Chapter 6
Denmark

6.1 INTRODUCTION

In the 1980s and 1990s, with broad political support, Denmark implemented vigorous energy policies involving a broad range of actors: energy companies, industry, municipalities, research institutions, NGOs, and consumers. A continuous effort since the beginning has led to an installed wind energy capacity of approximately 2,936 megawatts (MW) by the end of 2002. In a year with normal wind conditions, this capacity will cover about 16.4% of Denmark's electricity demand.

In the following, the development and the status of wind energy in Denmark at the end of 2002 are presented.

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 (such as certification schemes and R,D&D programs) have been used as tools in the strategies.

During 2002 the main instrument for wind energy deployment on land has been an incentive motivating owners of old and less than 150-kilowatt (kW) turbines to scrap those and invest in capacity in larger and more efficient machines. The technology push instruments have been reduced in steps with the development of a liberalized market for electricity including wind energy. Also the government has changed the 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. Instead, the government has introduced a new overall strategy for research also covering renewable energy, which will be implemented over the coming years. Additionally, 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 at sites 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 will take place offshore. After 2005 the wind turbine capacity on land will be affected, among other things by renovation of wind turbine areas as well as by removal or replacement of existing wind turbines in accordance with regional and municipal planning.

In spring 1999, an electricity reform was introduced unbundling the electricity sector. The reform also contributes to ensuring the fulfillment of the long-term, international environmental commitments in 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 development of renewable energy.

For the period 2000 to 2003 a ceiling for carbon dioxide emission was established for the electricity sector expressed in carbon dioxide quotas. In 2000 it was 23 million tons;

in 2001, 22 million tons; in 2002, 21 million tons; and in 2003, it will be 20 million tons. The ceiling was split among the electricity production companies. If the annual quota is exceeded, the production companies must pay the sum of 40.00 DKK per ton carbon dioxide to the state.

The renewable energy quotas announced by the government mean that all consumers are obliged to purchase a share of electricity from renewable energy. The quota laid down means that 20% of the electricity consumption should be covered by renewable energy at the end of 2003. Since wind power is the most developed and one of the cheapest ways to save carbon dioxide, a major part of renewable energy has come from wind power. It is predicted that, with the full deployment of the new offshore wind farms, electricity from wind energy alone will cover about 18% of electricity consumption in 2003.

A rising share of electricity consumption will in the future be covered by electricity produced from renewable energy sources. It is the Danish government's policy that a more competition-based market mechanism should ensure the cost-effective development of future renewable energy production.

Progress Towards National Targets

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 only little growth in future capacity on land after 2003.

Several investigations of offshore wind resources have been conducted since 1977. As a result, two demonstration projects have been finalized. In July 1997 a Plan of Action for Offshore Wind Farms was submitted to the Minister of Environment and Energy. The plan was prepared by the two utility associations, Elkraft and Elsam, and the min-

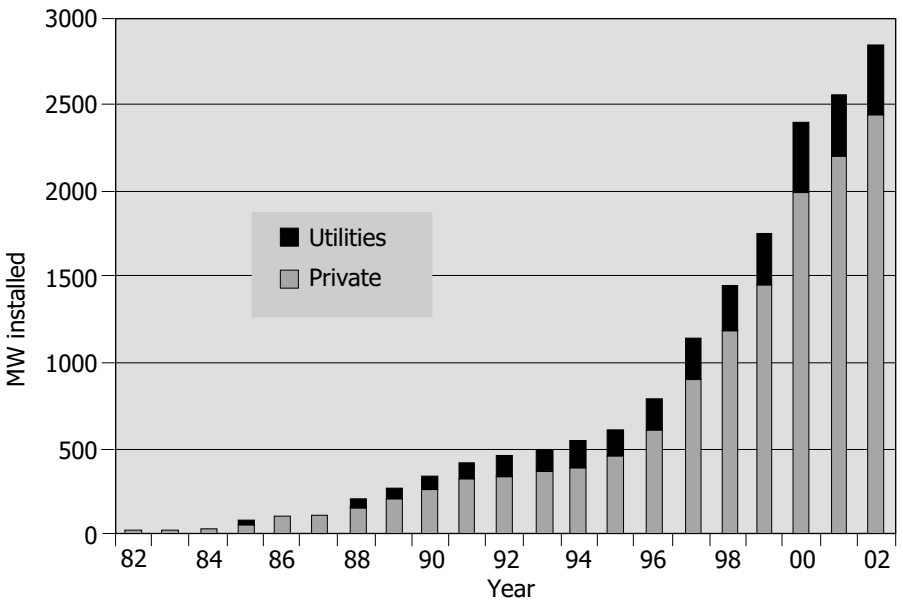

Figure 6.1 Accumulated wind turbine capacity in Denmark (1982 to 2002)

Year of installation	Number	Power (kW)	Average power (kW)
Before 1990	2,601	258,169	99
1990	385	81,913	213
1991	372	74,136	199
1992	217	45,230	208
1993	142	36,399	256
1994	135	48,604	360
1995	191	92,017	482
1996	400	205,853	515
1997	536	300,445	561
1998	462	312,925	677
1999	415	311,355	750
2000	675	600,365	889
2001	131	117,100	894
2002*	366	490,000	1,335

Table 6.1 Installed wind turbine capacity and development in size (*Year 2002 estimated). Source: E&M-Data until 2000

istry's Energy Authority and Environmental Protection Agency.

The plan shows how a total capacity of 4,000 MW of offshore wind power in Denmark could be established by 2030. The corresponding annual electricity production would be 12 to 14 terawatt-hours (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 Reef in the North Sea was installed in 2002, and a second is under construction in the Baltic Sea south of the island of Lolland. Future offshore installation will be decided based on economic possibilities and needs specified by the government's future climate policy.

6.3 COMMERCIAL IMPLEMENTATION

Installed Capacity

According to the Danish Wind Turbine Owners' Association, the total capacity of wind power in Denmark was 2,556 MW by the end of 2001. By February 2003, final statistics for year 2002 were not yet available. However it is estimated that the capacity has increased by about 380 MW in 2002, bringing the total up to 2,936 MW. The accumulated wind turbine capacity of private and utility wind turbine installations is shown in Figure 6.1.

Rates and Trends in Deployment

The deployment rate in Denmark in numbers and electrical capacity is shown in Table 6.1.

The deployment has been almost constant from 1996 to 1999, adding approximately 300 MW wind-power capacity onshore annually. In 2000 an extraordinarily 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 newly installed wind turbines has grown gradually,

being 750 kW in 1999, approximately 889 kW in 2000 to 2001, and an estimated 1.34 MW in 2002.

Contribution to National Energy Demand

The total electricity production from wind energy in 2002 was 4,877 GWh, corresponding to about 14% of the total electricity demand in Denmark. The wind's energy index in 2002 describing the energy in the wind of a normal year was relatively low (approximately 85%). The wind energy production with a wind index 100 would correspond to about 16.5% of the electricity demand. The development in the wind energy index is shown in Figure 6.2.

6.4 MARKET DEVELOPMENT AND STIMULATION

Main Support Initiatives and Market Stimulation Incentives

The owners of the power grid are in most cases obliged by law to connect wind turbines to the grid and to receive and pay for wind-generated electricity. Different arrangements have existed over the years. Since 1993, the payment for wind-generated electricity has been related to the utilities' tariffs. A law has obliged the power grid owners to pay wind turbine owners a kilowatt-hour (kWh) rate of 85% of the standard selling prices (85% of 0.37 to 0.45 DKK/kWh in 1998). Up to 2002, 0.10 DKK/kWh carbon dioxide tax has been reimbursed to wind turbine owners and 0.17 DKK /kWh has been added in direct subsidy. As a result, in 2001 the average purchase price for electricity from private wind turbines was between 0.43 DKK/kWh and 0.58 DKK/kWh.

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

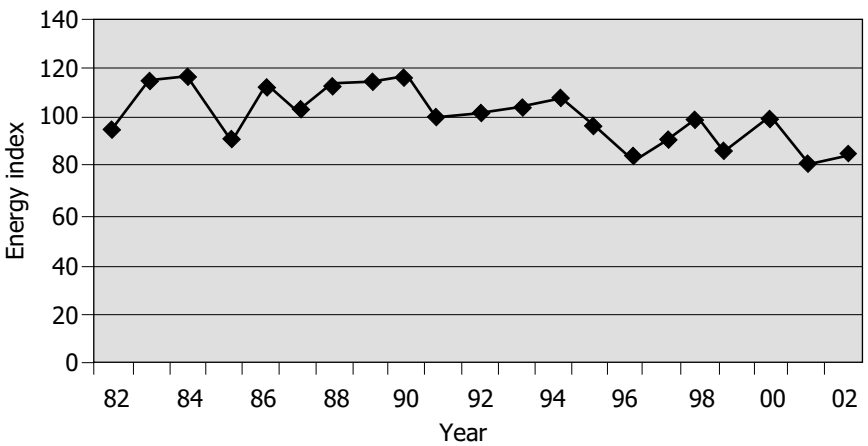

Figure 6.2 Energy in the wind energy index in Denmark, 1982 to 2002

not been installed in fulfillment of the obligations of the power companies is shown in Table 6.2.

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 receives 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 below 100 kW, the additional support can be had for three times the scrapped capacity, whereas 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 wind turbines less than 100 kW, which will also be scrapped.

Small wind turbines up to 25 kW used for households will still receive 0.60 DKK for surplus electricity delivered to the grid.

Earlier regulations limiting private wind developments were withdrawn in 2000. Favorable taxation schemes were used earlier to stimulate private wind turbine installations. Today, income from wind turbines, by and large, is taxed 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 web site, www.dawt.dk.

Danish wind turbines power purchase prices:	Wind turbines bought until 31 Dec 1999	Wind turbines bought after 1 Jan 2000.
Until end of 2002	0.60 DKK/kWh until end of assigned full load hours, then 0.43 DKK/kWh. Purchase obligation.	0.43 DKK/kWh for 22000 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.
From 2003	0.60 DKK/kWh until end of assigned full load hours, then 0.43 DKK/kWh until age 10 years with purchase obligation. 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.	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.

Table 6.2 Prices and subsidies as per end of 2002.

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 International Electrotechnical Commission (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. See Table 6.3.

6.5 DEPLOYMENT AND CONSTRAINTS

Wind Turbines Deployed

Wind turbines are typically installed in clusters of three to seven machines. Clusters of wind turbines are preferred in the spatial planning by local and regional planning authorities. At a few places, larger wind farms

Service	Authorized 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 6.3 Bodies authorized by the Danish Energy Authority to provide services under the Danish scheme for certification and type-approvals for wind turbines (Dec 2002)

Figure 6.3 Offshore wind farm at Horns Rev, 160 MW (Pubished with the permission of ELSAM)

are also allowed. Denmark's largest wind farm on land (in capacity) is still Rejsby Hede from 1995 with 39 600-kW machines. The largest offshore wind farm is the new 160-MW Horns Rev, consisting of 60 2-MW wind turbines placed in the North Sea 14 to 20 kilometers (km) offshore Blaavands Huk.

Different entities own wind turbines: private individuals, private co-operatives, private industrial enterprises, municipalities, and 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 increased slightly, 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 the regulation, the ownership has become more mixed.

The 160-MW offshore wind farm at Horns Rev (see Figure 6.3) is owned by the utilities alone (Elsam), whereas the 40-MW Middelgrunden offshore wind farm is a 50-50 shared ownership between a private corporation and a utility. Construction of a 166-MW offshore wind farm at Roedsand and a smaller farm of 23 MW south of Samsoe was started in 2002.

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. The results are published in the association's magazine Vindstyrke.

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 at shorter intervals. Consumables

such as oil in gearbox, braking clutches, etc., are often replaced at intervals of one to three years. Parts of the yaw system might be replaced at intervals of five years. Vital components exposed to fatigue loads such as main bearings and bearings in gearboxes might be replaced halfway through the total design lifetime. This is dealt with as a reinvestment.

Operation and maintenance 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 operation and maintenance costs. The model is based on statistical surveys and analyses in 1991, 1994, and 1997. The model includes a large reinvestment after the tenth operational year on 20% of the cost of the wind turbine. This reinvestment is distributed over operational years 10 to 20. (See Table 6.4.)

In an ongoing project, both the technical and the economical lifetime of wind turbines are being investigated. The work is concerned with machine sizes of 55, 150, 225, 300, 500, 600, 660, and 750 kilowatts, and it is based on empirical data from a major questionnaire that has been sent to approximately 2,500 wind turbine owners in Denmark. The returned data have been merged with the database mentioned previously. The first results on the operational experience are gathered in Table 6.5. The first part of this table shows the costs of repair and maintenance, while the second part presents the total operation and maintenance (O&M) costs, i.e., including costs from insurance, service, administration, site rental, etc.

It is normally expected that O&M costs increase over time. Nevertheless, the empirical costs for the 55-kW turbine actually decreased after 10 years of operation, as can be observed in Table 6.5.

Main Constraints on Market Development

Since the mid-1990s, the Danish market has been of significant size and been remarkably constant. It was expected that the market would slow down due to uncertainty regarding future purchasing prices and constraints due to spatial planning, but for 2002 the replacement program and offshore development have kept the market up.

In certain regions of Denmark, the deployment of wind energy has now reached a point of saturation with respect to spatial planning. Future land-based market development will therefore mainly be tied to replacement of smaller wind turbines with new, higher-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 exploit energy from water and wind within the territorial waters and the economical zone (up to 200 nautical miles) around Denmark belongs to the Danish government.

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 6.4 Annual operational and maintenance costs in % of the investment in the wind turbine. Source: Danish Energy Authority, E&M-Data and Risø National Laboratory.

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 6.5 O&M-costs in DKK/kW after machine size and year.
Source: Danish Energy Authority, E&M-Data and Risø National Laboratory.

Approval of electricity production from water and wind, and preinvestigation of such within the national territorial waters and within the economical 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 EIA for each project.

Electricity Surplus

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 (~50%) of electricity from combined heat and power (CHP) and the high share (~14%) from renewable electricity (mainly wind power), a substantial part of Danish electricity production is derived mainly from weather conditions (outdoor temperature and wind speed), thus limiting 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 and electricity from renewable energy can be developed. On the other hand, it poses a new challenge to the electricity system in general and the system operators in particular to handle fluctuating electricity production.

In 2001, the Danish Energy Authority set up a commission with the task of illustrating the challenges from the increasing share of electricity from wind turbines and CHP. The report was submitted for hearing by the end of 2001. The commission looked in particular at the electricity surplus. Electricity surplus is generally exported. If it is not physically possible to export the entire surplus, a critical situation arises.

The commission concluded regarding the critical surplus that it happens already today in the western part of Denmark with increasing frequency, while in the eastern part it may be seen in the future.

The economical 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 exported from Denmark. In general, more flexibility in power production and demand will be appropriate to enable response to market conditions. The economical best means are to move the power demand, move

production with heat storages, replace CHP with heat pumps, and replace CHP with heat boilers fired with natural gas or biomass. Also, stopping the wind turbines for a few hours can be a solution.

6.6 ECONOMICS

Trends in Investment

The ex-works cost of wind turbines decreased significantly with the introduction of 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, DKK 3.1 million to DKK 3.5 million, and for 750-kW in 1998 it was DKK 3.4 million to DKK 4.1 million depending on rotor diameter and tower height.

For the recent MW machines the ex-works cost might be slightly higher per kilowatt of capacity. But as the wind resource at rotor height is greater and the harvest of wind energy therefore better, the total economy of the MW projects will be better.

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 1000 kW wind turbine project.

Source: E&M-Data, Nov 2001)

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 10 years.

Additional costs depend on local circumstances, such as condition of the soil, road conditions, proximity to electrical grid sub-stations, etc. Additional costs on typical sites can be estimated to be 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 Energy and Buy-Back Prices

The production cost per kilowatt-hour for wind-generated electricity has decreased rapidly over the past 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 estimated cost is shown in Figure 6.4. Average consumer (4,000 kWh/year) net electricity price from power distribution utilities is around 0.56 DKK/kWh. This figure comprises subscription, grid and PSO tariff, and commercial and prioritized power cost. For private consumers (connected to the 400/230-volt distribution grid) several taxes are added to this price. On the top a 25% Value Added Tax (VAT) is added. 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 regulation from year 2000, the whole payment for wind-generated power comes from the electricity consumers. The price that the distribution companies pay after a transition period will be the ac-

tual 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 among several European countries on the practical arrangements.

Table 6.2 gives an overview of the price subsidies.

6.7 INDUSTRY

Manufacturing

Danish-based manufacturers of large commercial wind turbines in the 150-kW to 3-MW range are Bonus Energy A/S, NEG Micon A/S, Vestas Wind Systems A/S, Norwin A/S, and Wincon West Wind A/S. The originally Danish company Nordex Borsig has the main part of its manufacturing in Germany and is therefore not included in the statistics for sale from Danish manufacturers.

Gaia Wind Energy A/S makes 11-kW machines for electricity to households. Calorius-Westrup A/S makes a 5-kW heat-producing turbine.

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

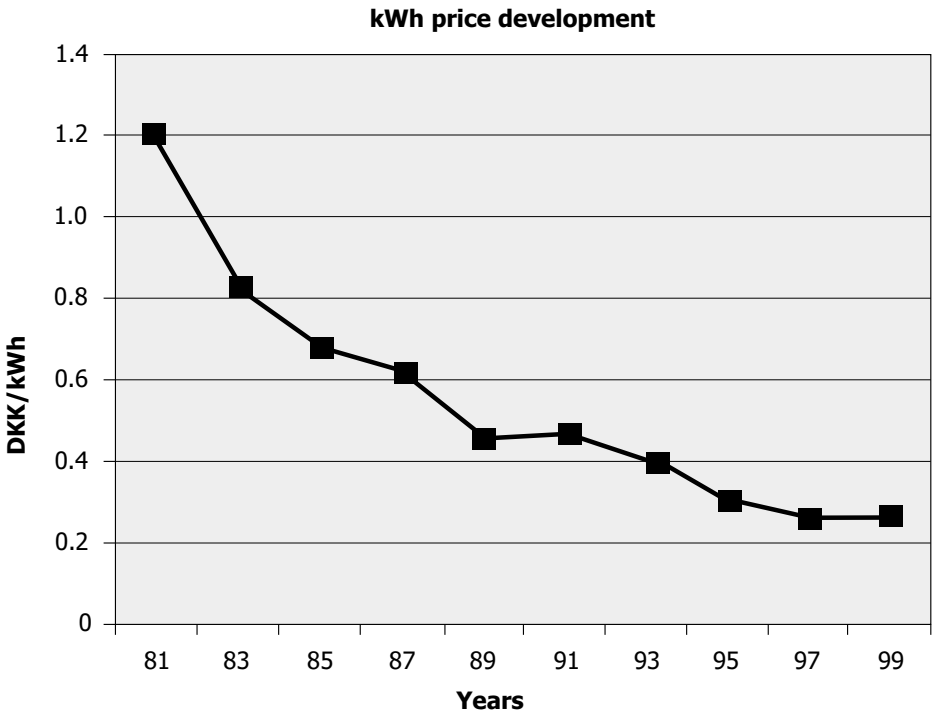

Figure 6.4 Estimated costs of wind generated electricity in Denmark. Based on 20 years' depreciation, 5% interest rates and siting in roughness class 1.

Industry Development and Structure

Industrial development in 2002 focused on refining the MW 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 diameter. The wind turbine types from Danish manufacturers are shown in Table 6.7. For most of the types, several versions with different tower heights can be supplied.

Estimated sales by Danish wind turbine manufacturers (excluding Nordex Borsig) were almost 3,150 MW in 2002, which is only slightly higher than the figure for 2001 (3,115 MW). The global increase of wind power capacity in 2002 is estimated to have been around 7,000 MW, corresponding to 28% increase of capacity, bringing the world's total up to about 32,000 MW by the end of 2002. The rate of growth was apart from the unusually high rate in 2001 (47%) on level with previous years development rate of the world market. The Danish wind turbine man-

Manufacturer	Type	Nominal power (kW)	Extra generator (kW)	Rotor diameter (m)	Power regulation
BONUS	600 MK IV	600	120	44.0	Stall
BONUS	1 MW	1,000	200	54.0	Ac stall
BONUS	1.3 MW	1,300	250	62.0	Ac stall
BONUS	2 MW	2,000	400	76.0	Ac stall
BONUS	2.3 MW	2,300	400	82.4	Ac stall
NEG MICON	NM600/43	600	150	43.0	Stall
NEG MICON	NM600/48	600	150	48.0	Stall
NEG MICON	NM750/44	750	200	44.0	Stall
NEG MICON	NM750/48	750	200	48.0	Stall
NEG MICON	NM900/52	900	200	52.0	Stall
NEG MICON	NM1500C/64	1,500	400	64.0	Stall
NEG MICON	NM2000/72	2,000	500	72.0	Ac stall
NEG MICON	NM 2750/80	2,750	-	80.0	Ac stall
NORDEX	N27/150	150	30	27.0	Stall
NORDEX	N43/600	600	125	43.0	Stall
NORDEX	N50/800	800	125	50.0	Stall
NORDEX	N60/1300	1,300	250	60.0	Stall
VESTAS	V27	225	50	27.0	Pitch
VESTAS	V39	500	-	41.8	Pitch
VESTAS	V47	660	200	47.0	Pitch
VESTAS	V52	850	0	52.0	Pitch
VESTAS	V66	1,750	0	66.0	Pitch
VESTAS	V80	2,000	0	80.0	Pitch
WINCON	W250/29	250	0	29.0	Stall
GAIA WIND	GW 11	11	0	13.0	Stall

Table 6.7 Wind turbines approved to the Danish market. Dec. 2002

ufacturers' share of the total world market in 2002 was thus about 45%. The Danish home market has amounted to about 490 MW, which is remarkably higher than the 117 MW in 2001. It is worth noting that a significant part of Danish wind turbines and components are produced abroad by sub-suppliers and/or by subsidiaries.

Service and maintenance of wind turbines in Denmark is carried out by the manufacturers' own service departments. 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 companies are specialized in providing cranes for installations of wind turbines; providing transport of turbines, towers, and blades domestically and for export; insurance, etc. Companies with expertise in offshore construction and operations in the field of oil and gas activities are now offering their assistance to the wind energy business in connection with the offshore wind farms. The major Danish consultancies in wind energy utilization are BTM Consult ApS, E&M Data, Tech-wise A/S, WEA ApS, and Tripod ApS. Several experienced engineering consulting companies such as Carl Bro, Rambøll, Cowi, and others have shown increasing interest and are taking active part in wind energy development. There is one major independent developer of wind farms in Denmark, Jysk Vindkraft A/S, that sells turnkey projects to farmers and co-operatives.

The two major organizations that represent the owners and the manufacturers are the Danish Wind Turbine Owners' Association, www.dkvind.dk, and the Danish Wind Industry Association, 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. Practically all projects are initiated through the annual calls for proposals issued for each area of energy, where wind energy is one of the issues. Projects are normally run over two or three years, and funding will be given by the end of each year. In almost all projects several partners participate, and industrial participation and co-financing are encouraged. The Danish Energy Authority finances 50% to 85% of the total costs. The budget for the EFP in 2002 has been 40 million DKK – almost one third of previous years. Out of that budget for 2002, two wind energy projects were supported with a total amount of 4 million DKK.

According to an agreement reached in 2002 between the government and the opposition, a total 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.

Until 2002 the Danish Energy Authority also managed a program for development and demonstration of renewable and information about it (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 the related activities was reduced to 3.7 million DKK.

In addition to the government R&D programs, the system operators (ELTRA and Elkraft System) have PSO-subsidized R&D programs for non-commercial projects con-

cerning new and environmentally friendly energy technologies. Prioritized issues are efficiency, costs and reliability of the wind turbines, regulation and forecasting of production, environmental impact, and maintenance. Calls for proposals have been issued with 15 September 2003 as the deadline, and several wind projects have been chosen for support. The programs include development of renewable energy technologies including wind power. Final approval rests with the Danish Energy Authority. For 2002, a total amount of 12.8 million DKK was PSO-subsidized to R&D wind energy

Figure 6.5 The new test station for MW wind turbines at Hoevsoere in Jutland

projects. For 2001 the total PSO funding for wind energy was 16.2 million DKK.

International co-operation on wind energy R&D is emphasized by the Danish Energy Authority. Denmark has participated in the international co-operation in IEA R&D Wind since its establishment 25 years ago.

Danish universities, research centers, power utilities, and the manufacturing industry participate in the European Union's RTD programs. No quantitative data are available for 2002.

Active Danish participation in international standardization in IEC and CEN/CENELEC has a high priority, and R&D efforts supporting international standardization are encouraged.

New R,D&D Developments

In recent years the Danish energy research program has emphasized the uncertainties and challenges associated with wind development offshore. In 1999, new R&D projects included wind resources and forecasting offshore, integration of the large offshore wind farms into the electricity system, and development of large wind turbines. For 2000 and 2001, new projects were initiated about components (e.g., gears), design conditions, integration with the electricity system, and environmental impact. For 2002 the calls for proposals have been limited to wind turbine technology and wind resources and climate.

Descriptions (in Danish) of the projects are available on the Danish Energy Authority's Internet site (refer to www.ens.dk).

These activities comprised 2002 activities for the test station for wind turbines.

- General support to the Danish Energy Agency
- Secretariat for the Danish certification and type-approval scheme
- Spot-check of type-approved turbines
- Inspections of major breakdown of turbines
- Danish and international standardization
- Development of framework for a new approval scheme
- Preparatory tests for new test station at Høvsøre

In May 2000 the Minister of Environment and Energy issued a directive allowing Risø to acquire and develop a test site for wind turbines in Høvsøre at the windy northwest coast of Jutland. The test site was inaugurated in December 2002. In the first phase it is equipped with five test sites for measurements on multi-megawatt wind turbines with heights up to 165 m. Four of the test sites were put into operation at the end of 2002. (See the photo, Figure 6.5.)

Offshore Siting and Wind Energy Development

The two small demonstration farms at Vindeby (4.95 MW) and Tunø Knob (5 MW) owned by the utilities have been in operation since 1999.

The 40-MW project at Middelgrunden 2 km outside the Copenhagen harbor in shallow water (3 to 5 m) was put into operation at the beginning of 2001. The farm comprises 20 Bonus wind turbines, each of 2 MW. The total projected power production per year is 89 million kWh, with a net production cost of 0.32 DKK/kWh. After a run-in period, the wind farm was set on full power from the end of March 2001, and owners report that production has been slightly higher than anticipated for 2001.

The wind farm is owned 50-50 by a wind energy cooperative, Middelgrundens Vindmøllelaug, and the utility, Copenhagen Energy. At its inauguration, the project was

the largest offshore wind farm worldwide. About 8,500 people and companies are members of the cooperative. The objective was to combine pollution-free electricity production with involvement of local people in Copenhagen.

Prior to the development of wind farms offshore, a governmental committee has been looking at the regulatory conditions for offshore wind power installations. Beyond selecting the sites for the small demonstration farms and the new larger farms, all interests in Danish waters were mapped. Also, a set of recommendations for future installations was given based on input from authorities and on surveys carried out over the years.

Studies financed by power utilities Danish Energy Agency and EU/JOULE indicated a substantial cost reduction for new 100-MW to 200-MW offshore projects: a 56% reduction compared with Vindeby. More accurate assessment of the offshore wind climate and prediction of wind loads are important research issues that have been supported by government funding.

A Plan of Action for Offshore Wind Farms was submitted to the Minister of Environment and Energy in 1997. The plan includes eight areas with water depths of up to 15 m. The total theoretical installed capacity of these areas is 28,000 MW, and it was estimated that about 12,000 MW realistically could be utilized in four major areas. These are west of Horns Rev in the North Sea, south of the island of Læsø in Kattegat, south of the island of Omø in Smålands Havet, and south of Lolland Falster (Rødsand and Gedser) in Østersøen (the Baltic Sea). Wind speeds in the areas allow 3,530 "net-full load hours" in the North Sea (Horns Rev) and between 3,000 and 3,300 hours in interior Danish waters. This corresponds to an annual electricity production of 36 TWh to 40 TWh. For comparison, the total Danish electricity consumption in 2000 was 35 TWh.

The Danish Energy Authority has continued the implementation of the first phase of the Plan of Action for Offshore Wind Farms in Danish Waters, which started in 1998. According to the agreement, 750 MW in five large offshore farms should be erected between 2001 and 2008.

In 2001, Elsam/Eltra was granted permission to develop a wind farm at Horns Rev at the west coast of Jutland, while SEAS on behalf of E2 was granted permission for a project at Rødsand, south of Seeland. Environmental impact assessments have been carried out for the projects.

Both wind farms consist of 80 wind turbines and a capacity of approximately 160 MW. The Horns Rev farm was completed and connected to the grid in 2002. The farm is located 14 km from the coast at Blåvandshuk. The turbines are 2-MW Vestas turbines with a total height of 110 m, and the farm occupies an area of 20 square kilometers. The wind turbines for the farm at Rødsand will be 2.3-MW Bonus turbines. Rødsand was under construction in 2002 and was expected to be put into operation in 2003. The other Danish offshore wind farms mentioned previously were put on hold by the government in 2002.

Estimates of the total realistic offshore power capacity and the electricity production are shown in Table 6.8.

According to Danish electricity supply law, the establishment of offshore wind farms has up to now required a permit as well as a license for operation. The twofold approval process includes permission for preliminary surveys and later a final approval of projects (a building permit). Both depend on a process of public hearing to take the different interests into account. In relation to the latter, the applicant is called on to do an EIA. The topics cover a wide range of environmental matters: sea bed conditions, raw materials,

	Realistic capacity	Realistic production	Percent of annual electricity consumption
Offshore	**12,000 MW**	**30 - 40 TWh**	**~ 100 %**

Table 6.8 Estimated wind turbine capacity and production in Denmark

hydrography, water quality and benthic fauna and vegetation, fish, birds, marine mammals, landscape and visual impact, marine archaeology, emissions, noise, matters of recreation and planning, and the impact on sailing and fishing in the area. The EIA will also contain suggestions for limiting or neutralizing potential negative effects on the environment.

Due to the special status of the demonstration program, an environmental measurement and monitoring program more comprehensive than the EIAs 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 to conduct the demonstration program has been established. Further the appointment of an international panel of experts with the objective of evaluating the demonstration program mirrors 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.

The environmental committee has prioritized activities in the demonstration program to clarify the following issues.

- The risk of having essential negative effects on the environment
- The ecological fragility of the specific areas
- The usefulness of the areas to investigate specific effects
- The relevance of the effects to decision-making regarding further development within the specific areas and the overall development of future offshore wind farms
- The importance of the different effects in relation to the demand for action and the economic framework for the program

Baseline studies are presupposed to be undertaken in all the projected areas to be able to compare the existing environmental condition 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.

To concentrate the investigations further it has been decided to conduct a monitoring program for prioritized subjects and to study effects in areas where the presence of species to investigate can be expected to be high. In addition, selected thematic effects studies are undertaken, such as the visual aspects, introduction of hard-bottom habitat (artificial reefs), and impact from electric or magnetic fields.

Also, the economic and technical aspects are to be evaluated as part of the demonstration program. If the experiences are positive, the areas will then become open for commercial projects.

An important concern for the Danish government is to ensure that future offshore development is based on market conditions in an economically efficient way. The government therefore in 2002 decided to set up a committee to study the possibilities and conditions of tendering future offshore wind farms. The main objective of the committee was to establish a framework of conditions for a tendering procedure for establishing

offshore wind farms in Danish waters. By applying such a procedure, competition among the bidders will be ensured and the most cost-effective offshore turbine developments will be undertaken. The committee finished its work at the end of 2002 by publishing a report that will be discussed in the government in connection with a climate policy to be published in the beginning of 2003.

The committee recommends that the first future offshore development take place at Horns Rev and points out that offshore wind farms are more stable power producers than turbines on land. Furthermore, the committee presents two scenarios for the economy of future offshore wind farms: with 3-MW wind turbines resulting in a production cost of 0.28 DKK/kWh to 0.34 DKK/kWh, and with 5-MW turbines for which the production cost is estimated to be 0.26 DKK/kWh to 0.31 DKK/kWh. Finally, the committee estimates that if the government decides to start the tendering in 2003, the next offshore wind farm in Denmark will be in place and grid-connected by 2007 at the earliest.

Authors: Peter Hauge Madsen, Risø National Laboratory, Denmark; Egon T.D. Bjerregaard, Risø National Laboratory, Denmark; and Jørgen Lemming, Danish Energy Authority, Danish Ministry of Economic and Business Affairs, Denmark.