

Chapter 6

Denmark

6.1 INTRODUCTION

The total installed wind power capacity in Denmark by the end of 2003 was approximately 3,114 MW. Of this capacity, 2,708 MW is installed onshore and 420 MW offshore. In a year with normal wind conditions, the electricity produced from wind energy will cover almost 20% of the country's present electricity demand (35,200 GWh in 2003).

Danish offshore wind power plants presently constitute more than 80% of the total installed offshore capacity in the world. Information about the offshore installations and the preliminary experience are included in this report.

6.2 NATIONAL POLICY

Strategy

Development and implementation of wind energy has been included in all Danish energy strategies. Both demand-pull policy instruments (financial and other incentives) and technology-push policy instruments (certification schemes and R,D&D programs) have been used as tools in the strategies.

In the 1980s and the 1990s, Denmark implemented vigorous energy policies with broad political support involving a broad range of actors: energy companies, industry, municipalities, research institutions, nongovernmental organizations (NGOs), and consumers. The latest pull-policy

instrument is a re-powering scheme motivating owners of old turbines (with capacities of less than 150 kW) to scrap those and invest in new, larger-capacity machines. The re-powering scheme has been a time-limited program running from the beginning of 2002 until the end of 2003. The support scheme has resulted in the replacement of 1,200 old, small turbines with 300 new, larger machines.

The technology-push instruments have been reduced in steps with the development of a liberalized market for electricity including wind energy. The government also changed its focus for support to R,D&D. Funds for the Energy Technology Programme were reduced, and the special Development Programme for Renewable Energy Sources was stopped in 2002.

In place of these programs, the government introduced a new overall strategy for renewable energy research, which will be implemented over the coming years. The Public Service Obligation funds within the electricity sector for supporting the development of clean energy technologies continues.

The area resources for wind turbines on land are limited in Denmark. Furthermore, wind conditions at sea are considerably better than those on land, and wind turbines erected offshore are expected to become competitive in step with the development of technology.

For this reason, the main part of new development in Denmark is expected to take place offshore. Renovation of wind turbine areas and removal or replacement of existing wind turbines in accordance with regional and municipal planning will affect wind turbine capacity on land, among other things, after 2005.

In spring 1999, an electricity reform was introduced that unbundled the electricity sector. The reform also contributes to ensuring the fulfilment of the long-term, international environmental commitments for 2008 to 2012. The agreement covers the years from 2000 to 2003 and is a framework for carbon dioxide emissions from the electricity sector and for the development of renewable energy.

The Danish government's policy is to strengthen the use of market-based instruments in the energy sector. In its 2002 strategy for liberalization of the energy markets, the government emphasized the need to increase competition in the energy sector and encourage cost efficiency in renewable energy plants.

In its 2003 climate strategy, the government again emphasized cost efficiency and prioritized the most cost-efficient instruments for carbon dioxide reduction.

The instruments planned to support wind energy are: (1) providing economic incentive to gradually change to market prices with the "electricity plus environmental bonus," (2) strengthening fundamental research, and (3) offering tenders for offshore wind.

Progress Towards National Targets

The electricity from wind energy alone has covered nearly 16% of the total electricity consumption in 2003, fulfilling a major part of the target of 20% total renewable energy production.

Denmark is a densely populated country, and the Danish onshore wind resource is limited by zoning restrictions and the balance between wind energy development and other claims or interests in the open land. For this reason, The Danish Energy

Authority estimates little future capacity growth on land after 2003.

Several investigations of offshore wind resources have been prepared since 1977. In July 1997, a plan of action for offshore wind farms was submitted to the Minister of Environment and Energy. Two utility associations, Elkraft and Elsam, and the ministry's Energy Authority and Environmental Protection Agency, prepared the plan.

The plan shows how a total capacity of 4,000 MW offshore wind power in Denmark by 2030 could be established. The corresponding annual electricity production would be 12 TWh to 14 TWh, which is more than one-third of the present electricity demand of 35 TWh. Based on the plan, the first major 160-MW wind farm at Horns Rev in the North Sea was installed in 2002 and followed by a second, 160-MW wind farm in 2003 at Nysted in the Baltic sea south of the Island of Lolland.

Future offshore installation will be decided based on economical possibilities and needs specified by the government's future climate policy. The Danish Energy Authority is preparing tender documents for a third offshore wind farm to be announced early in 2004.

6.3 COMMERCIAL IMPLEMENTATION

Installed Capacity

The total capacity of wind power in Denmark increased to 3,114 MW by the end of 2003, distributed with 2,372 MW in western Denmark, and 742 MW in eastern Denmark. The total number of turbines was 5,389.

The development in accumulated wind turbine capacity and number of wind

turbines is shown in Figure 6.1. In spite of the growing total capacity, the number of wind turbines decreased, illustrating the success of the re-powering scheme.

Rates and Trends in Deployment

The deployment rate in Denmark in numbers and accumulated capacity are shown in Figure 6.2. Deployment has been almost constant from 1996 to 1999, adding approximately 300 MW of wind power capacity onshore annually.

In 2000, an extraordinary high capacity of about 600 MW was installed. In 2001, that figure fell to 117 MW, whereas in 2002, about 490 MW of new capacity was installed, including 160 MW offshore. In 2002, about 1,230 old wind turbines – amounting to a capacity of 110 MW – were removed.

The average size of the new installed wind turbines has grown gradually, from 750

kW in 1999; 889 kW in 2000 and 2001; 1.36 MW in 2002; and 2 MW in 2003. The development in wind turbine size is illustrated in Figure 6.2.

In 2003, offshore installations accounted for 196 MW, whereas onshore capacity only increased by 29 MW. This also means that private investment in wind turbines – during which the whole history of deployment in Denmark has been the main driver – now has been taken over by professional investors and utilities. By the end of 2003, a little more than half of the capacity in eastern Denmark was owned by utilities, whereas more than 80% was privately owned in the whole country.

Contribution to National Energy Demand

The total electricity production from wind energy in 2003 was 5,542 GWh, corresponding to about 15.7% of the total electricity demand in Denmark. The wind

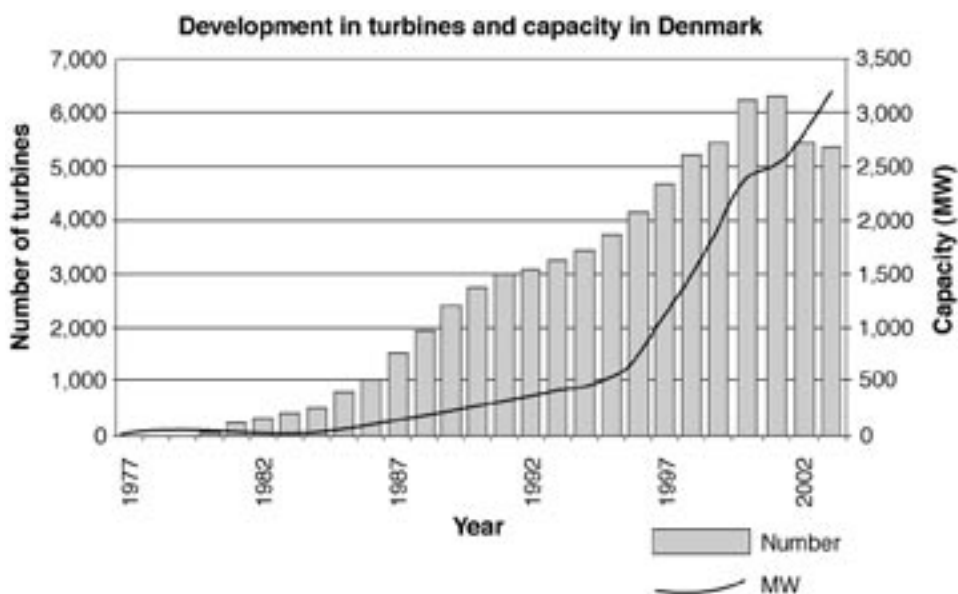


Figure 6.1 Development in number of wind turbines and accumulated electrical capacity in Denmark

energy index in 2003 (which describes the energy in the wind for a normal year) was similar to 2002: relatively low (approximately 84%).

For the western part of Denmark, Eltra reports that wind energy has covered 20.7% of the total electricity demand of 21 TWh in the Jutland-Fyn region. Development in the wind energy index is shown in Figure 6.3.

6.4 MARKET DEVELOPMENT AND STIMULATION

Main Support Initiatives and Market Stimulation Incentives

On 19 June 2002, the government entered into an agreement with the opposition about the future conditions for wind turbines. Consumers' obligations to purchase electricity from wind turbines are to be phased out. The support will be remodelled as financial support of 0.10 DKK/kWh, corresponding to the carbon

dioxide tax on electricity. Total support-plus-market price will be capped. New turbines must be encompassed by the new system of environmental bonuses with an aggregate cap for support-plus-market price of electricity of 0.36 DKK/kWh.

An overview of the selling prices for electricity produced by wind turbines in 2003 is shown in Table 6.1. On average wind turbines were paid approximately 0.5 DKK/kWh.

Present deployment activities are mainly due to the scheme for replacement of old wind turbines, which is valid until the end of 2003. New wind turbines installed according to this scheme receive an additional support of 0.17 DKK/kWh for the first 12,000 full-load hours. The replacement scheme is limited to wind turbines up to 150 kW.

For scrapped turbines of less than 100 kW, the additional support can be had for three

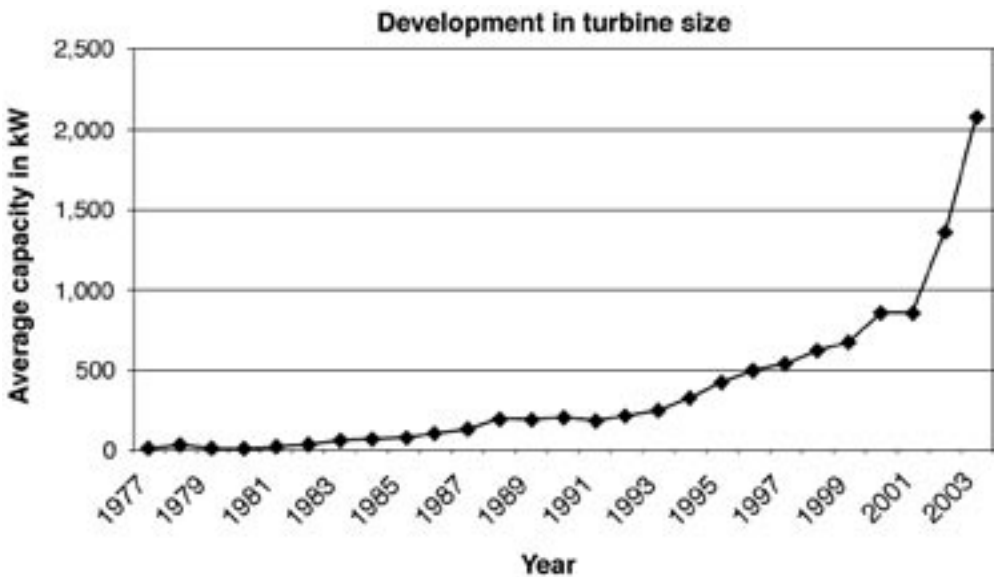


Figure 6.2 Development of average capacity of wind turbines installed in Denmark

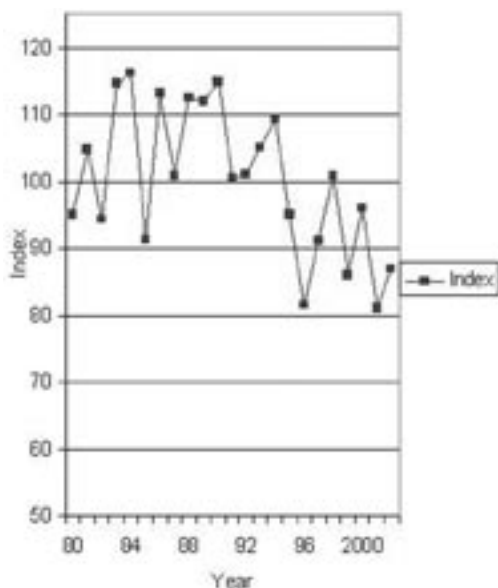


Figure 6.3 Annual wind energy in Denmark, illustrated by the wind energy index

times the scrapped capacity. For scrapped wind turbines in the range of 100 kW to 150 kW, support for twice the scrapped capacity can be had, provided that the scrapped wind turbines are situated less than 2.5 km from a wind turbine less than 100 kW, which will also be scrapped.

Favorable taxation schemes have earlier been used to stimulate private wind turbine installations. Today, income from wind turbines, by and large, is taxed depending on ownership as any other income.

Wind turbines erected in Denmark still have to fulfill the Danish approval scheme for wind turbines. The approval is partly based on a type-approval of the turbine and partly on a certified quality assurance system for the production and installation of the turbine. Today, all manufacturers have an ISO 9000 quality assurance system.

The Danish Energy Authority is responsible for administration of the scheme. Risø National Laboratory acts as secretariat and

information center for the approval scheme. All documents related to the approval scheme can be found on the Internet at <http://www.dawt.dk>.

The approval scheme is undergoing a transition into an international scheme, in step with development and recognition of international standards for wind turbines by IEC and CENELEC. Since 1979, Risø has been authorized by the Danish Energy Agency to issue licenses or type-approvals for wind turbines, as well as to perform the tests and measurements required for the approvals. Today the market for these services is liberalized, and private enterprises can be authorized to perform type approvals, certifications, tests, and measurements. This market is open for international competition, and several foreign enterprises are active (Table 6.2).

6.5 DEPLOYMENT AND CONSTRAINTS

Wind Turbines Deployed

Wind turbines are typically installed in clusters of three to seven machines. Local and regional planning authorities prefer clusters of wind turbines in spatial planning. Larger wind farms are allowed in some places.

Denmark's largest wind farm on land (in capacity) is still Rejsby Hede from 1995, with 39 machines of 600 kW each. The largest offshore wind farms are: (1) the 160-MW Horns Rev wind farm, consisting of 80 wind turbines of 2 MW each, placed in the North Sea, 14 km to 20 km offshore Blaavands Huk; and (2) the 165-MW Nysted wind farm south of Lolland in inland waters consisting of 72 wind turbines of 2.3 MW each.

Different groups own wind turbines: private individuals, private co-operatives, private industrial enterprises, municipalities, and

| Wind turbines bought until 31 Dec 1999 | Wind turbines bought after 1 Jan 2000. | New turbines from 2003 |
|--|--|--|
| <p>0.60 DKK/kWh until end of assigned full load hours, then 0.43 DKK/kWh until age 10 years with purchase obligation.</p> <p>From age 10 to 20 years market price plus financial support of 0.10 DKK/kWh. Cap of total support plus market price will be 0.36 DKK/kWh. No purchase obligation.</p> | <p>0.43 DKK/kWh for 22,000 full load hours with purchase obligation. From then on market price plus financial support of 0.10 DKK/kWh. Cap of total support plus market price will be 0.36 DKK/kWh. No purchase obligation.</p> | <p>Market price plus financial support of 0.10 DKK /kWh. Cap of total support plus market price will be 0.36 DKK/kWh. No purchase obligation.</p> |

Table 6.1 Prices and subsidies for 2003

power utilities. During the 1980s and early 1990s, most new turbines were installed by cooperatives. Since the mid-1990s, primarily farmers have installed wind turbines. This development is due to several factors: general interest rates have decreased; prices for wind power electricity have slightly increased; and laws for facilitating structural changes in the farming sector have, as a side effect, opened up new possibilities for farmers. Since the withdrawal of regulation, ownership has become more mixed. From the beginning of 2003 – when the new, liberal, market-based price system with a cap of 0.36 DKK/kWh including carbon dioxide compensation went into effect – the private investment in wind turbines has come to a complete stop.

The two 160-MW offshore wind farms at Horns Rev (Figure 6.4) and Nysted (Figure 6.5) are owned by utilities alone, whereas the 40-MW Middelgrunden offshore wind farm is a 50-50 shared ownership between a private co-operation and a utility. The smaller offshore wind farm of 23 MW south of Samsø, which was completed in 2003, is owned partly by municipality and private investors.

Operational Experience

Technical availability of new wind turbines in Denmark is usually in the range of 98% to 100%. The Danish Wind Turbine Owners' Association is recording operational experiences.

Technical lifetime or design lifetime for modern Danish machines is typically 20 years. The maintenance scheme may require that individual components are replaced or renewed with shorter intervals. Consumables, such as gearbox oil and braking clutches, are often replaced with intervals of one to three years. Parts of the yaw system might be replaced with intervals of five years. Vital components exposed to fatigue loads, such as main bearings and gearbox bearings, might be replaced halfway through the total design lifetime. This is dealt with as a re-investment.

Operation and maintenance (O&M) costs include service, consumables, repair, insurance, administration, lease of site, etc. The Danish Energy Agency, E&M-Data, and Risø National Laboratory have developed a model for annual O&M costs. The model is based on statistical surveys and analyses in

| Service | Authorised body |
|---|--|
| Type approvals of wind turbines | Det Norske Veritas Germanischer Lloyds |
| Production and installation certification | Germanischer Lloyds Certification GmbH Det Norske Veritas Certification of Mgt. Systems Bureau Veritas Quality Assurance |
| Basic tests | Risø, Test & Measurements Tripod Consult Aps Wind Test GmbH Ingenieurbüro für Windenergie |
| Power curve measurement | Risø, Test & Measurements DEWI, Wilhemshafen Tripod Consult Aps Wind Test GmbH Windconsult GmbH Ingenieurbüro für Windenergie |
| Testing of systems and concepts | Risø, Test & Measurements |
| Blade testing | Risø, Sparkær blade test centre |
| Noise measurement | DEWI, Wilhemshafen Wind Consult GmbH Wind Test GmbH DELTA Akustik & Vibration + bodies approved by DELTA |

Table 6.2 Bodies authorized by the Danish Energy Authority to provide services under the Danish scheme for certification and type-approval for wind turbines

1991, 1994, and 1997. The model includes a large re-investment, after the tenth operational year, on 20% of the cost of the wind turbine. This re-investment is distributed over the operational years 10 to 20 (Table 6.3).

Based on a previous study, results on operational experience are gathered in Table 6.4. The first part of this table shows the costs of repair and maintenance, while the second part presents the total O&M costs (i.e., including costs from items such as insurance, service, administration, and site rental).

Main Constraints on Market Development

Since the mid-1990s, the Danish market has been of a significant size and has remained remarkably constant. It was expected that the market would slow down due to

uncertainty on future purchasing prices and constraints due to spatial planning. But for 2002, the replacement program and offshore development have kept the market up. However, from the beginning of 2003, the market has vanished due to the low and unpredictable purchasing prices of wind electricity on the liberalized market. In certain regions of Denmark the deployment of wind energy has now reached a point of saturation with respect to spatial planning. Therefore, future inland market development will mainly be tied to replacement of smaller wind turbines with new, megawatt machines.

The conditions for connecting wind turbines to the grid and the establishment of future offshore farms have now been laid down in the electricity law as a result of the reformation of the Danish electricity sector. According to that law, the right to



Figure 6.4 Offshore wind farm at Horns Rev, 160 MW

Published with the permission from Elsam

exploit energy from water and wind within territorial waters and the economical zone (up to 200 nautical miles) around Denmark belongs to the Danish Government.

Approval of electricity production from water and wind and pre-investigation of such within the national territorial waters and within the economic zone belonging to Denmark are given by the Danish Energy

Authority. Permission will only be given for specific areas, and the impact on the environment must be documented by an environmental impact assessment for each project.

A possible constraint to the future deployment of wind energy into the Danish energy system is maintaining the power balance or dealing with the electricity surplus. Due to the high share (approximately 50%) of electricity from combined heat and power (CHP) and the high share (approximately 20%) from renewable electricity (mainly wind power), a substantial part of the Danish electricity production is derived mainly from weather conditions (outdoor temperature and wind speed). This limits the system's ability to adapt to quickly changing electricity prices on the market.

On cold, windy nights, an electricity surplus may arise. On one hand, this is a successful demonstration of how far CHP



Figure 6.5 Offshore wind farm at Nysted, 158 MW

Published with the permission of Energi E2

| Machine size | year 1 - 2 | year 3 - 5 | year 6 - 10 | year 11 - 15 | year 16 - 20 |
|--------------|------------|------------|-------------|--------------|--------------|
| 150 kW | 1.2 | 2.8 | 3.3 | 6.1 | 7.0 |
| 300 kW | 1.0 | 2.2 | 2.6 | 4.0 | 5.0 |
| 5 – 600 kW | 1.0 | 1.9 | 2.2 | 3.5 | 4.5 |

Table 6.3 Annual O&M costs by percent of wind turbine investment

Source: Danish Energy Authority, E&M-Data, and Risø National Laboratory

and electricity from renewable energy can be developed. On the other hand, it poses a new challenge to the electricity system and system operators to handle the fluctuating electricity production.

Electricity surplus is generally exported. If it is not physically possible to export the entire surplus, a critical situation arises. This happens already today in the western part of Denmark with increasing frequency – in the eastern part, it may be seen in the future. The economic benefit of reducing the surplus in general (rather than exporting it) depends on the price on the power market and on the environmental value of electricity export from Denmark. In general, more flexibility in power production and demand will be appropriate to be able to

respond to market conditions. The best economic means are to: move the power demand, move production with heat storage, replace CHP with heat pumps, and replace CHP with heat boilers fired with natural gas or biomass. Stopping the wind turbines for a few hours can also be a solution.

Offshore Wind Energy Development

With a couple of pilot projects in the 1990s and a number of large demonstration projects in recent years, Denmark has taken the lead in exploiting the specially favorable wind conditions at sea for carbon-dioxide-free electricity production from large, megawatt wind turbines. Danish experience encompasses the special production

| Reparation and maintenance costs (DKK/kW) after age | | | | |
|---|----------|----------|------------|--------------|
| Machine size | Year 0-4 | Year 5-9 | Year 10-14 | From year 15 |
| 55-65 kW | 100 | 300 | 300 | 250 |
| 75-200 kW | 80 | 120 | 150 | 200 |
| 210-599 kW | 60 | 100 | 120 | - |
| 600-750 kW | 30 | 40 | - | - |
| Summarized O&M-costs (DKK/kW) after age | | | | |
| Machine size | Year 0-4 | Year 5-9 | Year 10-14 | From year 15 |
| 55-65 kW | 330 | 530 | 530 | 480 |
| 75-200 kW | 290 | 330 | 360 | 410 |
| 210-599 kW | 225 | 265 | 285 | - |
| 600-750 kW | 155 | 165 | - | - |

Table 6.4 O&M costs in DKK/kWh after machine size and year

Source: Danish Energy Authority, E&M-Data, and Risø National Laboratory

conditions with stronger wind and less turbulence at sea, the technical conditions for grid connection, and the environmental impacts. There is great interest in the Danish experience at the international level, and several other European countries are now running offshore wind turbine projects.

Interest in the potential development of offshore wind energy has generally grown in step with the up-scaling of wind turbines. The overall maximum height of the tower and rotor of the wind turbine of about 150 m means that megawatt-scale wind turbines will dominate the landscape and that the precondition for continued large-scale development of wind energy in Denmark will be the exploitation of offshore potential.

The mapping of potential major sites for offshore wind farms in 1997 identified an immediate potential of approximately 4,000 MW in Danish waters. However, there are many indications that along with the development of more cost-efficient foundations, more sites can be found because wind turbines can be located at greater depths than foreseen in 1997.

The increased costs of foundations, grid connection, and service inspections for offshore wind farms will, to a steadily increasing extent, be balanced by higher energy production and longer lifetimes. The additional costs of electricity production from offshore wind farms for the largescale demonstration projects in Horns Rev and Nysted have been estimated as 20% in relation to good locations onshore. But when experience from these projects can be incorporated into incoming projects, additional costs are expected to be significantly reduced.

During the 1990s, Denmark implemented two pilot projects that provided crucial new knowledge about the economic and

environmental conditions for developing offshore wind farms. These two small demonstration farms are owned by utilities and are located at Vindeby (4.95 MW) and Tunø Knob (5 MW), respectively. They have remained in operation since the 1990s.

Since 2001, these projects have been followed up by a pilot project at Copenhagen (Middelgrunden), and three large-sale demonstration projects at Horns Rev at Esbjerg, and Nysted at Rødsand, respectively, with a total installed output of approximately 360 MW and wind turbines of 2 MW to 2.3 MW. The two large demonstration projects at Horns Rev and Nysted were constructed following orders from the government to the power sector.

The main data of the two Danish large wind farms at Horns Rev and Nysted are given in Table 6.5.

The 40-MW project at Middelgrunden, 2 km outside the Copenhagen harbor in shallow water (3 m to 5 m) was put into operation at the beginning of 2001. The farm comprises 20 Bonus wind turbines, each of 2 MW.

In December 2002, the last wind turbine in the 160-MW Horns Rev farm became operational. The farm is located 14 km from the coast at Blåvandshuk. The turbines are 2-MW Vestas with a total height of 100 m to 110 m, and the farm occupies an area of 20 km². (Figure 6.4)

The Nysted 72-turbine wind farm project, comprised of 2.3-MW Bonus wind turbines, has also been completed. For this wind farm, grid-connection work began in April 2002, installation of cables and turbines started in May 2003, and the last turbine was put into operation in September 2003. The total approved and installed wind farm capacity offshore is currently 406 MW. (Figure 6.5).

On 28 February 2003, the Samsø offshore wind farm, consisting of ten Bonus wind turbines, was inaugurated. The farm has an installed capacity of 23 MW and is located approximately 4 km south of Samsø. The turbines have a height of 100 m and are erected on monopiles.

In 2003, Elsam established an experimental offshore wind cluster of four wind turbines on a harbor site in Frederikshavn. It consists of two 3-MW Vestas turbines, one 2.3-MW Bonus turbine, and one 2.3-MW Nordex turbine.

Due to the special status of the demonstration program, an environmental measurement and monitoring program more comprehensive than the EIA's, has been initiated to investigate the effects on the marine environment before, during and after the completion of the wind-farms. The point is to provide a solid basis for decisions for the further development of offshore wind power. An environmental committee involving authorities and project-

responsible personnel to conduct the demonstration program has been established.

Further, the appointment of an international panel of experts with the objective to evaluate the demonstration program mirror the importance of gaining solid experience for large-scale wind-farms in our endeavor to increase the share of renewable energy and reduce the negative impact on the environment.

Also the economic and technical aspects are to be evaluated as part of the demonstration program. The objective is to ensure that the future offshore development is based on market conditions in an economically efficient way.

6.6 ECONOMICS

Trends in Investment

New information on investment costs is not available due to the new installed capacity being large, offshore projects.

| Wind farm characteristics | Horns Rev Wind Farm | Nysted wind farm |
|--|--------------------------|--------------------------|
| Installed capacity | 160 MW | 158.4 MW |
| Number of turbines | 80 | 72 |
| Wind turbine type | Vestas 2 MW | Bonus 2.2 MW |
| Expected annual production | 600 GWh | 595 GWh |
| Hub height | 70 | 70 m |
| Wind farm area | 20 km² | 24 km² |
| Water depth | 6.5-13.5 m | 6-9.5 m |
| Distance to shore | 14-20 km | 10 km |
| Distance between rows | 560 m | 850 m |
| Distance between turbines in rows | 560 m | 480 m |
| System solution type | B | A |
| Internal grid voltage | 34 kV | 33 kV |
| Transmission to shore voltage | 150 kV | 132 kV |

Table 6.5 Main data of the two large Danish wind farms at Horns Rev and Nysted

The ex-works cost of wind turbines decreased significantly with the introduction of the 600-kW and 750-kW generation (44-m to 48-m rotor diameter). For 600-kW machines installed in 1997 and 1998, the ex-works cost was typically 3.1 million DKK to 3.5 million DKK. For 750-kW in 1998, the ex-works cost was 3.4 million DKK to 4.1 million DKK, depending on rotor diameter and tower height.

For the recent megawatt machines, the ex-works cost might be slightly higher per kilowatt capacity. But because the wind resource at rotor height is larger and the harvest of wind energy therefore improved, the total economy of the megawatt projects is improved.

Availability of capital for wind power projects is not a problem. Financial institutions compete efficiently on this market, and different financial packages have been developed. Typical projects are financed over ten years.

Additional costs depend on local circumstances, such as the condition of

the soil, road conditions, and proximity to electrical grid sub-stations. Additional costs on typical sites can be estimated to approximately 20% of total project costs. Only the cost of land has increased during recent years.

Based on information from 65 new 660-kW to 1,000-kW wind turbine projects, the average cost of a 1,000-kW wind turbine project is estimated in Table 6.6.

Trends in Unit Costs of Generation and Buy-Back Prices

The production cost for wind-generated electricity per kilowatt-hour has decreased rapidly over the last 18 years, and today the costs are getting close to the cost of electricity production from a new, coal-fired power station based on condensation.

The average consumer (4,000 kWh/yr) net electricity price from power distribution utilities is approximately 0.56 DKK/kWh. This figure comprises subscription, grid, PSO tariff, and commercial and prioritized power costs. For private consumers (connected to the 400/230-V distribution grid), a number of taxes are added to this price. On the top, is a 25% value-added tax (VAT). In 2002, the total consumer price for Danish low-voltage customers was about 1.59 DKK/kWh in the eastern part and 1.67 DKK/kWh in the western part of Denmark.

With the 2000 regulation, the whole payment for wind-generated power comes from electricity consumers. The price that the distribution companies pay after a transition period will be the actual market prices for electricity. On top of that, it was proposed that the producers of electricity from wind should receive green certificates. The implementation of a market for these certificates is awaiting an international agreement between several European countries on the practical arrangement.

| Component | kDKK |
|---------------------------------|--------------|
| Turbine ex works | 5,364 |
| Foundation | 321 |
| Grid connection | 464 |
| Electrical installations | 79 |
| Communication | 12 |
| Land | 114 |
| Roads | 64 |
| Consulting | 38 |
| Finance | 27 |
| Other | 16 |
| Total | 6,500 |

Table 6.6 Cost of a 1,000-kW wind turbine project

Source: E&M-Data, November 2001

Table 6.1 gives an overview of the price subsidies.

6.7 INDUSTRY

Manufacturing

The major Danish-based manufacturers of large commercial wind turbines up to 3-MW size are: Bonus Energy A/S, NEG Micon A/S, and Vestas Wind Systems A/S. Late in 2003, Vestas and NEG Micon announced their merger. Gaia Wind Energy A/S makes 11-kW machines for electricity to households. Calorius-Westrup A/S makes a 5-kW, heatproducing turbine.

A number of industrial enterprises have developed important businesses as suppliers of major components for wind turbines. LM Glasfiber A/S is a world-leading producer of fiberglass blades for wind turbines. Mita Teknik A/S produces controller and communication systems. Svendborg Brakes A/S is a leading vendor of mechanical braking systems. Danish subsidiaries of large international industries – such as Siemens, ABB, SKF, and FAG – have developed businesses in the wind power industry.

Industry Development and Structure

Industrial development in 2003 focused on refining the megawatt generation of turbines and adapting to the emerging offshore wind farms. This includes, among other things, upgrading the turbines with larger generators and larger rotor diameters. The largest prototype is the 4.2-MW wind turbine from NEG Micon, which was erected in late 2003 at the Høvsøre test site.

The estimated sales by the Danish wind turbine manufacturers (Vestas, NEG Micon, and Bonus) were 3,219 MW in 2003, which is only slightly higher than the figure for 2002 (3,147 MW). The global increase of

wind power capacity in 2003 is estimated by BTM-Consult as 8,344 MW, bringing the world's total up to about 40,300 MW by the end of 2003. The rate of growth was 15% over 2002, giving an average growth rate during the last five years of 26.3%.

The Danish home market only amounted to 218 MW in 2003, considerably less than in 2002.

Manufacturers' internal service departments carry out service and maintenance of wind turbines in Denmark, but a handful of independent service companies have also been established. These are companies such as DWP Mølleservice A/S and DanService A/S. Some of the electricity companies service their own turbines.

Other industrial service enterprises have created important businesses in servicing the wind power industry. For example, various companies specialize in providing such products and services as cranes for installations of wind turbines; transport of turbines, towers, and blades domestically and for export; and insurance.

Companies with expertise in offshore construction and operation in the field of oil and gas activities are now offering their assistance to the wind energy business in connection with offshore wind farms. The major Danish consultancies in wind energy utilization are BTM Consult Aps, E&M Data, Elsam Engineering, WEA ApS, and Tripod ApS. Several experienced engineering consulting companies – such as Carl Bro, Rambøll, and Cowi – have shown increasing interest and are taking an active part in wind energy development.

The power production companies, Elsam and Energi E2, as well as DONG, have entered the wind energy business as developers, owners, and operators of wind farms in Denmark and internationally.

The two major organizations that represent the owners and the manufacturers are:

(1) the Danish Wind Turbine Owners' Association (<http://www.dkvind.dk>) and (2) the Danish Wind Industry Association (<http://www.windpower.org>).

6.8 GOVERNMENT-SPONSORED R,D&D

Priorities

The Danish Energy Authority, under the Ministry of Economic and Business Affairs, is responsible for the administration of the Energy Research Programme (EFP), which covers both conventional energy and renewable energy. The EFP is intended to contribute to establishing the technological possibilities required for the practical implementation of Danish energy policy. Therefore, using the results of the energy research projects creates part of the basis for Danish energy policy. The EFP is also intended to contribute to reinforcing exports of Danish energy technology and expertise. Active Danish participation in international standardization in IEC and CEN/CENELEC has a high priority, and R&D efforts supporting international standardization are encouraged.

Descriptions (in Danish) of the projects are available on the Danish Energy Authority's website, located at <http://www.ens.dk>. The budget for the EFP in 2002 and 2003 has been 40 million DKK, which is almost one-third that of previous years. Out of the budgets for 2002 and 2003, the following wind energy projects were supported. (In addition, EFP supports international R&D cooperation through IEA, with a total of approximately 1.4 million DKK from EFP 2002 and 2003). Wind energy projects funded by EFP in 2002 and 2003 are shown in Table 6.7.

Until 2002, the Danish Energy Authority also managed a program for development,

demonstration, and information of renewable energy (UVE). The Test Station for Wind Turbines at Risø National Laboratory has been supported under that program. The budget for the test station task at Risø, including administration of the Danish Approval Scheme, was close to 7 million DKK for 2001. For 2002, the budget for related activities was reduced to 3.7 million DKK.

The Test Station for Wind Turbines conducted the following activities in 2002:

1. General support to the Danish Energy Agency
2. Secretariat for the Danish certification and type-approval scheme
3. Spot-check of type-approved turbines
4. Inspections of major break-down of turbines
5. Danish and international standardization
6. Development of framework for a new approval scheme
7. Preparatory tests for a new test station at Høvsøre

In 2003, a contract with a budget of 900,000 DKK between the Danish Energy Authority and Risø was signed, whereby Risø operates an administrative secretariat for the type-approval. The type-approval system will be further internationalized, basing it on IEC standards. The wind turbine manufacturers have agreed to support international standardization through IEC and CENELEC.

The PSO-Program of the Transmission System Operators

In addition to government R&D programs, the transmission system operators (ELTRA and Elkraft System) have PSO-subsidized R&D programs for non-commercial projects concerning new and environmentally friendly energy technologies. The programs include development of renewable energy

| Title | Applic. | Total budget in 1,000 DKK | EFP support in 1,000 DKK |
|--|--------------|---------------------------|--------------------------|
| Application, demonstration and development of advanced aerodynamic models – EFP 2002 | Risø | 6,055 | 3,445 |
| Aero-elastic integrated wind turbine control – EFP 2002 | Risø | 3,120 | 2,010 |
| Material technology for surface coating of wind turbine blades and development of test methods for life time – EFP 2003 | Force | 4,670 | 2,355 |
| Wind measurements, development and demonstration of new and existing methods for remote and in-situ measurements – EFP 2003 | Risø | 3,945 | 2,499 |

Table 6.7 Wind energy projects funded by EFP in 2002 and 2003

technologies including wind power. The final approval rests with the Danish Energy Agency.

Since 1998, 25 wind projects have started under Elkraft and 23 under ELTRA, with a total PSO-support of 72 million DKK. The project topics and the funding are shown in Table 6.8. Of the total annual budget of 100 million DKK, approximately 10% has been used on wind energy. Efficiency, costs, reliability of wind turbines, regulation, production forecasting, environmental impact, and maintenance are the items that take priority.

For the 2003 PSO-Program, 3 million DKK has been allocated for a project on remote condition monitoring of wind turbine blades. Because especially large offshore turbines are inaccessible, the perspective is to equip blades with sensors to create a continuous-as-possible condition monitoring from ashore. Risø is the main contractor together with Force, InnospeXion Aps, and STC and Demex.

For the environmental offshore demonstration program, a total of 84 million DKK has been allocated as a PSO in the period 2001 - 2006. Baseline studies have to be undertaken in the projected

areas to be able to compare the existing environmental conditions to the introduction of a wind-farm in relation to topics such as birds, mammals, fish, benthic invertebrates and plants, hydrology and geomorphology as well as noise. In order to concentrate the investigations, it has been decided to conduct a monitoring program for prioritized subjects and to make effect-studies in areas where the presence of species to investigate can be expected to be high.

The Danish Research Agency – the National Research Councils

According to an agreement reached in 2002 between the government and the opposition, an amount of 110 million DKK (20 million DKK in 2003 and 45 million DKK in 2004 and 2005) will be devoted to strategic renewable energy research projects. An additional 15 million DKK were allocated for the 2003 call-for-proposals with a deadline of 1 October 2003. The funds will be administered by the Danish Research Agency – The Danish Technical Research Council.

The programs and the available funds, which may fund renewable energy R&D projects including wind energy, are summarized in Table 6.9.

| Topic | Number of projects | Funding support in 1,000 DKK | Percentage |
|------------------------------------|--------------------|------------------------------|------------|
| Wind resources | 13 | 17,891 | 24.8 % |
| Loads and safety | 5 | 10,555 | 14.7 % |
| Control and regulation | 3 | 5,000 | 6.9 % |
| Power transmission and integration | 4 | 5,286 | 7.3 % |
| Monitoring | 4 | 2,066 | 2.9 % |
| Technology projects | 9 | 6,261 | 8.7 % |
| Measurement programmes | 3 | 9,035 | 12.5 % |
| Other | 7 | 15,915 | 22.1 % |
| | 48 | 72,009 | 100 % |

Table 6.8 Topics and funding statistics for wind energy projects supported by the PSO-Program

Risø National Laboratory

In May 2002, in order to strengthen its competence to cover all sides of offshore development, and in order to strengthen the education of doctorate and engineering candidates, Risø formed a consortium with the Technical University of Denmark (TUD) in Lyngby, Aalborg University (AaU), and Danish Hydraulic Institute (DHI). This relationship builds on the existing close co-operation with TUD on aeroelastic design and with AaU on electrical design. The cross-disciplinary consortium is intended to improve the network and coordination between research, education, and industry. The research is planned and implemented around the following themes: (1) climatic conditions; (2) wind turbine design; (3) electrical systems; (4) control and integration; and (5) society, market, and energy systems.

In addition to project co-operation between the consortium partners, the Council of Researchers Education recently gave a grant to a national research school, the Danish

Academy in Wind Energy, with the purpose of strengthening the education of doctoral candidates and attracting visiting students, researchers, and professors.

During recent years, large efforts have been spent on establishing a new test site for multi-megawatt wind turbines. The test site has been selected at Høvsøre, at the northwest coast of Jutland, in order to have a reasonable number of high-wind situations during a limited test period. The annual average wind speed at 78 m high is 9.1 m/s. The test site consists of five test stands that allow turbines with heights up to 165 m and capacities of 5 MW each. West of each test stand, a met-mast has been erected, and two 165-m masts with light markings have been installed. Four manufacturers have leased test stands: Vestas, NEG Micon, Bonus, and Nordex. The first wind turbine at the test site, a 3-MW turbine with a rotor diameter of 90 m and hub height of 80 m, was put in operation on 7 November 2002. At present, five wind turbines are installed. The test site is shown in Figure 6.6.

| | Consumption | Transmission/ distribution | Production |
|--|--|--------------------------------|--|
| Objective | Savings | System integration | Environment-friendly technologies |
| Eltra/Elkraft general PSO | | (10 mio. DKK estimated) | |
| Non-commercial (R&D) PSO | 10-25 mio. DKK? | | 100 mio. DKK |
| EFP | 40 mio. DKK | | |
| Renewable energy R&D – Danish Research Agency | 35 mio DKK in 2003 45 mio. DKK in 2004 and 2005 | | |

Table 6.9 Programs and available funds for renewable energy R&D projects including wind energy

Authors: Peter Hauge Madsen and Egon T.D. Bjerregaard, Wind Energy Department, Risø National Laboratory, Denmark; and Jørgen

Lemming, Danish Energy Authority, Danish Ministry of Economic and Business Affairs, Denmark.



Figure 6.6 Høvsøre test site for megawatt-sized wind turbines