market price, amount to a price of 45.3 øre/kWh (EUR 0.060/kWh) for 42,000 full-load hours. A feed-in tariff of up to 0.7 øre/kWh (EUR 0.001/kWh) is paid as compensation if the production is subject to a network tariff. Once the full-load hours have been reached, a feed-in tariff of up to 10 øre/kWh (EUR 0.013/kWh) is paid until the wind turbine has been in operation for 20 years. The feed-in tariff is regulated in relationship to the market price, given that the sum of the feed-in tariff and the market price may not exceed 36 øre/kWh (EUR 0.048/kWh).

A SIGNIFICANT INDUSTRIAL SECTOR

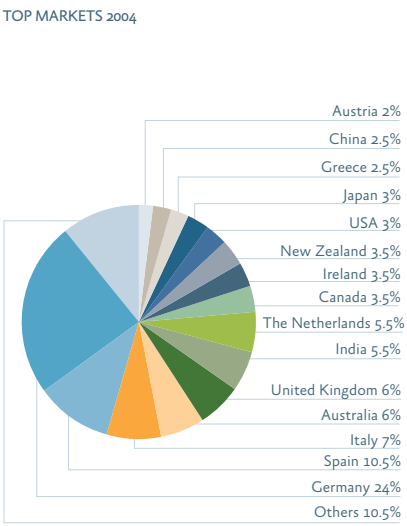


Figure 8.1: The European countries, led by Spain, Germany, Italy and United Kingdom, account for over half of Danish wind turbine exports, but in the years to come, the USA may become a significant market after having introduced new tax incentives. In the slightly longer term, it is expected that a large market will develop in China.
Source: Danish Wind Industry Association

In the course of only a few years, the Danish wind power industry has grown into a significant industrial sector with impressive export trade. With a turnover in 2004 of approximately DKK 21 billion (EUR 3 bn), with essentially all production sold abroad and by employing - directly and indirectly - approximately 20,000 people, the wind power industry accounted for approximately 4% of Danish industrial production.

PRODUCTION INCREASED 100-FOLD

The Danish wind power industry has grown uninterruptedly to its current level. Upscaling and technological advances have made it possible to produce approximately 100 times more electricity at the newest MW wind turbines than at the first modern versions. The most recent wind turbines have been built higher and higher, which has meant that, for visual reasons and in consideration of potential neighbours onshore, it has become attractive for the wind power industry to prioritise locating wind turbines offshore.

This development has become possible because the higher installation and operating costs for offshore wind farms are, to a determining extent, offset by increased production and better locations. With continued upscaling of wind turbines and with the development of improved offshore foundations, the Danish wind power industry is very well positioned to maintain its international competitiveness in a global market in which wind power plays an increasingly important role.

STRUCTURE RATIONALISATION

There are many reasons why the Danish wind

The Danish wind power industry has grown into a significant industrial sector. Here, towers are being produced at Vestas for the Horns Rev Offshore Wind Farm.

power industry has become an international market leader.

The very successful development of the Danish wind power sector has been due to a series of important preconditions. Enterprises have had the commercial competence necessary to enable them to operate in a risky and complicated global market, the development of which is to a large extent influenced by both local and global energy-policy decisions. The sector has rapidly proven able to transform research results and other technological innovations into practical product development and upscaling. Enterprises have had access to well-trained workers from other industrial sectors, shipbuilding in particular.

State subsidies for research and development in wind energy have meant that the relatively small Danish wind power manufacturers have been able to maintain an innovative initial advantage. Danish research environments continue to be so strong internationally that leading foreign wind power manufacturers and consultants have recently located their development divisions in Denmark.

The wind power sector has undergone wide-ranging structure rationalising that has merged most of Danish wind turbine and wing production into three large enterprises supported by a series of sub-suppliers.

40% GLOBAL MARKET SHARE

In 2004, the global wind power market had a turnover of approximately €7 billion, of which the Danish wind power industry accounted for approximately 40%. >

Photo: Nils Rosenvold

GLOBAL MARKET SHARE IN 2004 AMOUNTING TO 8,154 MW

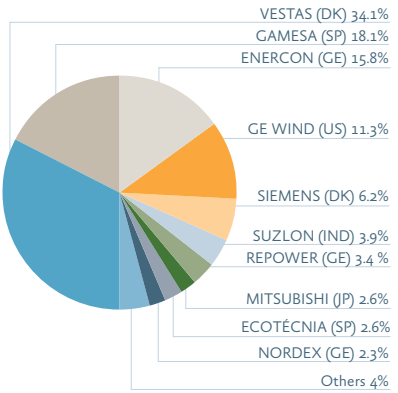


Figure 8.2: Two Danish wind turbine producers, Vestas Wind Systems and Siemens Wind Power, together have a market share of more than 40%. In addition, the wing producer LM Glasfiber supply to foreign factories.
Source: BTM Consult World Market Update 2004

TURNOVER IN DKK BN

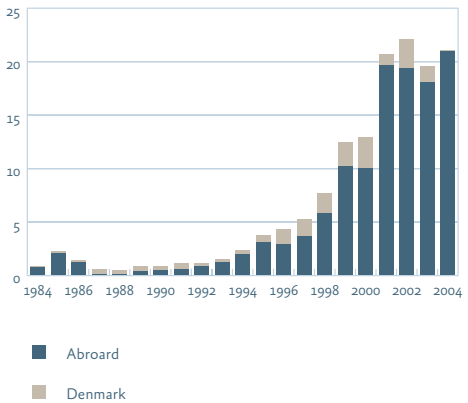


Figure 8.3: In recent years, the Danish wind power industry has increased its trade tenfold. More than 90% of all sales are for export.
Source: Danish Wind Industry Association

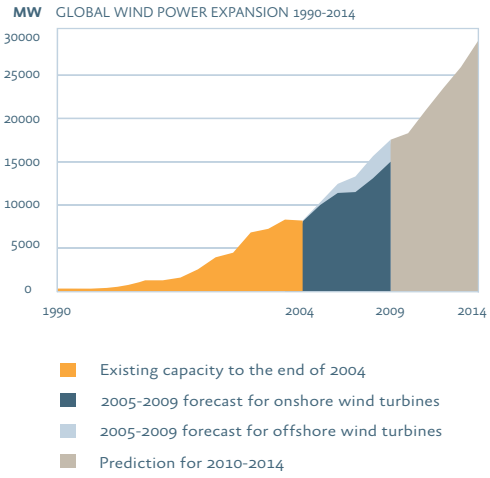


Figure 8.4: Since the middle of the 1990s, global demand for wind turbines has increased exponentially and is expected to continue to grow at an even faster rate in the years to come. Source: BTM Consult World Market Update 2004

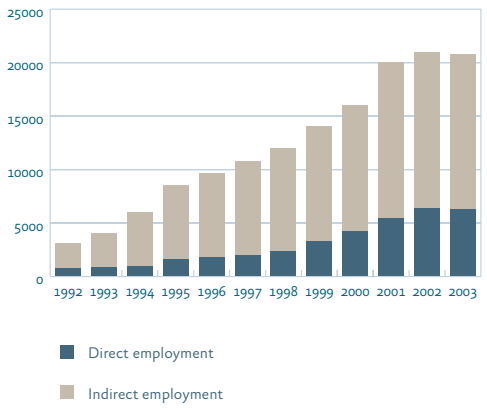


Figure 8.5: With approximately 20,000 employees (directly and through sub-suppliers, etc.), the Danish wind power industry has developed into a major industrial sector in the last 10 years.
Source: Danish Wind Industry Association

Europe continues to play the leading role in the global market, with Spain and Germany as the largest domestic markets, although the market in United Kingdom is growing strongly, especially with respect to large offshore wind farms. The American market also seems to have impressive potential.

SYNERGY WITH THE OIL INDUSTRY

Offshore wind farms are being set up in deeper and deeper water. This means that installation and subsequent repairs are becoming increasingly expensive and more difficult to carry out, which in turn means that overall production costs are rising. After decades of offshore activities in Denmark, the oil industry has gained invaluable experience with relatively small offshore installations, including foundations in deep water.

Closer collaboration between the oil and gas- and wind power industries can therefore lead to pooling of highly developed technological and commercial competencies, thus creating the conditions for increasingly competitive concepts for wind power projects. And this will lead to increased trade for both sectors.

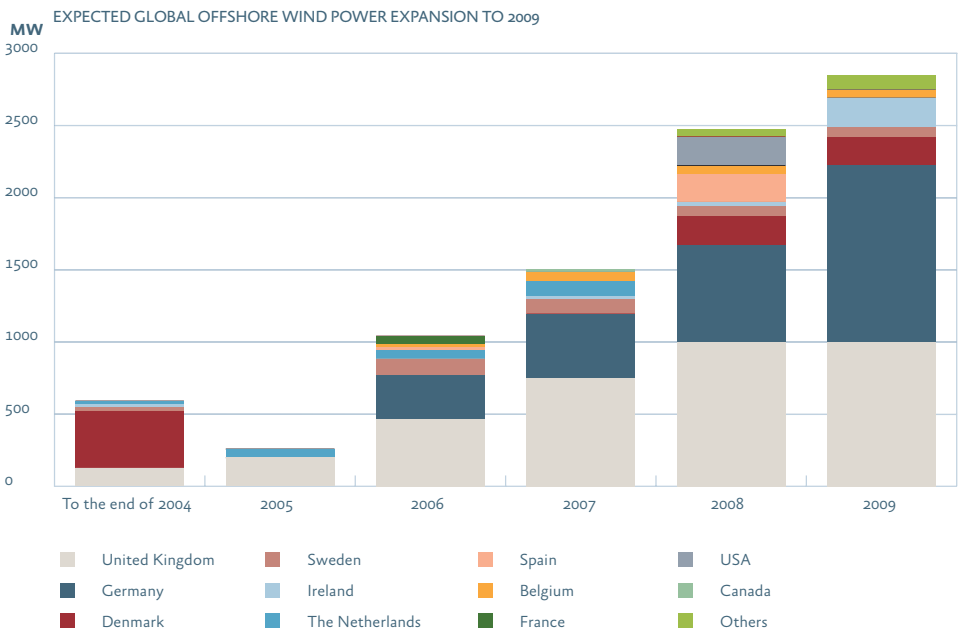


Figure 8.6: It is expected that there will be major expansion of offshore wind farms in the next 5 years, with United Kingdom and Germany in particular becoming major markets. It is expected that, in 2009, offshore wind farms will account for approximately 7% of total global wind turbine capacity.
Source: BTM Consult World Market Update 2004

RESEARCH AND DEVELOPMENT

At the present time, wind energy is an excellent example of how research and development work can make a technology more competitive with conventional energy forms. In recent years, research has been increasingly directed at advancing wind power technology and at integrating wind power into the overall electricity system.

MW WIND TURBINES

Offshore wind farms make new technological demands on the wind power industry not only with respect to the development of the wind turbines themselves and with their connection to the electricity grid but also with respect to the logistics of transport, installation, operation and maintenance. This has led to the need for a new combination of research areas. New foundation techniques are under development. New knowledge about the sea bottom, waves, currents and the environment is being acquired and research into the load conditions for offshore wind turbines has been intensified.

When the Danish electricity companies' development programme for large-scale wind-power installations, initiated in the early 1980s, studied the conditions for the setting up of offshore wind turbines, it was concluded that there was a need for 1-2 MW wind turbines so as to compensate for the extra costs of foundations and cables. At the time, the necessary technology was not available. But it is available today.

3 MW wind turbines have already been installed in Danish waters and abroad, and even larger wind turbines, of up to 5 MW, are being tested as prototypes. In Denmark, this testing is being done at the Risø Research Centre's new research area at Høvsøre in northwestern Jutland. The research area has been divided into five sections for which wind turbine manufacturers are able to acquire short-term leases. In 2005, wind turbines up to 165 m high with individual capacities of up to 5 MW were set up. The research area has an annual average wind speed at a height of 78 m of more than 9 m/sec., which means that it is possible to reach wind conditions comparable to those offshore.

With the Horns Rev tender, location was reserved for the setting up of three research wind turbines as part of the planned farm. With the Rødsand tender, it is expected that place will be similarly allocated for the setting up of three research wind turbines. >

Photo: Forskningscenter Risø

FACT BOX

ERP (ENERGY RESEARCH PROGRAMME) PROJECTS OF SIGNIFICANCE TO OFFSHORE WIND TURBINE EXPANSION

The expansion of offshore wind farms has benefited from general research in wind power technology, which has made it possible to upscale to MW wind turbines. In addition, in the 1998-2005 period, the Danish Energy Authority provided support for a range of projects of particular significance to the expansion of offshore wind power:

ERP-98 Project: **Simplification of joints in offshore wind turbine foundations** with the consultant LIC as a project leader and an ERP grant of DKK 1.8 million (EUR 0.24 million).

ERP-99 Project: **Design basis for offshore wind farms** with the transmission company SEAS as project leader and an ERP grant of DKK 6.2 million (EUR 0.83 million).

ERP-2001-2005 Project: **Improved design basis for large wind turbine wings of fibre composites** with the Risø Research Centre as project leader and an ERP grant of DKK 8.7 million (EUR 1.16 million).

ERP-2005: **Soil/structure interaction of foundations for offshore wind turbines** with Aalborg University as project leader and an ERP grant of DKK 2.3 million (EUR 0.31 million).

The Risø Research Centre has received state aid to establish another testing station at Høvsøre in western Jutland. The station will be able to test five large wind turbines.

FACT BOX

PSO-FINANCED R&D PROJECTS OF RELEVANCE TO OFFSHORE WIND POWER EXPANSION

During the 1999-2005 period, the two TSO's, Eltra and Elkraft System (now merged as Energinet.dk), provided support to many R&D projects of particular significance to offshore wind power expansion, with grants amounting to a total of approx. DKK 57 million (EUR 7.6 million). The following are among the major projects:

Wave-forecast model for offshore wind turbine projects with Elsam Kraft as project leader and a PSO grant of DKK 2.8 million (EUR 0.37 million).
Measuring programme for wind, waves and current for Horns Rev and Læsø with Elsam Engineering as project leader and a PSO grant of DKK 7.6 million (EUR 1.01 million).
Shadow effects of offshore wind turbines in the form of several projects with Elsam and the Risø Research Centre as project leaders and a combined PSO grant of DKK 12 million (EUR 1.6 million).
Combination of natural loads with the transmission company SEAS as project leader and a combined PSO grant of DKK 3.6 million (EUR 0.48 million).
Lifetime- and load calculations on gear with Elsam Kraft as project leader and a PSO grant of DKK 3 million (EUR 0.4 million).
Dimensioning of offshore wind turbines, experience collection from offshore demonstration projects in the interests of an improved and integrated design process with Risø Research Centre as project leader and a combined PSO grant of DKK 11.7 million (EUR 1.56 million).
Design of erosion protection around offshore wind turbine foundations, experience collection with DHI as project leader and a PSO grant of DKK 1.3 million (EUR 0.17 million).
Power fluctuations from large offshore wind turbines with Risø Research Centre as project leader and a PSO-grant of DKK 3.5 million (EUR 0.47 million).
Necessary distance between large offshore wind farms with Risø Research Centre as project leader and a PSO grant of DKK 1.6 million (EUR 0.21 million).
Ice loads on offshore wind turbine foundations with Energi E2 as project leader and a PSO grant of DKK 3.2 million (EUR 0.43 million).

NEW FOUNDATION TYPES

Current offshore wind power technology is based on foundation types most suitable to shallow water. These foundations are either gravitation foundations made of cement or foundations consisting of steel monopiles driven into the sea bottom and used at depths of up to 19 m. In deeper water, tripod foundations, of the kind used for small offshore oil- and gas recovery installations or, alternatively, a floating "foundation", should presumably be used. At a special research area in Frederikshavn, a new type of foundation is being studied that uses a "suction cup" principle, according to which the foundation is secured to the sea bottom in a way that requires less material than with standard, gravitation foundations.

Denmark currently has a wide range of unique technological development environments in the wind power industry that, combined with government-subsidised research environments, give rise to optimistic expectations for further economic growth in the wind power sector. This applies both to large wind turbine manufacturers and to Danish research institutions and universities, which work together with industry at a high international level. Danish wind power installations both on land and offshore constitute a valuable data- and experience basis for the export of technologies and energy supply solutions.

RESEARCH INITIATIVES

One of the most important advances contributing to increased use of wind power, an advance in which Danish research and development programmes played a key role, is software for wind analyses. This software, known as WasP, makes it possible to determine where best to locate a

Photo: Elsam

wind turbine or wind farm so as to produce the greatest possible amount of power. WasP was developed with support from the ERP. In recent years, programmes have also been developed for short-term wind-energy projections at wind farms, with a forecast horizon of up to three days.

Another initiative of major significance for future upscaling is the research programme for aeroelasticity. In lay terms, this can be described as a toolkit providing manufacturers with new knowledge on aerodynamics and structure dynamics that they can use for the development of new and larger wings and to improve the design and stability of new wind turbine types. New, more powerful computers have made it possible not only to develop existing calculation programs further but also to carry out virtual flow studies in 3-D. In the long term, this possibility can reduce the need for expensive, full-scale rotor studies for MW wind turbines.

A cross-disciplinary research collaboration has begun a development that, within a few years, will produce user-friendly models for the design of large wind turbine wings made of newer and lighter, composite-fibre materials. Increased knowledge of the ultimate stress of glued joints, as well as other new knowledge, is expected to enable this research to lead to lower maintenance costs for wind turbine wings on offshore wind farms. These research initiatives have been undertaken in close co-operation between industry and research environments. >

Photo: Jan Kofod Winther

Photo page 28: At a special research area in Frederikshavn new types of offshore foundations are studied at three of the four wind turbines installed offshore.

Nysted Offshore Wind Farm is equipped with three meteorology masts that collect essential data on wind conditions.

Photo page 31: Ambitious expansion with offshore wind power in Denmark has resulted in new research concerning the electricity system's ability to handle large amounts of widely fluctuating electricity production.

Photo below: Placing the large foundations for the Nysted Offshore Wind Farm was a major logistical challenge.

Yet another area in which new initiatives are underway that have already proven to be of significance to the introduction of large quantities of wind power to the electricity system is the development of communication- and management technologies. New knowledge having to do with calculation tools for the simulation of wind turbines' electrical and regulations characteristics, with new management principles, new components and concepts for the integration of wind power into decentralised and centralised electricity systems has contributed in a major way to the accommodation of the large quantities of wind power produced in Denmark. Very large quantities of wind power have made it necessary to develop wind turbines that remain stable on the grid when grid outages occur. These developments are well on the way, thanks to new and cheaper electronic instruments specifically designed for wind turbines and wind turbine operation.

TECHNICAL APPROVAL SCHEME

In order for wind turbines to be set up in Denmark or in Danish waters, they, and the foundation used, must first be approved according to the Danish Energy Authority's technical approval scheme. This scheme, which has been in place since the beginning of the 1980s, is intended to ensure that wind turbines and their foundations are constructed and installed in agreement with regulations governing safety, energy and quality.

The scheme has also been valuable in the setting of international standards for wind power. Today, technical requirements for both land-based and offshore wind turbines are based on

Photo: Jan Kofod Winther

the standards established by the International Electrotechnical Committee (IEC) and by the set of rules in the IEDC WT01 (IEC System for Conformity Testing and Certification of Wind Turbines). The set of rules establishes a context for reciprocal international recognition of approvals and type tests.

RESEARCH AND TRAINING COMPETENCE

In order to strengthen the competence of research and training in Denmark, i.e. concerning offshore wind farms, the Risø Research Centre set up a consortium in May 2002 with the Danish Technical University, Aalborg University and the Danish Hydraulic Institute. The consortium was based on previous co-operation between the aeroelastic and electrical disciplines. The consortium, which is a cross-disciplinary network, is intended to strengthen co-operation between industry, training and research. It focuses on research areas such as climate conditions, wind turbine design, electrical systems, the control and integration of wind power in the electricity grid and market- and societal conditions.

Research and development in these areas is considered to be of great importance to the consolidation of Denmark's position of strength and to the integration of large numbers of wind turbines into the electricity system, as well as to the training of a qualified workforce. Within the sector, it is expected that there will be future challenges in the form of increased international competition from both new, resource-strong industrial players (from Europe, the USA and Japan) as well as from other technologies.

Photo: Forskningscenter Risø

The Risø Research Centre is the leader of a multiyear research project intended to improve design guidelines for large wind turbine wings. Vestas delivered a wing for full-scale testing at the research centre's laboratory.

Photo: Gunnar Britse/Energi E2

FACT BOX

RESEARCH STRATEGY FOR WIND POWER TECHNOLOGY

In co-operation with Energinet.dk, the power companies, the Danish Wind Industry Association, the Danish Research Consortium for Wind Energy and the Danish Society for Wind Energy, the Danish Energy Authority in 2003 has drawn up a strategy for future wind power research. The strategy has been widely supported by the sector and is to be used to develop a roadmap in the following initiative areas, among others:

- **Offshore wind energy production** with the development of new, large multi MW wind turbines (5-10 MW), the development of lighter and stronger compost materials for wings and the development of foundations for deeper water.
- **General cost reduction** with a long-term goal to halve the costs per kWh produced.
- **Operation and maintanance**, including through underlying knowledge on loads and materials as well as through better methods for surface treatment and corrosion protection.
- **Projection of wind energy production**, including through better wind-forecast methods.
- **Inclusion of wind energy production in the electricity system**, including through increased competence in the electrical systems and power electronics.
- **Inclusion of wind energy production in power- and energy markets**, including through identification of the correlation between the wind-energy contribution and the electricity system, and well-documented studies of wind turbine economy and environmental advantages.

INFORMATION ON THE INTERNET ABOUT OFFSHORE WIND POWER

Nysted Offshore Wind Farm has published its own website where visitors can follow the ongoing operation and make various virtual experiments. The site is in English, Danish and German.

There is a great deal of useful information available on the Internet regarding Danish offshore wind power expansion. Some of the main Danish websites in English are described here and links are given to further information, such as that provided by international wind power organisations.

OFFSHORE WIND POWER IN DENMARK

On the Danish Energy Authority"s website, there is a thorough presentation of Danish wind power expansion, including links to the relevant electricity legislation in English. After the general presentation of wind energy in Denmark, there is a more detailed discussion of offshore wind power expansion with support material on the legislative basis, on the environmental impact of the projects and on the various types of offshore wind power projects (pilot projects, projects with connection to technical installations, the Renewable-Energy Island project on Samsø, demonstration offshore wind farms and the most recent call for tenders for the Horns Rev II and Rødsand II installations.
www.ens.dk/wind

THE RISØ RESEARCH CENTRE

On this part of the research centre's website, its wind energy department presents the research activity underway on aeroelastic design, loads and safety, standardisation, wind-energy systems and test and measurements, etc. The Høvsøre test station, which has been especially set up to test offshore wind turbines, is also presented. The website provides visitors with the opportunity to order any of the almost 200 research- and test reports published by the wind energy department during the last 10 years.
www.risoe.dk/vea/index.htm

ENVIRONMENTAL MONITORING PROGRAMMES FOR THE DEMONSTRATION PARKS

Elsam/Vattenfall and Energi E2/DONG/ Sydkraft, which own and operate the two large Danish demonstration offshore wind farms at Horns Rev and Nysted, have each published a website about these farms. Here, visitors will find various virtual facilities, background information, news, photos and a complete overview of the monitoring programme's environmental reports. Nysted Offshore Wind Farm's website is in Danish, German and English. The German version is accessed by clicking on "deutsch" on the Danish version's opening page (*www.nystedhavmoellepark.dk/frames.asp*), while the English version is at the following address: *http://uk.nystedhavmoellepark.dk/frames.asp*.
The Horns Rev website is available in Danish and English versions at:
www.hornsrev.dk/Engelsk/default_ie.htm.

OTHER OFFSHORE WIND FARMS

Middelgrundens Vindmøllelaug, which is co-owner of the pilot project outside Copenhagen with twenty 2 MW wind turbines has opened a website where visitors can follow the electricity production and obtain more detailed information on the cooperatively owned parts of the offshore wind farm.
www.middelgrunden.com

Samsø Havvind A/S, which owns the offshore wind farm south of Samsø, has on its website integrated a facility which allows visitors constantly to follow the electricity production, wind speed and other operating conditions at the ten wind turbines. Of the ten turbines, five are owned by the local authorities, four by private investors, whilst the last one is owned by the partnership Paludans Flak Havvind I/S.
www.samsohavvind.dk/windfarm

THE DANISH WIND INDUSTRY ASSOCIATION

The Danish wind manufacturer's sector organisation has published a multilingual website with a large quantity of data and background information on wind power in general and specifically on wind power expansion in Denmark.
www.windpower.org

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ens@ens.dk
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National Registry
of Enterprises no.:
59 77 87 14

The Danish Energy Authority was established in 1976. Since 18 February 2005, it has been an Authority under the Ministry of Transport and Energy.

The Danish Energy Authority carries out tasks, nationally and internationally, in relation to the production, supply and consumption of energy. This means that the Authority is responsible for the entire chain of tasks linked to the production of energy and its transportation through pipelines to the stage where oil, natural gas, heat, electricity etc., are utilised for energy services by the consumer.

By establishing the correct framework and instruments in the field of energy, it is the task of the Danish Energy Authority to ensure security of supply and the responsible development of energy in Denmark from the perspectives of the economy, the environment and security.

It is the task of the Danish Energy Authority to advise the minister, to assist other authorities, to administer Danish energy legislation and to conduct analyses and assessments of developments in the field of energy, nationally and internationally.

DANISH ENERGY AUTHORITY