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Contribution to the Chapter on Wind Power Energy Technology Perspectives 2008

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Abstract :
Over the last 5 years the growth rate in wind energy has been as high as 30% an on average nearly 25% in all continents, and a considerable number of countries have very ambitious goals concerning their wind energy development, therefore it could be likely to cover as much as 20% of the world's electricity consumption by wind in 2030 and 35% in 2050, although on the shorter term growth is expected to take place mainly in Europe, USA and China.

The market is maturing, therefore achieving more stable economies in the wind energy sector. As a result, better electrical grids suited for wind power are being developed and better planning tools as well as other frameworks, which benefit the market for installation of wind turbines, are being implemented across all wind energy countries.

The cost of wind-generated electricity has fallen steadily for the last two decades, driven largely by technological advances, increased production levels and the use of larger turbines. Between 1985 and 2005, production costs energy from of wind turbines decreased by nearly 100% in 2006 prices. The price rises seen in last three years due to capacity problems in the industry are expected to stop, once supply system constraints are overcome.

Onshore wind is considered commercial at sites with good wind resources and grid access. Cost reductions in both turbines and infrastructure are expected to bring investment costs to 0.88 mill. €/MW in 2030 and 0.8 mill. €/MW in 2050.
On the other hand, offshore wind is in pre-commercial development phase. Considerable costs improvements are expected in all areas making costs go down to 1. 4 mill. €/MW in 2030 and 1.3 mill.€/MW in 2050.

Priority RD&D areas to foster continued growth in wind power are to increase the value and reduce uncertainties. This will mean further cost reductions on longer terms, enabling large-scale use by improved grid integration and storage facilities and minimizing environmental impact.

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Preface

The market for wind energy is maturing with growth rates as high as 30% an on average nearly 25%, therefore achieving more stable economies in the wind energy sector. As a result, better electrical grids suited for wind power are being developed and better planning tools as well as other frameworks, which benefit the market for installation of wind turbines, are being implemented across all wind energy countries.

This report starts by making a review of the wind onshore technology deployment status, where market, technological, and policy variables are analysed. It concludes with a description of the future technological development and RD&D needs, making emphasis on the priority RD&D areas.

A description of the wind technology status is made, which precedes the analysis of changes in wind turbines size, and efficiency, as well as a description of the environmental factors that affect onshore projects. Additional to this, an analysis of onshore wind power costs is made, where different factors like the investment structures, operation and maintenance, and the costs of generated electricity from wind power are taken into consideration. The report describes what the onshore wind prospects for 2015, 2030, and 2050 are, then it further presents different scenarios to describe the future development of wind power in order to wrap up with the long-term costs perspectives for onshore wind turbines.

Furthermore, the report continues making a review of the status and prospects of offshore wind, where the deployed offshore projects in Europe are described. It continues by describing the present costs and economics of offshore wind energy in the U.K., Sweden and Denmark. The environmental factors concerning offshore wind projects are described, starting with the Danish experience on the matter, and how the monitoring program took place in Denmark in the period 1999-2006. Then, it further describes the experiences in the U.K., Sweden and Holland. Additionally, the report describes what the offshore wind prospects for 2015, 2030, and 2050 are, in first place by describing the present offshore wind farms under construction and planning in Europe, in second place by using different scenarios to describe the future development of wind power, and in third place by taking into account future technological developments in wind technology, in order to conclude with the long-term costs perspectives for offshore turbines.

The following sections follow with a description of new designs, concepts and the main drivers behind the technological innovation for onshore, offshore and small wind turbines, which are under development in USA, Norway, the U.K., Japan and Denmark across different Universities, research institutions and corporations.

The report is finished with and overview of the electric system aspects that are relevant for wind power, where important factors such as variability, predictability, flexibility, cost and large scale grid integration of wind are presented.

1 Key Findings and Highlights

Wind power has been growing at spectacular rates. Today it is the largest non-hydro renewable power technology. Worldwide there is 74 GW of installed capacity which is 1.7% of power generation capacity and in 2006 it accounted for 0.82% of electricity production.

Today wind power is a robust technology that has made great strides in the last decade and could provide more than 2/3 of electricity generation in 2050 even taken into account that also other renewable energies will be more economical on a longer term. Growth is expected worldwide with Europe and USA and China as the leading countries on the shorter term. Wind turbines need no fuel, have no CO_2 emissions and can be installed in relatively short periods of time, which provide a low risk profile and are the main competitive advantages of the technology. Wind is a variable resource making large scale wind power dependents of good tools for predictability, adapted power transmission system and back-up capacity and/or storage system.

Over the last 5 years the yearly growth rate has been as high as 30% and on average nearly 25%. This growth rate will probably not continue on a longer term but it might not be unrealistic that as much as 20% penetration of electricity consumption in the world could be covered by wind in 2030 and 35% in 2050.

The cost of wind-generated electricity has fallen steadily for the last two decades, driven largely by technological advances, increased production levels and the use of larger turbines. Between 1985 and 2005, production costs energy from of wind turbines decreased by nearly 100% in 2006 prices. Thanks in large part to successful RD&D and government support measures, the wind energy market is in a rapid state of deployment and the outlook is for continued double digit growth at least for the next 15 years. The price rises seen in last three years due to capacity problems in the industry is expected to stop, when supply system constraints have been overcome.

Onshore wind is considered commercial at sites with good wind resources and grid access. Cost reductions in both turbines and infrastructure are expected to bring investment costs to 0.88 mill. €/MW in 2030 and 0.8 mill. €/MW in 2050.

Offshore wind is in pre-commercial development phase. Considerable costs improvements are expected in all areas making the cost go down to 1. 4 mill. €/MW in 2030 and 1.3 mill. in 2050.

Priority RD&D areas to foster continued growth in wind power are to increase the value and reduce uncertainties. This will mean further cost reductions on longer terms, enabling large-scale use by improved grid integration and storage facilities and minimizing environmental impact.

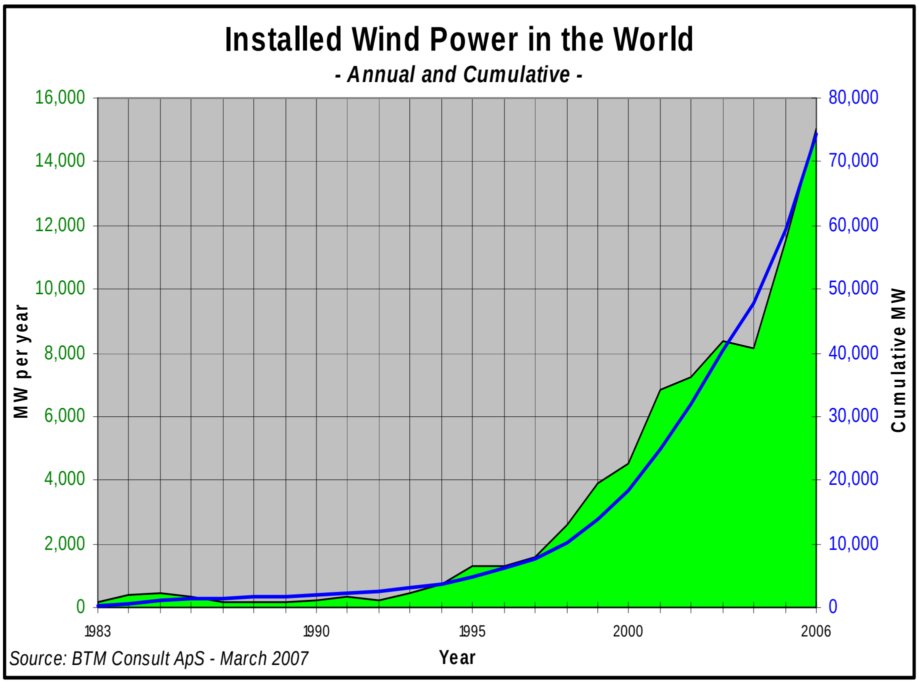
2 Overview Deployment Status

2.1 Introduction

Over the last 5 years the growth rate in wind energy has been very high in all continents and a considerable number of countries have very ambitious goals concerning their wind energy development. The market is maturing achieving more stable economies in the wind energy sector. Better electrical grids suited for wind power are being developed and better planning tools and other frameworks, which benefit the market for installation of wind turbines, are being implemented in all wind energy countries.

2.2 Current status

The wind power development has resulted in a dramatic increase in capacity and electrical generation from wind worldwide (Figure 2.1). Capacity has increased from a few GW in the early 1990th to more than 74 GW in 2006 including 0.9 GW offshore wind energy.



Source: BTM Consult ApS - March 2007

Figure 2.1. Annual and accumulated installed wind power capacity worldwide

More than 15,000 MW was added alone in 2006 worldwide. With an average investment of 1200 €/kW this corresponded to a total investment in wind power in 2006 of around 18 Billion €.

In the 1990's there were only four to five larger 'wind energy countries' throughout the world: Denmark, US, Germany, Spain and India. Today wind turbines are installed in more than 30 countries all over the world. Since year 2000 the development primarily has taken place in Europe, but high growth rates in capacity are also seen in USA, Asia and other places in the World (Figure 2.2). Alone in India and China more than 3220 MW was added in 2006 bringing the capacity in Asia up to more than 8800 MW in those two countries.

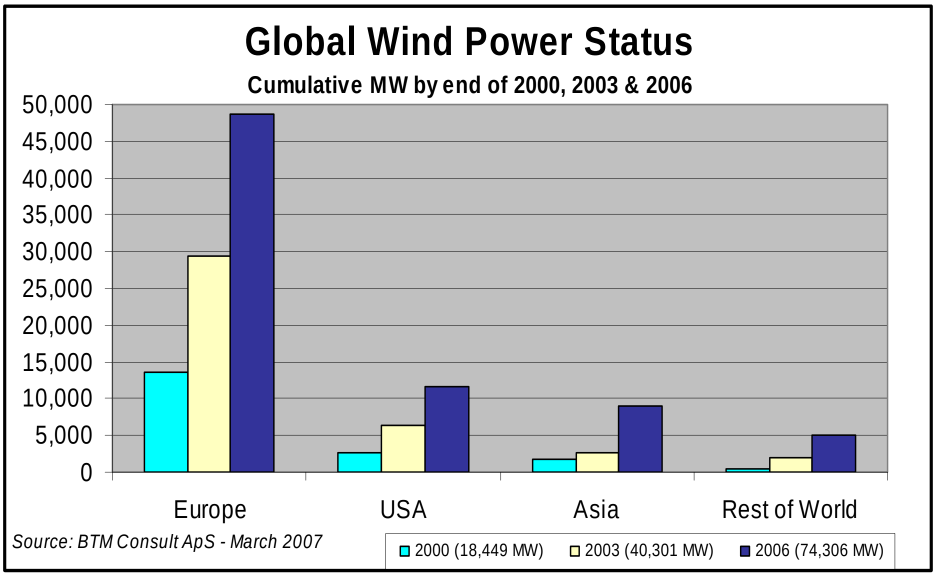


Figure 2.2. Global distribution of wind power developments.

As shown in Table 2.1 the growth in total capacity have been between 20 and 30 percent yearly over the last five years and in many countries significant amounts of capacity is in the planning stages.

Year:	Installed MW	Increase %	Cumulative MW	Increase %
2001	6,824		24,927	
2002	7,227	6%	32,037	29%
2003	8,344	15%	40,301	26%
2004	8,154	-2%	47,912	19%
2005*	11,542	42%	59,399	24%
2006	15,016	30%	74,306	25%
Average growth - 5 years		**17.1%**		**24.4%**

Source: BTM Consult ApS - March 2007

Table 2.1 Growth in wind energy capacity from 2001 - 2006

2.2.1 Contribution to Electrical Demand

This electrical production from wind met 0.82% of the total electrical demand in the world (Table 2.2) according to BTM [ref.0], and 1.42% of the demand in the IEA Wind member countries - up from 0.67%, and 1.2% respectively, in 2005 [ref.0]. The contribution from wind power grew only slowly because electrical demand also grew in many of the countries. Even so, the electrical output from wind in the IEA Wind member countries alone was sufficient to cover the total electricity consumption of the Netherlands.

Year	Electricity from wind power TWh*	Electricity from all power sources TWh**	Share of Wind Power %
2001	50.27	15,577	0.32
2002	64.81	16,233	0.40
2003	82.24	16,671	0.49
2004	96.50	17,408	0.55
2005	120.72	17,982	0.67
2006	152.35	18,576	0.82

*Source: *BTM Consult ApS – March 2007; **World Figures: IEA Energy Outlook 2006*

Table 2.2: Development of the production from wind power 1996-2006 and estimates for the next 10 years

Within the IEA member countries, contribution to national electrical demand varied from under 1% to 16.8% in Denmark. Ten countries exceeded the 1% mark for contribution of wind energy to national electricity demand (Table 2.3) [ref.0].

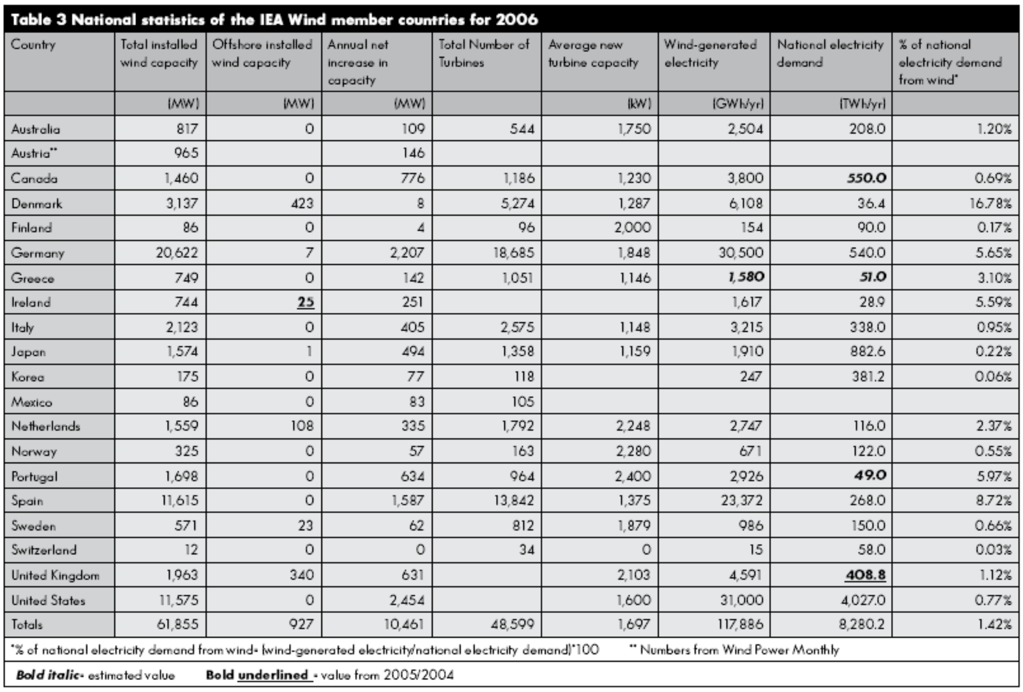


Table 3 National statistics of the IEA Wind member countries for 2006

Country	Total installed wind capacity	Offshore installed wind capacity	Annual net increase in capacity	Total Number of Turbines	Average new turbine capacity	Wind-generated electricity	National electricity demand	% of national electricity demand from wind*
	(MW)	(MW)	(MW)		(kW)	(GWh/yr)	(TWh/yr)	
Australia	817	0	109	544	1,750	2,504	208.0	1.20%
Austria**	965		146					
Canada	1,460	0	776	1,186	1,230	3,800	***550.0***	0.69%
Denmark	3,137	423	8	5,274	1,287	6,108	36.4	16.78%
Finland	86	0	4	96	2,000	154	90.0	0.17%
Germany	20,622	7	2,207	18,685	1,848	30,500	540.0	5.65%
Greece	749	0	142	1,051	1,146	***1,580***	***51.0***	3.10%
Ireland	744	**25**	251			1,617	28.9	5.59%
Italy	2,123	0	405	2,575	1,148	3,215	338.0	0.95%
Japan	1,574	1	494	1,358	1,159	1,910	882.6	0.22%
Korea	175	0	77	118		247	381.2	0.06%
Mexico	86	0	83	105				
Netherlands	1,559	108	335	1,792	2,248	2,747	116.0	2.37%
Norway	325	0	57	163	2,280	671	122.0	0.55%
Portugal	1,698	0	634	964	2,400	2,926	***49.0***	5.97%
Spain	11,615	0	1,587	13,842	1,375	23,372	268.0	8.72%
Sweden	571	23	62	812	1,879	986	150.0	0.66%
Switzerland	12	0	0	34	0	15	58.0	0.03%
United Kingdom	1,963	340	631		2,103	4,591	**408.8**	1.12%
United States	11,575	0	2,454		1,600	31,000	4,027.0	0.77%
Totals	61,855	927	10,461	48,599	1,697	117,886	8,280.2	1.42%

*% of national electricity demand from wind= (wind-generated electricity/national electricity demand)*100 ** Numbers from Wind Power Monthly

Bold italic= estimated value **Bold underlined** = value from 2005/2004

Table 2.3 National statistics of the IEA member countries for 2006.

2.3 Cost Development

2.3.1 Turbine and total installed project costs onshore

Turbine costs in the IEA Wind member countries have in 2006 been documented from a low of 636 €/kW (Japan) to a high of 982 €/kW (Germany) (Figure 2.3). Higher turbine costs are found in several countries in 2006 compared to earlier years mainly due to insufficient production of turbines, shortage of materials and rising cost of raw materials.

Total installed costs for 2006 range from a low of 979 €/kW (Denmark) to a high of 1,366 €/kW onshore (Canada). Even though project costs are influenced by numerous factors, increasing turbine costs are the largest contributor. Turbine prices, in particular, have increased, on average, by over 400 USD/kW (303 €) since 2001. For offshore – which will be analyzed in chapter 4 – Total installation cost in 2007 have been reported as high as 2,375 €/kW in UK.

Wind is now the fifth largest generation technology after coal, nuclear energy, natural gas, and hydropower. In Spain wind supplies nearly 9% of its electricity demand. In Denmark in 2006, the average coverage of wind power was nearly 17% and between 27% and 29% of the total electricity consumption was covered by wind power in November and December alone.

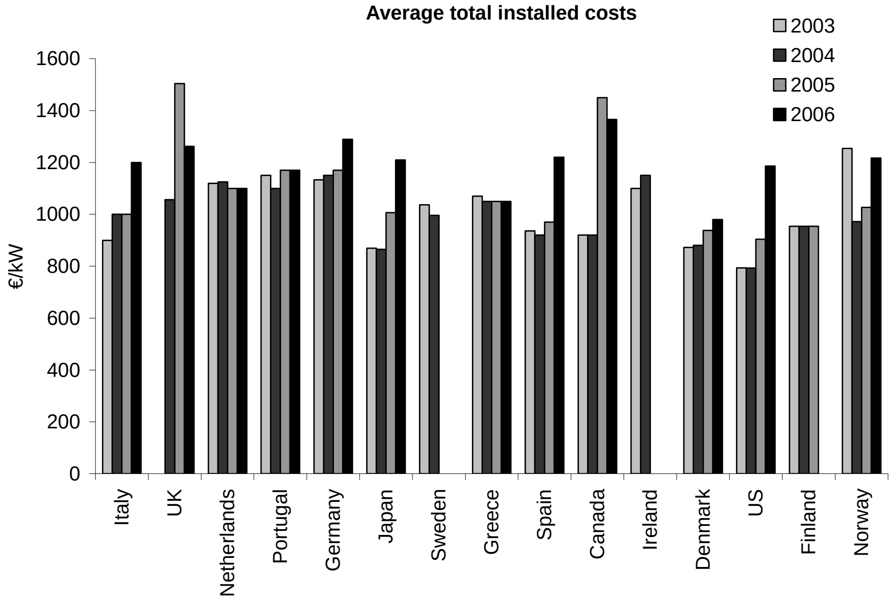


Figure 2.3: Average total installed costs of onshore wind projects 2003–2006 in some IEA Wind member countries. These include costs for turbine, roads, electrical, installation, development, and grid connection.

2.3.2 Operations & Maintenance Costs

Costs for service, consumables, repair, insurance, administration, lease of site, etc. for new large turbines ranged from 2–3.5% of capital cost or from 10 €/MWh to about 19 €/MWh. When O&M costs are mentioned by the member countries, they are reported as fairly constant over the years. O&M costs are expected to be higher for offshore turbines, but more data is needed to find out how much.

2.3.3 Cost of wind energy

Using various methods several IEA Wind members report the cost of energy from wind in their countries. Canada: 75–120 CAD/MWh; Finland: 45–65 €/MWh without investment subsidy; Greece: 26–47 €/MWh; Japan: 9.00–11.00 JPY/kWh (57–70 €/MWh) for 500 to 1,000-kW machines) and 7.00–9.00 JPY/kWh (40–57 €/MWh) for 1,000-kW and larger machines; Norway: 46 €/MWh; Switzerland: 135 €/MWh.

2.3.4 Tariffs and buyback rates

The key to the economic viability of a wind project is the balance of costs and revenue. Wind energy tariffs, feed-in tariffs, or buy-back rates are the payments to the wind farm owner for electricity generated. In some countries, this is the market price of electricity. In others, the wind energy tariff includes environmental bonuses, or other added incentives to encourage wind energy development. In many countries, the revenue of each wind farm is governed by the contract (power purchase agreement) negotiated with the purchaser, so these numbers reported are estimated averages or ranges. The price paid to wind project operators in 2006 ranged from 49–125 €/MWh (Figure 2.4).

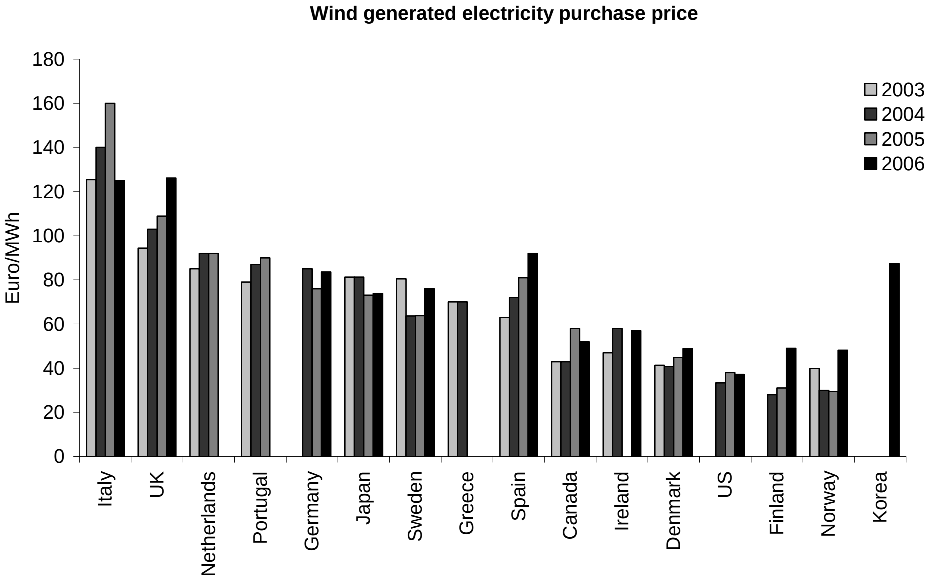


Figure 2.4: Price paid to wind farm project owner for reporting countries in 2003–2006 [ref. 0]

2.4 Market overview

The modern age of wind energy all started in the 1980's, when there were two major but very different markets: Denmark and California, USA. In Denmark the deployment of new wind power capacity installed annually was rather constant from the year 1980 to 2000. In California, however, there was a very aggressive deployment starting 1982-83 and peaking in 1986, then followed by a sudden market collapse in 1987, due to a halt in market incentives. As a result, most of the wind turbine manufacturers in the US and abroad faced very hard times, including many bankruptcies and financial reconstructions. However, the Danish wind turbine manufacturers survived the crisis due to a fall back on their – on that time - relatively stable home market.

As of the beginning of the 1990's Germany too initiated a very dynamic development of domestic wind power, and from the middle of the 1990's to 2005 Germany has been the largest wind turbine market worldwide. Also in the mid nineties Spain initiated a very dynamic domestic market development, and in 2006 Spain was the second largest market in the world bringing them up to number 3 in the world in total installed capacity (Table 2.4).

Country	2004	2005	2006	Share %
Germany	16,649	18,445	**20,652**	**27.8%**
USA	6,750	9,181	**11,635**	**15.7%**
Spain	8,263	10,027	**11,614**	**15.6%**
India	3,000	4,388	**6,228**	**8.4%**
Denmark	3,083	3,087	**3,101**	**4.2%**
P.R. China	769	1,264	**2,588**	**3.5%**
Italy	1,261	1,713	**2,118**	**2.9%**
UK	889	1,336	**1,967**	**2.6%**
Portugal	585	1,087	**1,716**	**2.3%**
France	386	775	**1,585**	**2.1%**
Total	**41,634**	**51,303**	**63,203**	
Percent of World	86.9%	86.4%	85.1%	

Source: BTM Consult ApS - March 2007

Table 2.4: Market share in 10 leading countries

2.4.1 Wind turbine manufacturers

In 2006 the six leading wind turbine manufacturers were responsible for just about 90% of the entire global turn-over, measured by installed MW. Several wind turbine manufactures use sub-suppliers of major components like gearboxes and generators and for some also blades, and are mainly doing the assembling and the control systems. Towers will normally subcontracted to local manufactures. Globally we see a concentration of the production of wind turbines. At the same time, however, new manufacturers emerge on the market. This is happening in India and China as well as the USA.

Table 2.5 show the 10 leading manufacturers on the world market. The table is from “World Market Up-date” [ref.0]. The table shows that Vestas is number one on the list with 28.2 % of the world market. The world leading manufacture is Vestas followed by Gamesa, GE Wind and Enercon, each of them representing about 15% of the world market. Suzlon and Siemens cover approximately 7.5% of the world market, and finally Nordex, Repower and Acciona and Goldwind each cover about 3% of the world market.

	Accu. MW 2005	Supplied MW 2006	Share 2006 %	Accu. MW 2006	Share accu. %
VESTAS (DK)	20,766	4,239	28.2%	25,006	33.7%
GAMESA (ES)	7,912	2,346	15.6%	10,259	13.8%
GE WIND (US)	7,370	2,326	15.5%	9,696	13.0%
ENERCON (GE)	8,685	2,316	15.4%	11,001	14.8%
SUZLON (Ind)	1,485	1,157	7.7%	2,641	3.6%
SIEMENS (DK)	4,502	1,103	7.3%	5,605	7.5%
NORDEX (GE)	2,704	505	3.4%	3,209	4.3%
REPOWER (GE)	1,522	480	3.2%	2,002	2.7%
ACCIONA (ES)	372	426	2.8%	798	1.1%
GOLDWIND (PRC)	211	416	2.8%	627	0.8%
Others	6,578	689	4.6%	7,267	9.8%
Total	**62,108**	**16,003**	**107%**	**78,110**	**105%**

Source: BTM Consult ApS - March 2007

Table 2.5: The top ten manufacturers (note that the total % do not add up 100% caused by time shift between manufactures recorded sales and the recorded total installations in the world).

2.4.2 Ownership patterns

Wind farms are usually owned by private corporations, independent power producers (IPPs), utilities, or by income funds. During the last 10 years larger development companies and electrical utilities have expressed a greater interest in wind asset ownership. Of the total 2006 wind additions, approximately 25% (615 MW) was owned by local electrical utilities, the vast majority of which are investor-owned utilities. See Table 2.6.

Name of wind farm operator	**Cumulative MW capacity by end of 2006**
1. Iberdrola (ES)	4,434
2. FPL (US)	4,300
3. Acciona Windpower (ES)	3,133
4. Babcock Brown Windpartner (AUS)	1,631
5. ScottishPower/PPM (UK)	1,593
6. Endesa (SP)	1,500
7. Eurus Energy Holding (JP)	1,324
8. EDP Electricidade de Portugal (P)	1,010
9. Shell Renewable (NL)	849
10. Essent /Nuon (NL)	840
11. Horizon (US)	824
12. EDF Energies Nouvelles (FR)	790
13. Dong Energy (DK)	724
14. ENEL (I)	600
15. Vattenfall (S)	534
Total of the shown companies	**24,086**

Source: BTM Consult ApS - March 2007

Table 2.6. Major wind farms operators in the world

2.5 Policy context

2.5.1 National CO_2 benefits and targets

All countries recognize the need to reduce carbon emissions and maintain that renewable energy in general and wind and solar energy in particular offer great potential to reduce overall carbon emission of the power industry. In addition, reducing the cost and security issues of using imported fuels is an element of several national targets. Establishing various types of national objectives or targets is used to define goals, develop policies, measure progress, and revise policies and goals as needed along the way.

In Spain, wind power helped decrease fossil fuel imports, achieving savings of more than 730 million € in 2006, mainly due to the reduction in purchases of natural gas and coal. In addition, the Spanish economy saved around 18 million tons of CO_2 and did not have to purchase emission permits that would otherwise have been required in 2006. This represents nearly 360 million € of savings, assuming a price of 20 €/ton of CO_2 emissions.

In the United States, the current wind capacity will generate 31 TWh/yr - enough to provide power for 2.9 million U.S. homes and displace approximately 23 million tons of carbon dioxide that would have been emitted by traditional resources.

Several types of targets are set in the IEA Wind member countries. Renewable energy targets have been set by Australia, Denmark, Finland, Germany, Ireland, Italy, the Netherlands, and the United Kingdom. Wind generating capacity (MW) or production (MWh) targets for a certain year has been established in e.g. Greece, Japan, Republic of Korea, Norway, Spain, Sweden, and Switzerland. Although targets are popular, Canada, and the United States have rapidly growing installed capacity without the benefit of official targets.

An important contributor to the growth of the European market for wind energy technology has been EU framework legislation combined with legislation at the national level, aimed at reducing barriers to the development of wind energy and other renewables. The new binding EU target is that 20% of Europe’s energy should be provided by renewables in 2020 (an increase from the existing indicative 12% target in 2010). There is a specific sectoral target for biofuels of 10% by 2020, but no target for renewable electricity or individual technologies such as wind power. National action plans will specify targets for each member state.

Trade associations and organizations promoting wind energy are having important effects on development of wind energy. For example, the Mexican Association of Wind Power (Amdee), founded in 2005, became an important stakeholder in the negotiation and lobbying of legislative and regulatory bodies. All the members of this association are promoting their own wind power projects. In addition, the National Solar Energy Association (ANES) continued more than 15 years of work promoting renewable energy. At the international level organisations like IEA and the Global Wind Energy Council (GWEC) are providing a platform for promoting the interests of the wind sector in the international policy arena and intergovernmental forums. In the EU, the European Wind Energy Association (EWEA) plays a key role in the debate in Europe regarding its future energy mix in the medium to long term with an agreed binding target of 20% by 2020 of renewable energy sources.

2.5.2 National Incentive Programs

Table 2.7 show the most used incentives in IEA Member countries related to investment, production and market [ref.0]

2.5.2.1 Capital Investment

Incentive programs that help offset the capital cost of wind farm development to varying degrees have been successful in several countries. Programs range from direct investment subsidies of 30- 50 %, over subsidies to different part of projects to subsidies to installation costs for demonstration projects.

2.5.2.2 Production Subsidies

Price incentives (feed-in tariffs) are paid to operators according to the amount of electrical generation of the wind project, thus rewarding productivity. Tariffs can also be used to promote specific national goals and have stimulated wind farm development in several countries.

		Australia	Canada	Denmark	Finland	Germany	Greece	**Ireland**	Italy	Japan	Korea	Mexico	Netherlands	Norway	Portugal	Spain	Sweden	Switzerland	United Kingdom	United States
Investment Support	Direct capital investment subsides/ grants		X		X		X	NDA	X	X	X			X	X	X			X	X
	Capital investment write-offs		X					NDA				X	X							
	Soft loans							NDA			X		X							X
	Others							NDA	X											
Production Support	Premium price for generation		X	X		X	X	NDA	X		X		X		X	X		X	X	
	Exemption from energy taxes				X			NDA									X		X	
	Production tax credits							NDA												X
	Others		X					NDA	X		X	X								X
Demand Creation	Obligation for production from renewables on suppliers	X	X					NDA	X	X						X	X		X	X
	Free market for green electricity				X			NDA	X				X		X	X		X		X
	Others					X	X	NDA			X									

*Table 2.7. Incentive programs offered in some IEA member countries. [Ref. 0] (**NDA means no data available**).*

In some countries, the premium price for renewable electricity is reduced in future years and policy audits are included in the laws.

Changing the rules governing subsidies can have dramatic effects on the wind energy market. E.G has stop and go effects been a negative experience in several countries.

2.5.2.3 Demand creation

Many national and state governments require utilities to purchase a percentage of their overall generating capacity from renewable resources. Wind energy is the preferred option by most utilities to satisfy this obligation. Also wind energy qualifies as green electricity to meet utility purchase obligations, to be traded as certificates, or to meet consumer preferences.

2.5.2.4 Other Support Mechanisms

Other kinds of support have accelerated the development of wind energy in the IEA Wind member countries. For example comprehensive Wind Energy Atlas that allows planners of wind energy projects to generate a detailed picture of wind patterns for any location. And in Germany and Denmark, Federal authorities have identified suitable areas for offshore wind farms in the North Sea and Baltic Sea, making planning easier for investors.

2.5.3 Benefits to national turnover and employments

The economic impact of wind energy development is reported in various ways by the IEA Wind member countries (Table 2.8). One measure, sometimes referred to as economic turnover or contribution to gross domestic product, is the value of all economic activity related to such development. It includes payments to labour, cost of materials for manufacture and installation, transportation, sales for export, and value of electricity generated. Other values reported include industrial activity, construction, and value of exports. More countries than ever are estimating the number of jobs created by wind energy manufacturing, development, and operation.

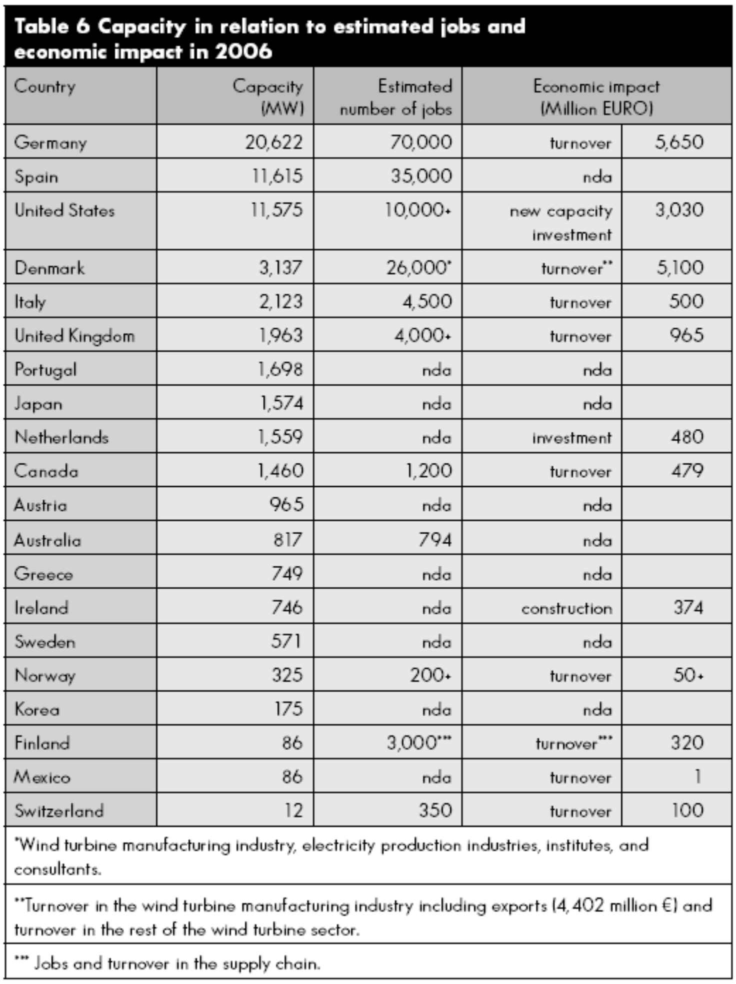


Table 6 Capacity in relation to estimated jobs and economic impact in 2006

Country	Capacity (MW)	Estimated number of jobs	Economic impact (Million EURO)	
Germany	20,622	70,000	turnover	5,650
Spain	11,615	35,000	nda	
United States	11,575	10,000+	new capacity investment	3,030
Denmark	3,137	26,000*	turnover**	5,100
Italy	2,123	4,500	turnover	500
United Kingdom	1,963	4,000+	turnover	965
Portugal	1,698	nda	nda	
Japan	1,574	nda	nda	
Netherlands	1,559	nda	investment	480
Canada	1,460	1,200	turnover	479
Austria	965	nda	nda	
Australia	817	794	nda	
Greece	749	nda	nda	
Ireland	746	nda	construction	374
Sweden	571	nda	nda	
Norway	325	200+	turnover	50+
Korea	175	nda	nda	
Finland	86	3,000***	turnover***	320
Mexico	86	nda	turnover	1
Switzerland	12	350	turnover	100

*Wind turbine manufacturing industry, electricity production industries, institutes, and consultants.

**Turnover in the wind turbine manufacturing industry including exports (4,402 million €) and turnover in the rest of the wind turbine sector.

*** Jobs and turnover in the supply chain.

Table 2.8: Capacity in relation to jobs and economic impact

2.6 Technology and Industry

2.6.1 Technology development

Technology development has been very successful from the 1970’s and up till now. We have seen a battle between the different wind turbine concepts from the 1970’s till the beginning of the nineties. A great variety of concepts took were involved during this period – e.g. horizontal axis wind turbines with one, two, three and four blades, downwind and upwind turbines, pitch, stall or yaw controlled turbines, and vertical axis wind turbines, e.g. Darrieus, the gyro-turbine and others. The winner today is the three-bladed horizontal axis, upwind, electricity producing and grid connected wind turbine shown. Figure 2.5 show how the size of the turbines has increased since 1980. The largest wind turbines on the global market today are around 5 MW with a rotor diameter of up to 120 meters. Up to 2005 the size of turbines has doubled every 5 years, but a slowdown is expected over next the 5 year period.

In the 1970’s the reliability and availability of the first generations of wind turbines were quite low. In the 1980’s and 90’s the reliability and availability in general reached an acceptable level of more than 95% [ref.0], and today the availability on mature markets lie around 99%. This position has been achieved by means of a regime of very extensive certification and testing schemes, which has required the wind turbine manufacturers to prove their engineering integrity and the safety, quality and performance of the wind turbines. Such certification schemes are required by governments in some countries and in others by the market agents.

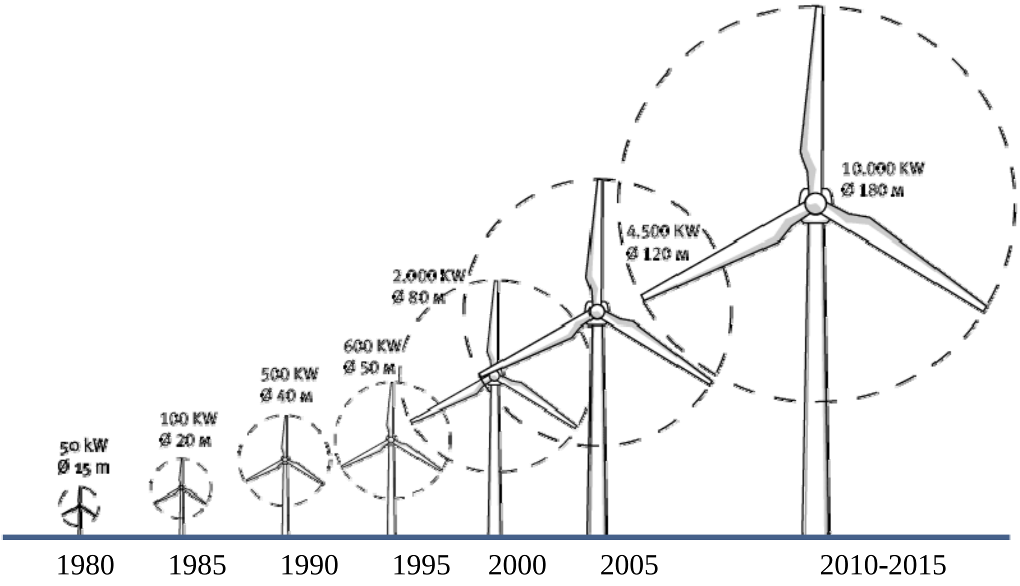


Figure 2.5: Development in wind turbine sizes from 1980 to 2005.

Turbine sizes in wind farms vary from one market to another, depending on the wind turbine manufacturers on the market in question. Table 2.9 shows the average rated power for the wind turbines sold in Germany, Spain, UK, USA, India and China for the past five years. Differences in the rated power reflect that in some countries fairly new manufacturers will not include large turbines in their product line. This is the case for instance in India and China where manufacturers typically produce turbines of up to 1-1.5 MW.

The general trend goes towards an increase in rated power, which is also shown in Table 2.9. Since 2005, however, there seems to be a slow-down in the up-scaling of the turbines, no doubt because of reliability issues related to the increase of size and complexity.

Year	Germany	Spain	UK	USA	India	China
2002	1,443	845	843	893	553	709
2003	1,650	872	1,773	1,374	729	726
2004	1,715	1,123	1,695	1,309	767	771
2005	1,634	1,105	2,172	1,466	780	897
2006	1,875	1,469	1,953	1,667	926	931

Table 2.9: Average rated power in MW installed in selected countries

The technical challenge of developing large turbines of increasing size and complexity with a new technology based on state-of-the art research in a number of fields such as aerodynamics, aeroelasticity, new materials and condition monitoring, requires new and more advanced methods for design and testing in order to ensure satisfactory reliability.

2.6.2 Turbine production

The average rated capacity of new turbines installed in 2006 continued the trend toward larger machines. The average rating in 2006 rose to nearly 1.7 MW. The IEA Wind Member Countries contain turbine manufacturers that serve global as well as national markets. Countries reporting a national manufacturer of 1-MW or larger turbines include Denmark (5,000 MW /yr), Finland, Germany, the Netherlands, Norway, Portugal, Spain (1,200 MW), and the United States.

In addition to MW-scale wind turbines, intermediate-sized turbines, 660 to 850 kW, are being manufactured in several countries for single turbine installations or small wind power plants (Germany, Italy, Korea, India, China, Netherlands, and the United States).

Small wind turbine domestic manufacturing and encouragement of micro-generation is expanding the market for small wind turbines (Canada, Denmark, Italy, Japan, Portugal, Spain, and the United States). Italy established net metering and reduced the minimum amount of capacity required for green certificates. In Japan, Zephyr Corporation has developed the Z-1000 Airdolphin, a small 1-kW wind turbine. The prototype machine is being demonstrated at many sites around the world. In the UK a micro generation strategy is being implemented.

2.6.3 Operational experience

Wind farm operation is well established in many of the IEA Wind member countries, drawing on decades of experience in turbine manufacture, project development, and generation operations. Turbine availability is high in all countries, ranging between 95 to 100% with most reporting 98% or higher. Productivity is also relatively high—the result of good siting of farms based on national wind atlas data. Large onshore farms have higher avail-ability than offshore farms. The UK reports offshore availability between 81 and 91.2%. Capacity factor estimates were reported by the following countries: Australia 35–50%; Mexico 30–40%; Switzerland 15–25%; UK onshore: average 26.6%, offshore 24–36%.

The number and causes of nearly 350 turbine failures from 2004 to 2006 have been analyzed by Japan and are being used as input to design efforts for the j-class turbine. Lightning strikes were the biggest known cause of wind turbine failure in Japan.

2.7 Environmental factors

Wind energy is a clean and environmentally friendly energy source. There are no emissions to air or water, nor greenhouse gases, it requires no mining or drilling for fuel, and produces no toxic waste. However at the local and regional level wind energy can have impacts, in particular on humans, wildlife and/or habitats. Balancing these by-and-large local concerns against the unrivalled benefits to society is a difficult task, and one that requires both a general knowledge of many different issues and disciplines, as well as deeper understanding of complex issues combined with detailed and specific data on the environment.

Obviously the environmental concerns are emphasised when it comes to establishing large wind farms of several hundred large wind turbines. Over the 30 years of implementation of modern wind turbines the three main environmental concerns have been visual impact, noise and the risk of bird-collisions.

The different impacts are discussed further in Chapter 3 and 4.

2.8 Future technological development

In the long-term perspective the offshore technology development has to be been seen in relation to areas as aerodynamics, structural dynamics, structural design, machine elements, electrical design and grid integration. The development can be structured in:

- Incremental developments
- New main component concepts
- New Wind turbine concepts

Right from the start back in the 1970s the wind turbine industry has been characterized by *incremental development*. In the future this development is especially to be seen in the following areas:

- Development of more efficient methods to determine wind resources
- Development of more efficient methods do determine the external design conditions e.g. normal and extreme wind conditions, wave conditions, ice conditions etc.
- Development of more efficient methods to design and construct the wind turbines blades, transmission and conversion system, load carrying structure, control system and grid interconnection system. Condition monitoring can trough the introduction of new and more advanced sensor systems open up for the development of important improvements of the reliability of offshore wind turbines which can be crucial for the development of more cost efficient and competitive technology
- Innovations with more efficient designs, introduction of new control elements e.g. new sensor systems, more intelligent communication between wind turbines, and introduction of new more advanced materials.
- Innovations in the wind turbine production, transportation and installation methods.

The incremental development of the technology is where the main research and development priority is in the industry and in the research community. The learning (cost reduction) in the industry comes from a combination of incremental development in design and construction of wind turbines and cost reduction due to increased production volume.

Development of *new main components concepts* has also been seen from the mid 1970s and new component concepts competes with existing concepts and thereby is continuously a challenge for the existing main component concepts. The main areas of the competition today are:

- New wind turbine blade concepts with new materials, new structural designs and new aerodynamic features
- New transmission and conversion systems e.g. wind turbines with gearboxes versus wind turbines without gearboxes with multipole generators
- New electrical generator concepts
- New power electronic concepts
- New grid integration concepts
- New foundation concepts e.g. gravitation foundations, monopole foundations, tripod foundations and floating wind turbines

The development of new main component concepts is a very dynamic part of the technology development of the wind energy field and opens often up for new innovative components. This development is extremely dependent of a very reliable verification of the performance of the new component concepts through research and experimental verification.

The competition between *new wind turbine concepts* was intense from the late 1970s to mid 1990s. The most important concepts were:

- 3-bladed upwind wind turbines with a ridged rotor connected to the electrical grid through a gearbox and an induction generator
- 2-bladed downwind wind turbines with at theater rotor connected to the electrical grid through a gearbox and an induction generator
- 2- or 3 bladed Darrieus wind turbine (vertical axis wind turbine) connected to the electrical grid through a gearbox and an induction generator.

Also other concepts were on the market but in the end the 3-bladed upwind wind turbine until now has been the winner in the competition. But in general the technological development combined with a rapid offshore development might open op for new concepts. On the other hand is the experience with existing concepts so valuable that it is a big challenge for new concepts to compete with the existing ones.

In general the future technological development of offshore wind energy is expected to be mainly incremental and more fundamental research is very important to continue the innovation in the industry. In the future development it might prove to be important to distinguish offshore wind turbines from onshore ones. The onshore development is more mature than offshore wind technology and new innovative concepts are more likely for offshore applications.

The development offshore goes from shallow water to very deep water. The development until now is mainly seen in areas with shallow water. Technologies used offshore are expected to differ depending on the water depth and can be divided into:

- Shallow water
- Intermediate depth (50 m > depth > 20 m) bottom mounted
- Floating concepts

It should be mentioned that availability and reliability is crucial for the development of a competitive offshore wind energy technology and will in coming years be the dominating factor for the development.

2.9 RD&D

2.9.1 Priority RD&D areas

During the last 30 years of modern wind energy deployment, national R&D programs have played an important role in promoting development of wind turbines towards more cost effectiveness and reliability. The technology has been deployed by accompanying demonstration programs in co-operation with industry. Commercial turbine sizes have increased from less than a hundred kilowatt to 5MW during this period. The interaction between industry and national R&D programs has been important for the development of effective turbines all the way from the early beginning in the 1970s.

Continued R&D is essential to provide the necessary reductions in cost and uncertainty to realise the anticipated level of deployment. Continued R&D will support revolutionary new designs as well as incremental improvements. The challenge is to try to find those evolutionary steps that can be taken to further improve wind turbine technology.

R&D areas of major importance for the future deployment of wind energy are improved forecasting techniques, grid integration, public attitudes, and visual impact. R&D to develop forecasting techniques will increase the value of wind energy by allowing electricity production to be forecasted from 6 to 48 hours in advance. R&D to facilitate integration of wind generation into the electrical grid and R&D on demand side management will be essential when large quantities of electricity from wind will need to be transported through a grid. R&D to provide information on public attitudes and visual impact of wind developments will be necessary to incorporate such concerns into the deployment process for new locations for wind energy (especially offshore).

For the long-term time frame, it is of vital importance to perform the R&D necessary to take large and unconventional steps in order to make the wind turbine and its infrastructure interact in close co-operation. Adding intelligence to the complete wind system and allowing it to interact with other energy sources will be essential in areas of large-scale deployment. R&D to improve electrical storage techniques for different time scales (minutes to months) will increase value at penetration levels above 15 to 20%.

Future R&D must also include incremental improvements in, for example, understanding extreme wind situations and reducing system weight. In addition to challenges associated with the integration of the technology to produce electricity, wind energy could be used to produce other energy carriers such as hydrogen. Wind energy technology has traditionally been used in producing electricity and will be continuing to do so in the future. But, innovative concepts in hybrid systems and storage techniques may benefit other sectors of the economy and the fight against climate change.

2.9.2 Frameworks

The European Commission launched a consultation process in March 2006 to discuss the medium- and long-term strategy for EU energy policy. The Green Paper “A European Strategy for Sustainable, Competitive, and Secure Energy” proposed the preparation of a “renewable energy roadmap” that would include specific measures to ensure that existing targets are met; consideration of which targets or objectives beyond 2010 are necessary; and research, demonstration, and market replication initiatives. The Green Paper also foresaw the preparation of a European Strategic Energy Technology Plan to move Europe towards a low-carbon energy system, e.g. “by permitting a sharp increase in the share of lower cost renewables, including the roll-out of offshore wind.”

A part of this EU effort, the European Wind Energy Technology Platform (TPWind) was launched on 19 October 2006. It is an industry-led initiative supported by the 6th Framework Programme of the European Union, channeled through the European Wind Energy Association. TPWind will identify areas for increased innovation and prioritize them on the basis of “must haves” versus “nice to haves.” The primary aim is overall cost reduction through research and economies of scale (market deployment). The platform will detail specific tasks, approaches, actors, and necessary infrastructure, in the context of private R&D and EU and Member States programs such as the 7th Framework Program. Finally it will assess the overall funding available to carry out this work from public and private sources.

In 2007, the IEA Wind agreement will develop a new strategic plan in preparation for extending the agreement for another five years from 2008 through 2013. Key to that activity is setting R, D&D priorities. Several analyses in 2006 will contribute to such R, R&D planning.

Common research tasks which are in progress at present under IEA Wind are:

- Base technology information exchange (Task 11)
- Wind Energy in Cold Climates (Task 19)
- Horizontal axis wind turbine aerodynamics (HAWT) and models from wind tunnel measurements (Task 20)
- Dynamic models of wind farms for power system studies (Task 21)
- Offshore Wind Energy Technology Development (Task 23)
- Integration of Wind and Hydropower (Task 24)
- Power System Operation with Large Amounts of Wind Power (Task 25)

The International Energy Agency (IEA) Wind agreement Task 11 is a vehicle for member countries to exchange information on the planning and execution of national large-scale wind system projects.

Based on an expert meeting on long term research needs arranged in 2001 within Task 11 IEA Wind developed a long term strategy for 2000 to 2020 (ref.0), and it is now due time to arrange a new meeting on the same subject in order to sum up progress and identify future research needs. Future R&D must support incremental improvements in e.g. understanding extreme wind situations, aerodynamics and electrical machines. But, the challenge is to try to find those evolutionary steps that can be taken to further improve wind turbine technology including offshore technologies, for example in large scale integration incorporating wind forecasting and grid interaction with other energy sources.

Within the ongoing IEA Wind Implementing Agreement's Task 23 Offshore Wind Technology Developments work is ongoing in 2 Subtasks – one on Experience with critical deployment issues and one on Technical research for deeper water.

Within *Subtask 1* focus is set on 3 issues:

- Ecological Issues and Regulations
- Electric System Integration of Offshore Wind Farms
- External Conditions, Layouts and Design of Offshore Wind Farms.

A number of workshops have been held and based on the conclusions special work will be continued within several areas e.g. grid issues like "Offshore wind meteorology and impact on power fluctuations and wind forecasting", "Technical architecture of offshore grid systems and enabling technologies, and within external conditions "Benchmarking of models for wakes from offshore win farms."

With *Subtask 2* participants have formed a working group named Offshore Code Comparison Collaboration (OC^3) to focus on coupled turbine/substructure dynamic modeling. The OC^3 participants developed dynamics models for an offshore wind turbine with a monopole foundation support structure. They made basic model-to-model comparisons of the wind-inflow, wave kinematics, and wind turbine response. They are currently focusing on comparisons of the monopile geotechnical response and are defining a tripod support structure to be used in the next phase of the project. The code comparison work has established a procedure and database that can be used for future code verification activities and analyst training exercises. In addition, the EU-integrated UpWind research program has adopted the NREL[1] offshore 5-MW baseline wind turbine model, which is used in the OC^3 project as its reference wind turbine. The model will be used as a reference by all UpWind Work Package teams to quantify the benefits of advanced wind energy technology.

3 Onshore Wind

3.1 Summary of technology status to day

Most of the world electrical generation capacity from wind power plants is still land based, except a small number of offshore installations, which have been built over the last 10 years especially in the Northern Europe. The size of wind turbines has increased continuously for the past 25 years. Therefore some of the numbers referred to in this chapter include also the offshore installations. The average rated capacity of new turbines installed in 2006 continued the trend toward larger machines.

3.1.1 Increases in Turbine Size

Figure 1 shows the development of the average size of wind turbines sold each year for a number of the most important wind power countries. As illustrated in Figure 3.1 the annual average size has increased significantly within the last 10-15 years, from approximately 200 kW in 1990 to approximately 1.5 MW in 2005 in Germany, U.S. and Denmark and even more in the UK. The large increases in UK and Denmark in recent years were mainly caused by a number of offshore projects equipped with 2 MW machines and above. But even so there is quite a difference between the individual countries. In Spain, the average size installed in 2005 was approximately 1100 kW, significantly below the level in Germany and the U.S. of 1634 kW and 1466 kW, respectively. In India the average size installed in 2005 was approximately 800 kW, significantly below the level of the other countries, mainly because the Indian manufacturers until now have not really moved into the MW-segment.

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[1] National Renewable Energy laboratory, Boulder CO. USA

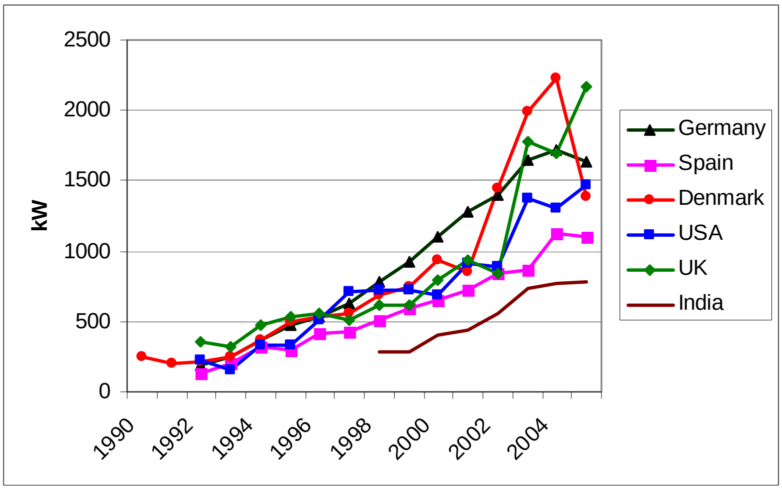

Figure 3.1 Development of the average wind turbine size sold in different countries. Source: BTM-consult. (to be updated)

In 2005, the best-selling turbines on the World market had a rated capacity of more than 1.5 MW, and these machines had a market share of more than 40%. But turbines with capacities of 1 to1.5 MW are still important having a market share of almost 35%. Finally, the smaller turbines with capacities of 750 to 1000 kW had a market share of 20%. At the end of 2005 turbines with a capacity of 2 MW and above are getting increasingly important, even for on-land siting.

3.1.2 Improvement in efficiency

The wind regime at the chosen site, the hub height of the turbines and the efficiency of production mainly deter-mine power production from the turbines. Thus, increasing the height of the turbines has by itself yielded a higher power production. Similarly, the methods for measuring and evaluating the wind speed at a given site have improved substantially in recent years and thus improved the siting of new turbines. In spite of this, the fast development of wind power capacity in a few countries such as Germany and Denmark implies that most of the good wind sites by now are taken and, therefore, new on-land turbine capacity has to be erected at sites with a marginally lower average wind speed.

The development of electricity production efficiency owing to better equipment design measured as annual energy production per unit swept rotor area (kWh/m2) at a specific reference site has correspondingly improved significantly over the last years. Taking into account all the three mentioned issues of improved equipment efficiency, improved turbine siting and higher hub height the overall efficiency has increased by 2 to 3 percent annually over the last 15 years.

3.2 Environmental factors onshore projects

Wind energy is a clean and environmentally friendly energy source. There are no emissions to air or water, nor greenhouse gases, it requires no mining or drilling for fuel, and produces no toxic waste. However at the local and regional level wind energy can have impacts, in particular on humans, wildlife and/or habitats. Balancing these by-and-large local concerns against the unrivalled benefits to society is a difficult task, and one that requires both a general knowledge of many different issues and disciplines, as well as deeper understanding of complex issues combined with detailed and specific data on the environment.

Over the 30 years of implementation of modern wind turbines the three main environmental concerns have been visual impact, noise and the risk of bird-collisions. A best practice for how to undertake the environmental side of the wind farm planning and development have emerged as well. Key lessons are:

- Start early
- Avoid areas of special conservation importance with respect to any of the key concerns
- Involve relevant stakeholders
- Inform neighbours

The site selection of a wind farm is the single most crucial action and should be accompayned with an appropriate screening of the environment involving the main issues.

Today noise is dealt with in the planning phase and normally it possesses little problems to build wind turbines close to human settlements. The visual effects of wind turbine may, however, create some controversy, as some people believe they are having a severe negative visual impact of the landscape, while others find them beautiful. Experience shows that it often pays to invest some effort in designing a good layout of the wind farm using well defined geometrical patterns while taking into the considerations the landscape features.

In some of the countries that installed wind turbines at an early stage, Denmark, Germany and Nederlands repowering has started i.e. small, old wind turbines are removed leaving space for modern and larger wind turbines. Denmark was the first country to actively support wind repowering, and the programs has led to the repowering of two-thirds of the oldest turbines in the country.
Denmark’s first incentive program for repowering wind operated from April 2001 – December 2003.
The second repowering scheme in Denmark was launched in 2005/06, but have been very slow partly due to a slowdown in planning efficiency (the responsibility of regional planning moved as a part of reform work on municipality and county level). At the same time groups of neighbors to projects with new large wind turbines have filed objections mainly due to visual impact from the new large turbines.

The environnental side of repowering is that the larger wind turbines have a slower rotational speed, which in general for most people has a less “aggressive” impact compared to the old fast-rotating turbines. On the other hand the modern turbines are taller and can be seen from a larger distance.

The impact on plants and animals is not very well established despite a sizable number of studies, but as it is with all power plants a certain amount of disturbance to flora, fauna birds and mammals will happen. With respect to wind energy the largest concern is on bird strikes and possible associated effects on resident bird population and migration paths. In general birds are able to nagigate around the turbines in a wind farm and recent studies report very low bird mortality numbers in the order of 0.1 to 0.6 birds per turbine per year [ref.0]

In two countries (UK and US) radar and other electromagnetic signal interference from wind farms have been an issue of debate, while in many other countries this is not an issue [ref.0].

For all the environmental impacts experience shows that dealing with them early and openly and enter into dialogue with relevant stakeholders will normally facilitate working out a solution satisfying all parties. Software tools for analysis and presentation to the public of the environmental impact of wind farms are available, which includes noise calculation, visualization and photomontage for illustration of visual impact as well as calculation of shadow flickering.

3.3 Cost of onshore wind power to day

3.3.1 Cost and investment structures

Although wind power worldwide is being developed rapidly, only at very few sites with high wind speeds wind power is at present economically competitive to conventional power production. This section focuses on the cost structures of a wind power plant, including the lifetime of the turbine and O&M-costs. Finally, it analyses how the costs of wind-generated power has developed in previous years and how it is expected to develop in the near future.

Wind power is used in a number of different applications, including both grid-connected and stand-alone electricity production, as well as water pumping. This section analyses the economics of wind energy primarily in relation to grid-connected turbines, which account for the vast bulk of the market value of installed turbines.

The main parameters governing wind power economics include the following:

- Investment costs, including auxiliary costs for foundation, grid-connection, and so on.
- Operation and maintenance costs
- Electricity production / average wind speed
- Turbine lifetime
- Discount rate

Of these, the most important parameters are the turbines’ electricity production and their investment costs. As electricity production is highly dependent on wind conditions, choosing the right turbine site is critical to achieving economic viability.

The following sections outline the structure and development of land-based wind turbines’ capital costs and efficiency trends. In general, three major trends have dominated the development of grid-connected wind turbines in recent years:

1) The turbines have grown larger and taller – thus the average size of turbines sold in the market place has increased substantially.
2) The efficiency of the turbines’ production has increased steadily.
3) In general, the investment per kW installed power has decreased.

3.3.1.1 Cost Decreases per square meter swept rotor area

More importantly, the investment per square meter swept rotor area has declined even more substantially, since there has been a general tendency towards more square meters of rotor area per kW installed power (lower specific generator load per square meter rotor area). In general, annual energy output from a wind turbine is roughly proportional to the swept rotor area (for fixed tip speed / mean wind speed ratio). The swept rotor area, as we have already said, is a better indicator of the production capacity of a wind turbine than the rated power of the generator. Also, the costs of manufacturing large wind turbines are roughly proportional to the swept rotor area. In the context of this paper, this means that when we (correctly) use rotor areas instead of kW installed as a measure of turbine size, we would see somewhat smaller (energy) productivity increases per unit of turbine size and a larger increase in cost effectiveness per kWh produced.

3.3.1.2 Capital costs

Capital costs of wind energy projects are dominated by the price of the wind turbine itself (ex works)2. Table 3.1 shows the cost structure for a medium sized turbine (850 kW to 1500 kW) sited on land and based on data selection from UK, Spain, Germany and Denmark. The turbine's share of total cost is typically a little less than 80 percent, but as shown in Table 1 considerable variations do exist ranging from 74 to 82 percent.

	Share of total cost %	Typical share of other costs, %
Turbine (ex works)	74-82	-
Foundation	1-6	20-25
Electric installation	1-9	10-15
Grid-connection	2-9	35-45
Consultancy	1-3	5-10
Land	1-3	5-10
Financial costs	1-5	5-10
Road construction	1-5	5-10

Table 3.1: Cost structure for a typically medium size wind turbine (850 kW – 1500 kW)3

3.3.1.3 Additional cost components

Of other cost components dominant ones are typically grid connection, electrical installation and foundations, but even road construction and financial costs might turn out to be substantial amounts of total costs. These auxiliary costs exhibit considerable variation, ranging from approximately 24% of total turbine costs in Germany and the UK to less than 20% in Spain and Denmark, though the costs do depend not only on the country of installation but also on the size of the turbine. Typical ranges of these other cost components as a share of total additional costs are also shown in

Table 3.1. As seen the single most important additional component is the cost of grid connection, which in some cases can account for almost half of auxiliary costs, followed by typically lower shares for foundation cost and cost of the electrical installation. These three items may add significant amounts to total cost of the projects. Cost components such as consultancy and land normally account for only minor shares of additional costs.

3.3.1.4 Differences between countries

Based on a limited sample of data4 an average total investment cost for turbines established in Europe in 2006 was calculated to approximately 1175 €/kW. This

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2 'Ex works' means that no balance of plant, i.e. site work, foundation, or grid connection costs are included. Ex works costs include the turbine as provided by the manufacturer, including the turbine itself, blades, tower, and transport to the site.

3 Based on a limited data-selection from Germany, Denmark, Spain and UK for 2001/02. The cost structure tends to be fairly stable over time.

4 Collected from wind turbine manufacturers, typically for turbine size of 2 MW, supplemented by Milborrow, Wind Power Monthly, January 2007.

figure is subject to a considerable variation between individual projects and between countries and typically a range of 950 to 1400 €/kW is to be expected[5].

The total cost per kW installed wind power capacity can differ significantly between countries, as exemplified in Figure 3.2. The cost per kW typically varies from approximately 1100 €/kW to 1400 €/kW (2001-sample updated to 2006-prices). As shown in Figure 3.2 the investment costs per kW were found to be almost at the same level in Spain and Denmark, while the costs in the data-selection were approximately 10 to 25% higher in UK and Germany. Though it should be observed that Figure 3.2 is based on a limited number of data and therefore the results might not be representative for the mentioned countries.

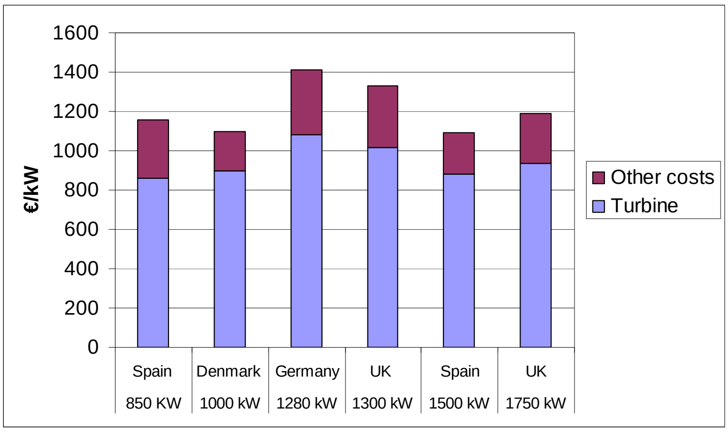

Figure 3.2: Total investment cost, including turbine, foundation, grid-connection etc, shown for different turbine sizes and countries of installation. Based on 2001-data from Germany[6], UK, Spain and Denmark updated to 2006-prices.

Figure 3.3 shows how investment costs have developed over the years, exemplified by the case of Denmark for the time-period 1987 to 2006. The data reflect turbines installed in the particular year shown[7] and all costs at the right axis are calculated per swept rotor area, while those at the left axis are calculated per kW of rated capacity.

The number of square meters the rotor of the turbine is covering - swept rotor area - is a good proxy for the turbines' power production and therefore this measure is a relevant index for the development in costs per kWh. As shown in the figure, there has been a substantial decline in costs per unit swept rotor area in the considered period except for 2006. Thus, from the late 90s until 2004 over-all investments per unit swept rotor area have declined by more than 2% per annum during the period analysed, corresponding to a total reduction in cost of almost 30% over these 15 years. But this trend was broken in 2006 where total investment costs rose by approximately 20% compared to 2004, mainly induced by a strong increase in demand for wind turbines combined with severe supply constraints.

Looking at the cost per rated capacity (per kW), the same decline is found in the period 1989 to 2004 with the 1000 kW-machine in 2001 as the exception. The reason has to be found in the dimensioning of this specific turbine. With higher hub heights

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[5] Milborrow, Wind Power Monthly, January 2007

[6] For Germany an average figure for the installed capacity in 2001 is used.

[7] All costs are converted to 2006 prices.

and larger rotor diameters, the turbine is equipped with a relatively smaller generator although it produces more electricity. This is particularly important to be aware of when analysing turbines constructed to be used in low and medium wind areas, where the rotor diameter is dimensioned to be considerably larger compared to the rated capacity. As shown in Figure 3 the cost per kW-installed also rose by 20% in 2006 compared to 2004.

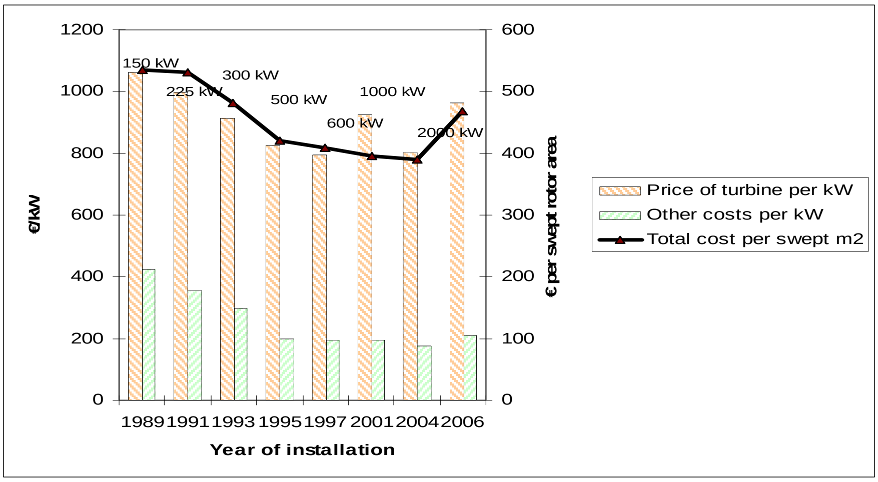


Figure 3.3: The development of investment costs exemplified by the case of Denmark for the time-period 1989 to 2006. Right axis: Investment costs divided by swept rotor area (€/m2 in constant 2006 €). Left axis: Wind turbine capital costs (ex works) and other costs per kW rated power (€/kW in constant 2006 €).

Also, the share of other costs as a percentage of total costs has in general decreased. In 1989, almost 29% of total investment costs were related to costs other than the turbine itself. By 1997, this share had declined to approximately 20%. The trend towards lower auxiliary costs continues for the last vintage of turbines shown (2000 kW), where other costs amount to approximately 18% of total costs. But from 2004 to 2006 other costs rose in parallel with the cost of the turbine itself.

3.3.2 Operation and maintenance costs of wind generated power

Operation and maintenance (O&M) costs constitute a sizeable share of the total annual costs of a wind turbine. For a new turbine O&M costs might easily have an average share over the lifetime of the turbine of approximately 20-25 percent of total leveled cost per kWh produced – as long the turbine is fairly new the share might constitute 10-15 percent increasing to at least 20-35 percent by the end of the turbine's lifetime. Thus O&M costs are increasingly attracting more attention manufacturers attempting to lower these significantly by developing new turbine designs requiring fewer regular service visits and less out-time of the turbines.

O&M costs are related to a limited number of cost components:

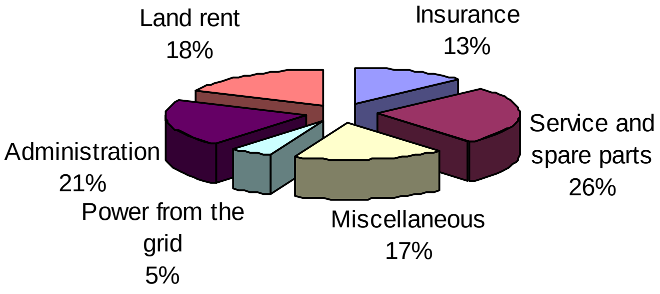
- Insurance
- Regular maintenance
- Repair
- Spare parts
- Administration

Some of these cost components can be estimated with relative ease. For insurance and regular maintenance, it is possible to obtain standard contracts covering a considerable portion of the wind turbines total lifetime. On the other hand, costs for repair and related spare parts are much more difficult to predict. Although all cost components tend to increase with the age of the turbine, costs for repair and spare parts are particularly influenced by turbine age, starting low and increasing over time.

Due to the newness of the wind energy industry, only a limited number of turbines have existed for the full-expected lifetime of 20 years. Of course these turbines are almost entirely small ones compared to the average size of the turbines sold at the market place nowadays and to a certain extent they have been constructed using more conservative though less stringent design criteria's than used to day. Nevertheless some experiences can be drawn from the existing older turbines but the estimates of O&M costs are still to be considered highly uncertain, especially around the end of turbines' lifetimes.

Based on the existing experiences from Germany, Spain, UK and Denmark O&M costs are in general estimated to be at a level of approximately 1.2 to 1.5 c€/kWh of produced wind power seen over the total lifetime of the turbines. Data from Spain indicate that a little less than 60% of this amount goes strictly to O&M of the turbine and the installations, split into approximately half to spare parts and the rest equally distributed onto labour costs and spare parts. The remaining 40% is almost equally split into insurance, rent of land8 and overhead.

In Figure 3.4 is shown an average over the time-period 1997-2001 of how total O&M-costs were split into 6 different categories based on the German data from Dewi. Observe that expenses for buying power from the grid and the rent of land (as in Spain) are parts of O&M-costs as calculated for Germany. For the first two years of its lifetime a turbine is normally covered by the manufacturer's warranty, thus in the German study is found fairly low total O&M-costs of 2-3% of total investment costs for these two years, corresponding to approximately 0.3-0.4 c€/kWh. After 6 years the total O&M-costs have increased to constitute a little less than 5% of total investment costs, which is equivalent to approximately 0.6-0.7 c€/kWh. These figures are fairly close in line with calculated O&M-costs for newer Danish turbines, see below.



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[8] In Spain the rent of land is seen as an O&M-cost.

Figure 3.4: O&M-costs for German turbines distributed into different categories as an average over the time-period 1997-2001. Source: Dewi.

Figure 3.5 shows the total O&M–costs as found in a Danish study and how these are distributed on the different categories of O&M, according to the type, size and age of the turbine. Thus for a three year old 600 kW machine, which was fairly well represented in the study[9] , approximately 35% of total O&M-costs is paid for insurance, 28% for regular service, 11% for administration, 12% for repair and spare parts and, finally, 14% for other purposes. In general it is found in the study that expenses for insurance, regular service and administration were fairly stable over time, while as mentioned above the costs for repair and spare parts were heavily fluctuating. Finally, in most cases other costs were of minor importance.

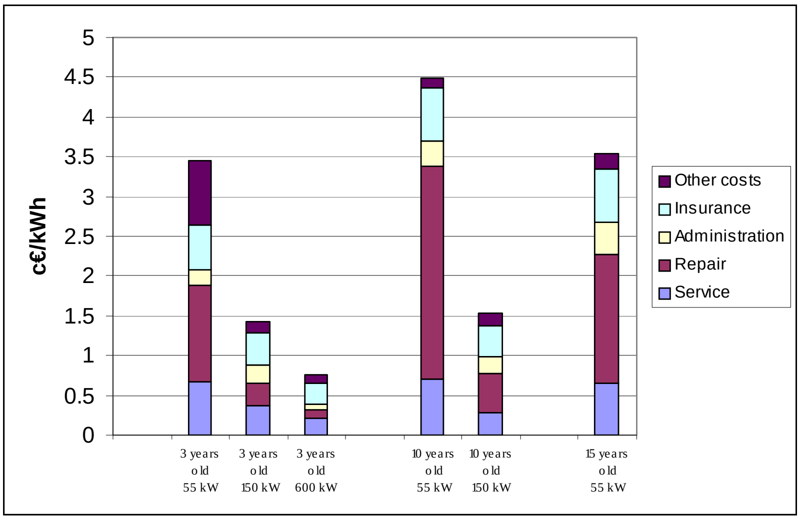

Figure 3.5: O&M costs as reported for selected types and vintages of turbines. Source: Jensen et al. (2002) ref.0.

Figure 5 shows clearly the trend towards lower O&M-costs for new and larger machines. Thus for an 3-year old turbine the O&M-costs have decreased from approximately 3.5 c€/kWh for the old 55 kW turbine to less than 1 c€/kWh for the newer 600 kW machine. The figures for the 150 kW turbine are almost at the same level as the O&M-costs identified in the three countries mentioned above. Moreover, Figure 5 shows clearly that O&M-costs increase with the age of the turbines.

Though, with regard to the future development of O&M-costs care must be taken in interpreting the results of Figure 3.5. First, as wind turbines exhibit economies of scale in terms of declining investment costs per kW with increasing turbine capacity, similar economies of scale may exist for O&M costs. This means that a decrease in O&M-costs to a certain extent will be related to the up-scaling of the turbines. Secondly, the newer and larger turbines are more optimised with regard to dimensioning criteria’s than the old ones, implying an expectation of lower lifetime O&M requirements than the older smaller turbines. But in turn this might have the adverse effect, that these newer turbines are not as robust towards unexpected events as the old ones.

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[9] The number of observations was in general between 25 and 60.

3.3.3 The cost of energy generated by wind power

The total cost per produced kWh (unit cost) is calculated by discounting and leveling investment and O&M costs over the lifetime of the turbine, divided by the annual electricity production. The unit cost of generation is thus calculated as an average cost over the turbine's lifetime. In reality, actual costs will be lower than the calculated average at the beginning of the turbine's life, due to low O&M costs, and will increase over the period of turbine use.

The turbine's production of power is the single most important factor for the cost per generated unit of power. If a turbine is sited at a good wind location or not might totally determine if the turbine is profitable or runs with a loss. In this section the cost of wind produced energy will be calculated given a number of basic assumptions. Due to the importance of the turbine's power production this parameter will be treated on a sensitivity basis. Other assumptions include:

- The calculations are performed for a new land based medium sized turbine that is of 850-1500 kW size, which could be erected today.
- Investment costs reflect the range given in section two, that is a cost per kW of 1100 to 1400 €/kW with an average of 1175 €/kW. These costs are based on data from Spain, UK, Germany and Denmark, updated to 2006-prices.
- Operation and maintenance costs are assumed to be 1.45 c€/kWh as an average over the lifetime of the turbine.
- The lifetime of the turbine is set to 20 years, in accordance with most technical design criteria's.
- The discount rate is assumed to range with in an interval of 5 to 10% p.a. In the basic calculations a discount rate of 7.5% p.a. is used, though a sensitivity analysis of the importance of the above-mentioned interest range is performed.
- The economic analyses are carried out as simple national economic ones. No taxes, depreciation, risk premium etc are taken into account. Everything is calculated in fixed 2006-prices.

The calculated costs per kWh wind generated power as a function of the wind regime at the chosen sites are shown in Figure 3.6 below[10]. As shown the cost ranges from approximately 7-10 c€/kWh at sites with low average wind speeds to approximately 5-6.5 c€/kWh at good coastal positions, with an average of approximately 7c€/kWh at a medium wind site. In Europe coastal positions as these are mostly to be found at the coast of UK, Ireland, France, Denmark and Norway. Medium wind areas are mostly to be found as inland terrain in Mid- and Southern-Europe, that is Germany, France, Spain, Holland, Italy, but also as inland sites in Northern Europe in Sweden, Finland and Denmark. In many cases local conditions do significantly influence the average wind speed at the specific site for which reason strong fluctuations in the wind regime are to be expected even for neighbouring areas.

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[10] In the figure the number of full load hours is used to represent the wind regime. Full load hours are calculated as the turbine's average annual production divided by its rated power. The higher the number of full load hours, the higher the wind turbine's production at the chosen site.

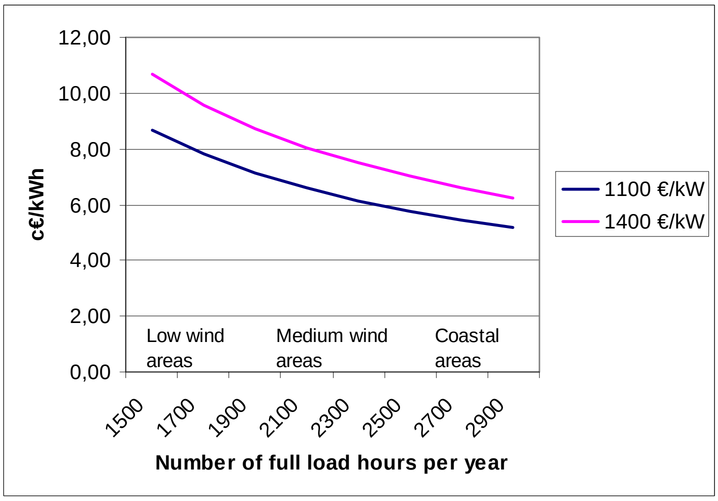

Figure 3.6: Calculated costs per kWh wind generated power as a function of the wind regime at the chosen site (number of full load hours). Assumptions: see text above.

Approximately 75-80% of total power production costs for a wind turbine are related to capital costs, that is costs for the turbine itself, foundation, electrical equipment and grid-connection etc. Thus a wind turbine is so called capital intensive compared with conventional fossil fuel fired technologies as a natural gas power plant, where as much as 40-60% of total costs are related to fuel and operation and maintenance costs. For this reason the costs of capital (discount or interest rate) is an important factor for the cost of wind generated power and at the same time it is a factor that varies substantially between the individual EU member countries.

In Figure 3.7 the costs per kWh wind produced power are shown as a function of the wind regime and the discount rate, where the last-mentioned parameter is varied between 5 and 10% p.a.

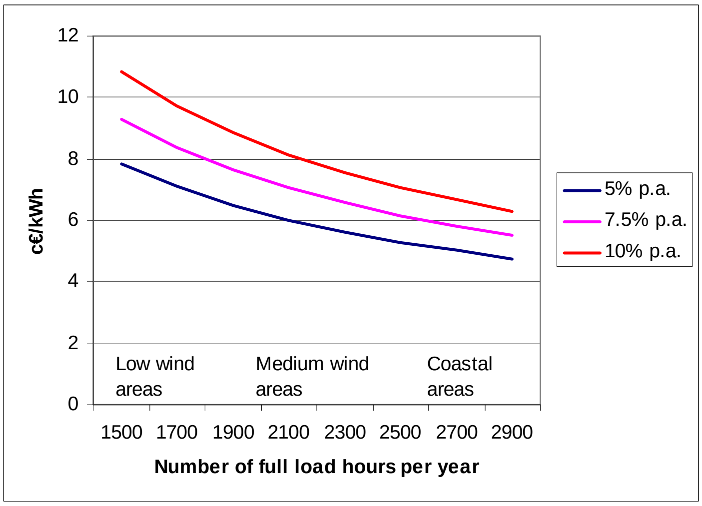

Figure 3.7: The costs of wind produced power as a function of wind speed (number of full load hours) and discount rate. Installed cost of wind turbines is assumed to be 1175€/kW.

As shown in Figure 3.7 the costs ranges between approximately 6 and 8 c€/kWh at medium wind positions, indicating that a doubling of the interest rate induces an increase in production costs of 2 c€/kWh. In low wind areas the costs are significantly higher, 7-10 c€/kWh, while the production costs range between 5 and 6.5 c€/kWh in coastal areas.

3.3.4 Cost profile

The rapid European and global development of wind power capacity has had a strong influence on the cost development of wind power within the past 20 years. To illustrate the trend towards lower production costs of wind generated power, a historical case showing the production costs for different sizes and vintages of turbines is constructed. Due to limited data the trend curve been only been constructed for Denmark, though a similar trend was observed in Germany at a little lower pace.

Figure 3.8 shows the calculated unit cost for different sizes of turbines based on the same assumptions as used in the previous section. Thus a 20-year lifetime is assumed for all turbines in the analysis and a real discount rate of 7.5% p.a. is used. All costs are converted into constant 2006-prices. The turbines' electricity production is estimated for two wind regimes, a coastal and an inland medium wind position, respectively. The starting point for the analysis is the 95 kW machine that mainly was installed in Denmark in the mid 80s, followed by successively newer turbines (150 kW, 225 kW etc.) and ending by the newest in the analysis, the 2000 kW turbine typically installed from around year 2003 and onwards. It should be noted that wind turbine manufacturers, as a rule of thumb, expects the production cost of wind power to decline by 3-5% for each new turbine generation they add to their product portfolio. Do observe that the calculations are performed for the total lifetime (20 years) of the turbines, which means that calculations for the old turbines are based on track records of up to 15 years (average figures), while newer turbines might have a track record of only a few years. Thus the newer the turbine the more uncertainty is related to the calculations.

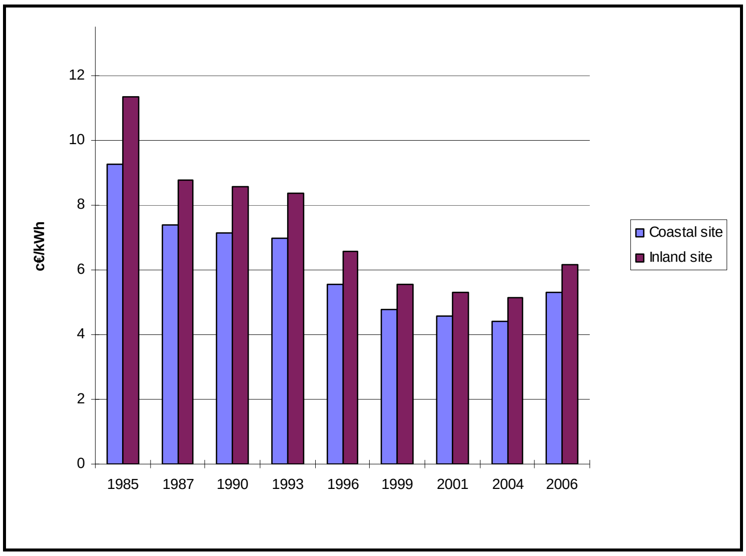

Figure 3.8: Total wind energy costs per unit of electricity produced, by turbine size. (c€/kWh, constant 2006 prices).

In spite of this Figure 3.8 clearly illustrates the economic consequences owing to the trend towards larger turbines and improved cost-effectiveness. For a coastal position, for example, the average cost has decreased from approximately 10.1 c€ /kWh for the 95 kW turbine (mainly installed in the mid 80s) to approximately 5.3 c€ /kWh for a fairly new 2000 kW machine, an improvement of almost 50 percent over a time span of 20 years (constant 2006 prices).

3.4 Outlook for cost reductions (Learning curve – short to medium term development (2015)

In this section the future development of the economics of wind power is illustrated by the use of the experience curve methodology. The experience curve approach was developed back in the 70s of the Boston Consulting Group and the main feature is that it relates the cumulative quantitative development of a product with the development of the specific costs (Johnson, 1984). Thus, if the cumulative sale of a product is doubled, the estimated learning rate tells you the achieved reduction in specific product costs.

The experience curve is not a forecasting tool based on estimated relationships. It is merely pointing out to you, that if the existing trends are going to continue in the future, then we might see the proposed development. It converts the effect of mass production into an effect upon production costs, other casual relationships not taken into account. Thus changes in market development and/or technological breakthroughs within the field might considerably change the picture.

In a number of projects different experience curves have been estimated11, but unfortunately also mostly using different specifications, which means that not all of these can be directly compared. To get the full value of the experiences gained not only the price reduction of the turbine (€/KW-specification) should be taken into account, but the improvements in efficiency of the turbine's production as well. The last mentioned issue requires the use of an energy specification (€/kWh), which excludes many of the mentioned estimations, leaving mainly (Neij, 1997) and (Neij et al., 2003). Thus using the specific costs of energy as a basis (costs per kWh produced) the estimated progress ratios in these publications range from 0.83 to 0.91, corresponding to learning rates of 0.17 to 0.09. That is when total installed capacity of wind power is doubled the costs per produced kWh for new turbines are reduced between 9 and 17%. In this way both the efficiency improvements and embodied and disembodied cost reductions are taken into account in the analysis.

Wind power capacity has developed very rapidly in recent years, on average by 25-30% per year during the last ten years. Thus at present the total wind power capacity is doubled approximately every 3rd to 4th year. In Figure 3.9 below are shown the consequences for wind power production costs according to the following assumptions:

- The present price-relation is expected to be kept until year 2010; that is no price reductions are foreseen in this period due to a persistent strong demand after new wind turbine capacity.
- From 2010 and until 2015 a learning rate of 10 % is assumed, implying that each time the total installed capacity is doubled then the costs per kWh wind-generated power is reduced by 10%.
- The growth rate of installed capacity is assumed to double cumulative installations each 3rd year.
- The curve illustrates cost development in Denmark, which is a fairly cheap wind power country. Thus the starting point for the development is a cost of

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[11] See for instance (Durstewitz and Hoppe-Klipper, 1999), (Neij, 1997), (Neij, 1999), (Milborrow, 2002) or (Neij et al.,2003)

wind power of approx. 6.1 c€/kWh for an average 2 MW turbine, sited at a medium wind regime (average wind speed of 6.3 m/s at a hub height of 50 m).

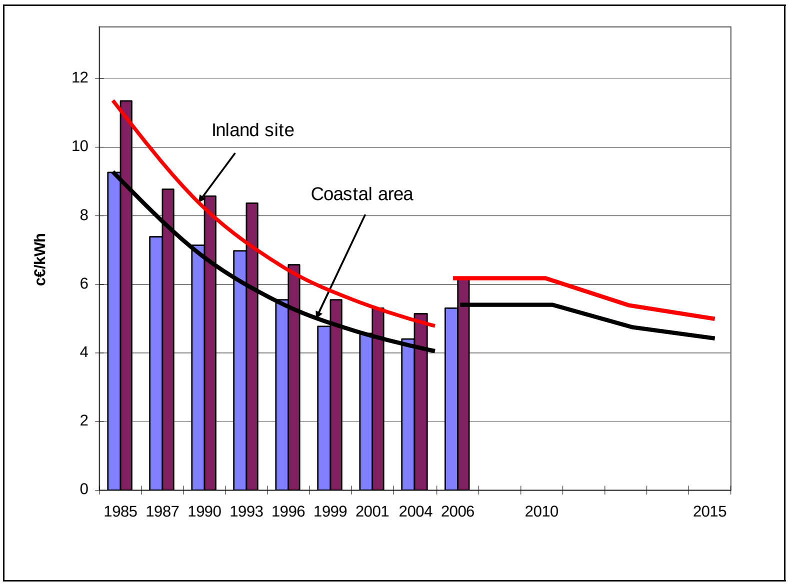

Figure 3.9: Using experience curves to illustrate the future development of wind turbine economics until 2015. Costs illustrated for an average 2MW turbine installed with a present day production cost of 6.1 c€/kWh in a medium wind regime.

At present the production costs for a 2 MW wind turbine installed in an area with a medium wind speed (inland position) is approximately 6.1 c€/kWh wind produced power. If sited at a coastal position costs today are approx. 5.3 c€/kWh. If a doubling time of total installed capacity of three years is assumed the cost interval would in 2015 be approximately 4.3 to 5.0 c€/kWh for a coastal and inland site, respectively. A doubling time of five years, would imply a cost interval in 2015 of 4.8 to 5.5 c€/kWh. As mentioned Denmark is a fairly cheap wind power country. For more expensive countries the cost of wind power produced will increase by 1- 2 c€/kWh.

3.5 Estimates of onshore wind power prospects in 2015, 2030 and 2050

We have seen a very dramatic development in the global utilization of wind power the last 10 years. At the end 2007, about 1% of the global electricity consumption will be produced by wind power.

As shown in Table 3.2 the growth in total capacity have been between 20 and 30 percent yearly over the last five years and in many countries significant amounts of capacity is in the planning stages. In the near future BTM Consult estimates a doubling of the annual wind power development alone in the period from 2006-2011.

Year:	Installed MW	Increase %	Cumulative MW	Increase %
2001	6,824		24,927	
2002	7,227	6%	32,037	29%
2003	8,344	15%	40,301	26%
2004	8,154	-2%	47,912	19%
2005*	11,542	42%	59,399	24%
2006	15,016	30%	74,306	25%
Average growth - 5 years		**17.1%**		**24.4%**

Source: BTM Consult ApS - March 2007

Table 3.2 Growth in wind energy capacity from 2001 - 2006

Several estimates of the future development have been made. The BTMs [ref.0] forecast (Table 3.3 and Figure 3.10) is based on very detailed market information collected over a longer period of years.
BTM Consult estimates a doubling of the annual wind power development alone in the period from 2006-2011. This would bring the total capacity above 200 GW.

	Cumulative installed capacity (MW) by end of in 2006	Installed capacity (MW) in 2006	**Forecast 2007-2011** **(incl. Offshore)**					Installed capacity between 2007-2011	Cumulative installed capacity (MW) by end of 2011
	2006	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**Sum**	**Accu.**
Total Americas	**13,577**	**3,515**	**4,850**	**5,700**	**6,250**	**7,750**	**8,500**	**33,050**	**46,627**
Total Europe	**48,627**	**7,682**	**8,610**	**9,760**	**12,030**	**13,150**	**15,600**	**59,150**	**107,777**
Total South & East Asia	**8,963**	**3,220**	**4,340**	**5,110**	**5,650**	**5,800**	**6,950**	**27,850**	**36,813**
Total OECD-Pacific	**2,617**	**485**	**725**	**1,000**	**1,150**	**1,250**	**1,400**	**5,525**	**8,142**
Total other areas	**522**	**114**	**275**	**410**	**650**	**885**	**1,050**	**3,270**	**3,792**
Total MW new capacity every year:		**15,016**	18,800	21,980	25,730	28,835	33,500	**128,845**	**203,151**
Accu. capacity (MW)	**74,306**		**93,106**	**115,086**	**140,816**	**169,651**	**203,151**		

Source: BTM Consult ApS - March 2007

Table 3.3. Forecast 2007-2011.

The forecast has been split into forecast 2007-2011 and predictions 2012-2016. The forecast is based on market information from national energy plans in a number of countries, and world market indicators. The prediction is an overall analysis based on the forecast and published potentials in major areas of the world. According to this forecast, the global capacity increases by a factor of 6 from today’s approximately 75,000 MW to 450,000 MW in year 2016. This is equivalent to about 5% of today’s electricity consumption.

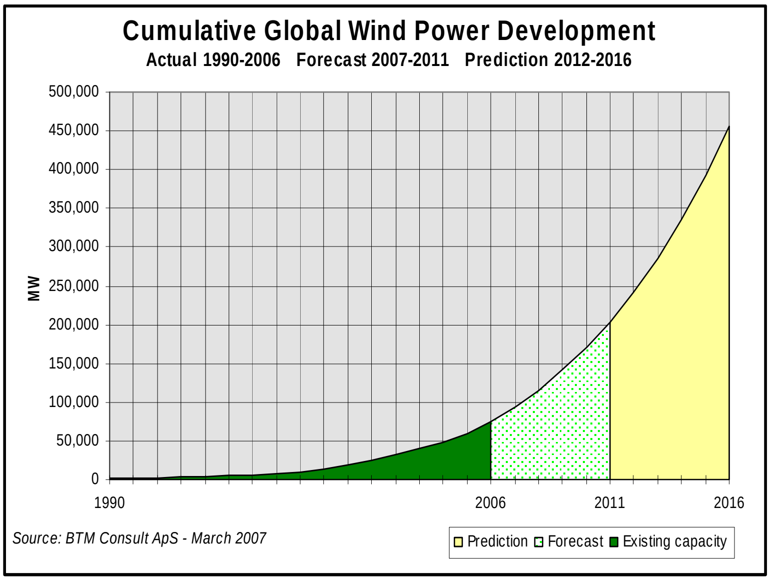

Figure 3.10. BTM's global wind energy forecast March 2007.

Several international institutions and agents such as IEA, the European Wind Energy Association, Geen Peace and GWEC have also formulated scenarios ending with as much as 12% of the electricity consumption 2030 to be covered by wind power.

3.6 Scenarios for the future development of wind power

In the last two decades wind power has developed rapidly. For 15 years annual growth rates in total accumulated capacity has ranged within 20 to 35%. At present the wind power market is characterized by a strong demand implying supply constraints within the turbine manufacturing industry and no signs indicate that demand will diminish within the coming years (BTM market world market updates [ref.0]. Turbine manufacturers and sub suppliers are expanding their manufacturing capacity and new companies are entering the arena. In the light of a growing concern for climate change and security of energy supply - increasing prices for fossil fuels, high crude oil prices - expectations are that the wind power industry also in coming years will witness a rapid growth.

Based on existing studies on future wind power development (ref. 0 and ref. 0) Risø has evaluated future opportunities in wind power and calculated a future scenario for wind power deployment. It should be strictly underlined that results shown in this chapter are subject to large uncertainties.

The following assumptions are used in the Risø wind power scenario:

- The present rapid growth within the overall wind power industry of approx. 25% increase in total accumulated capacity will continue until 2015, including both on- and offshore capacity. Up and downs will exist, but on average the growth rate will be 23% annually. The high demand will be driven by increasing demand for energy in developing regions (as China), increasing environmental concerns and by increasing fossil fuel prices.
- As the wind industry grows more mature capacity growth rates for on- and offshore wind power will decline, to 17% on average in the period 2015-20, to approx. 10% in 2020-30 and, to 2.4% in 2030-50.

- The capacity factor will on average be 25% for on land turbines (2200 full load hours) for the whole period until 2050, covering that new wind turbines will have a higher production being moderated by a lower availability of sites with high wind speeds. Correspondingly, the capacity factor for offshore installations will on average be 37,5% (3300 full load hours) until 2050
- The global expected final electricity consumption will follow existing forecasts (ref.12 and ref. 0); that is approx. 2.8% annual growth until 2030, followed by an assumed slower growth of 1.5% p.a. in the period 2030-50.

Based on the above-mentioned assumptions, the future scenario for wind power development is given in Table 3.4.

	Total installed Wind GW	Yearly growth rate of wind %	Production from wind total TWh	Expected electricity consumption TWh	Penetration of wind %
2006	74		163	15500	1.1
2015	486	23	1084	21300	5.1
2020	1066	17	2392	23800	10.1
2030	2633	9.5	6019	29750	20.4
2050	4200	2.4	10100	40100	25.2

Table 3.4: Scenario for global on and offshore wind power development.

As shown in Table 3.4 total wind power production (on land and offshore) is calculated to be 10,100 TWh in 2050, wind power supplying approx. 25% of global electricity consumption. The assumed growth implies that the accumulated global wind power capacity will double each 3rd year until 2015, each 4th year from 2015-20, and, each 7th year from 2020-30. In the period 2030-50 growth will be much slower.

On land wind power will constitute the vast bulk of this development, offshore mainly starting in the period up to 2020, becoming increasingly important until 2050. Table 3.5 shows the development of on land turbines until 2050.

	On landwind GW	Yearly growth on land wind %	On land of total wind power, %	Production from on land wind, TWh	Expected electricity consumption TWh	Penetration of on land wind, %
2006	73		98.8	160	15500	1.0
2015	474	23	97.4	1042	21300	4.9
2020	1024	17	96.0	2252	23800	10.7
2030	2382	9	90.5	5240	29750	17.6
2050	3430	1.8	81.6	7542	40100	18.8

Table 3.5: Scenario for global offshore wind power development.

As shown in Table 3.5 the total on land wind power production is calculated to approx. 7,500 TWh in 2050, supplying approx. 17.6% of global electricity consumption and constituting approx. 81.6% of total wind power capacity. The assumed growth implies that the accumulated global on land wind power capacity will double each 3rd year until 2015, each 5th year from 2015-20, each 7th year from 2020-30. In the period 2030-50 growth rates will be much lower.

3.7 Long-term cost perspectives for on land turbines

Until 2004 the cost of wind turbines in general followed the development of a medium-term cost reduction curve (learning curve) showing a learning rate of approximately 10% that is each time wind power capacity was doubled the cost was reduced by approx. 10% per MW-installed. This decreasing cost-trend was interrupted in 2004-6 where the price of wind power in general increased by approx. 20%, mainly caused by increasing material costs and a strong demand for wind capacity implying scarcity of wind power manufacturing capacity.

Although at present a large number of wind-projects are carried out worldwide each year, do to confidentiality reasons it gets incereasingly difficult to get trustworthy investment and O&M-costs. Based on the available data it is calculated, that today's expected investment costs for a new on land wind turbine will on average be 1.2 mill.€/MW, with a minimum of of 1.0 mill.€/MW and a maximum of 1.4 mill.€/MW

In the following the long term cost development of on land wind power will be estimated using the learning curve methodology. However, learning curves are not developed to be applied for that long a time period and for this reason the estimated figures are mainly to be seen as the results of a long term scenario development.

The long term cost perspectives for on land wind power is shown in Table 3.6 given the following conditions:

- The total capacity development of wind power (Section 3.6) is assumed to be the main driving factor for the cost development of on land turbines, because the major part of turbine costs are related to the general wind power industry development.
- The existing manufacturing capacity constraints for the wind turbines will persist until 2010. Although we gradually will see an expanding industrial capacity for wind power, a continued increasing demand will also continue to strain the manufacturing capacity and not before 2011 increasing competition among wind turbine manufacturers and sub suppliers will again imply unit reduction costs in the industry.
- For the period 1985 to 2004 a learning rate of approx. 10% was estimated [ref.0]. With the return of competition in the wind industry again in 2011 this learning rate is again expected to be realized by the industry in the period until 2020. The wind power industry growing mature the learning rate is assumed to fall to 6% in 2020, in 2030 decreasing further to 3% keeping this level until 2050.

Given these assumptions minimum, average and maximum cost-scenarios are reported in Table 3.6

	Investment costs, Mill. €/MW			O&M	Cap. factor
	Min	Average	Max	€/MWh	%
2006	1.0	1.2	1.4	12	25
2015	0.86	1.03	1.20	10	25
2020	0.76	0.92	1.07	9	25
2030	0.70	0.84	0.99	8	25
2050	0.69	0.83	0.97	8	25

Table 3.6: Scenarios for cost development of on land wind turbines, constant 2006-€.

As shown in Table 3.6 average cost of offshore wind capacity is calculated to decrease from 1.2 mill.€/MW in 2006 to 0.83 mill€/MW in 2050 or by approx. 30%. A considerable spread of costs will still exist, from 0.69 mill. €/MW to 0.97 mill.€/MW. A capacity factor of constant 25% (corresponding to a number of full load hours of approx. 2200) is assumed for the whole period, covering an increasing production from newer and larger turbines moderated by sites with lower wind regimes

4 Offshore Wind – Status and Prospects

4.1 Introduction

Offshore wind still only counts for a very small amount and development has only taken place in North European counties round the North Sea and the Baltic Sea, where around 1 GW has been installed over the last 15 years. Offshore wind is still some 50% more expensive than onshore wind, but due to expected benefits of more wind and lesser visual impact from larger turbines several countries have very ambitious goals concerning offshore wind.

Since the early 1990s, where the first small demonstration offshore installations of less than 5 MW were built in the Danish, Dutch and Swedish waters, offshore wind farms with a capacities of over 100 MW have been erected in both Denmark, the Netherlands, Sweden and in UK. Prospects are that the better wind resources offshore at the longer term will be able to compensate for the higher installations cost.

4.2 Overview of Status and Prospects

4.2.1 Deployment

Wind turbines are not only installed on land. By the close of 2006, more than 900 MW of capacity was located offshore in 4 countries: Denmark, Ireland, Netherlands, Sweden, and the United Kingdom (Table 4.1 and Table 4.2), and in 2007 110 MW at Lillgrunden Sweden has been installed. Most of the capacity has been installed on relatively low water dept and close to the coast to keep the extra cost to foundations and sea cable as low as possible. As can be seen from Table 4.2 sea dept is < 20 meter and within a distance to the coast of 20 km

The total capacity is still limited but growth rate has on average been 64% over the last 12 years. Offshore wind farms are installed in large units - often 100-200 MW and only two units installed a year will results in future growth rates between 20-40%. Higher costs and temporally capacity problems in the manufacturing stages and in availability of installation vessels causes some delays at present, but still several projects in both UK, Denmark will be finish with in the next 3 years.

Country	MW Installed in 2005	Accumulated MW end 2005	MW Installed in 2006	Accumulated MW end 2006
Denmark	0	423	0	423
Ireland	0	25	0	25

The Netherlands	0	18.2	108	126.8
Sweden	0	23.3	0	23.3
UK	90	214	90	304
Total in the world	90	703.5	198.0	902.1

Table 4.1: Installed offshore capacity in offshore wind countries. Source BTM Consult and Danish Energy Authority

	Turbines	Sea dept in m.	Distance to coast in km.	MW	Year
Vindeby (DK)	11 x 450 kW, Bonus	2.5-5.1	2.3	4.95	1991
Lely (Ijsselmeer) (NL)	4 x 500 kW, NEG Micon	5-10	<1	2	1994
Tuno Knob (DK)	10 x 500 kW, Vestas	2.5-7.5	5-6	5	1995
Dronton (Ijsselmeer) (NL)	28 x 600 kW, NEG Micon	5	<0.1	16.8	1996
Bockstigen (S)	5 x 550 kW, NEG Micon	6	3	2.75	1997
Blyth (UK)	7 x 1.5 MW, GE Wind	6-11	<1	4	2000
Utgrunden (Oland) (S)	2 x 2 MW, Vestas	7-10	8	10.5	2000
Middelgrunden (DK)	20 x 2 MW, Bonus	3-6	1.5-2.5	40	2000
Yttre Stengrund (S)	5 x 2 MW, NEG Micon	6-10	5	10	2001
Horns Rev (DK)	80 x 2 MW, Vestas	6-14	14-20	160	2002
Samsø (DK)	10 x 2.3 MW, Siemens	18-20	3-6	23	2002
Ronland (DK)	Mix of Vestas and Siemens	< 1	<1	17.2	2003
Frederikshavn (DK)	Mix of Vestas and Siemens	1-3	< 1	7.6	2003
North Hoyle (UK)	30 x 2 MW, Vestas	12	6-8	60	2003
Arklow Bank (UK)	7 x 3.6 MW,GE Wind	2-5	10	25.2	2003
Nysted (DK)	72 x 2.3 MW, Siemens	6-9.5	10	166	2003
Scroby Sands (UK)	30 x 2 MW, Vestas	2-8	3	60	2004
Kentish Flat (UK)	30 x 3 MW, Vestas	5	8.5	90	2005
Barrow (UK)	30 x 3 MW, Vestas	21-23	7.5	90	2006
NSW (NL)	30 x 3 MW Vestas	19-22	10	108	2006
Lillgrunden (S)	48 x 2.3 MW, Siemens	3-6	7-10	110	2007
Burbo Bank (UK)	24 x 3.6 MW, Siemens	2-8	5-7	90	2007

Table 4.2: Installed offshore wind farms in the world (BTM Consult [ref.0] and Risø)

*** Under construction**

4.2.2 Present cost of offshore wind energy

Most offshore wind farms are installed in British and Danish waters, but recently also Sweden has entered the large scale offshore arena establishing the Lillgrunden wind farm. Table 4.3 gives information on some of the recently established offshore wind farms.

Offshore costs are largely dependent on weather and wave conditions, water depth, and distance to the coast. The most detailed cost information on recent offshore installations comes from the UK where 90 MW was added in 2006. The present-day costs of installing wind energy in the UK are between 585 and 800 £/kW (868 and 1,187 €/kW) onshore, rising to 1,200 to 1,600 £/kW (1,781 to 2,375 €/kW) offshore. The higher capital costs of offshore are due to the larger structures and complex logistics of installing the towers. The costs of offshore foundations, construction, installations, and grid connection are significantly higher than for onshore. For example, typically, offshore turbines are 20% more expensive, and towers and foundations cost more than 2.5 times the price for a project of similar size onshore.

	In operation	Number of turbines	Turbine size	Capacity MW	Invest-ment cost mill. €	Mio. €/MW
Middelgrunden (DK)	2001	20	2	40	47	1.2
Horns Rev I (DK)	2002	80	2	160	272	1.7
Samsø (DK)	2003	10	2.3	23	30	1.3
North Hoyle (UK)	2003	30	2	60	121	2.0
Nysted (DK)	2004	72	2.3	165	248	1.5
Scroby Sands (UK)	2004	30	2	60	121	2.0
Kentich Flat (UK)	2005	30	3	90	159	1.8
Barrows (UK)	2006	30	3	90	-	-
Burbo Bank (UK)	2007	24	3.6	90	181	2.0
Lillgrunden (S)	2007	48	2.3	110	197	1.8
Robin Rigg* (UK)	2008	60	3	180	492	2.7

Table 4.3: Key information on recent offshore wind farms. **(Note that Robin Rigg is *planned to be in operation in 2008***

As shown in Table 4.3 the chosen turbine size for offshore wind farms ranges from 2 MW to 3.6 MW, the newer wind farms equipped with the larger turbines. Also the turbine farm sizes differ substantially from the fairly small Samsø wind farm of 23 MW to Robin Rigg with a rated capacity of 180 MW, which will be the world largest offshore wind farm. Investment costs per MW range from a low of 1.2 mill.€/MW (Middelgrunden) to almost the double of 2.7 mill.€/MW (Robin Rigg) to a certain extent covering differences in water depth and distance to shore (Figure 4.1)

In general the costs of offshore capacity have increased in recent years as seen for on land turbines and these increases are only partly reflected in the costs shown above in Figure 4.1. For that reason average cost of future offshore farms will expectedly be higher. On average investment costs for a new offshore wind farm are expected be in the range of 2.0 to 2.2 mill. €/MW for a near-shore shallow depth facility

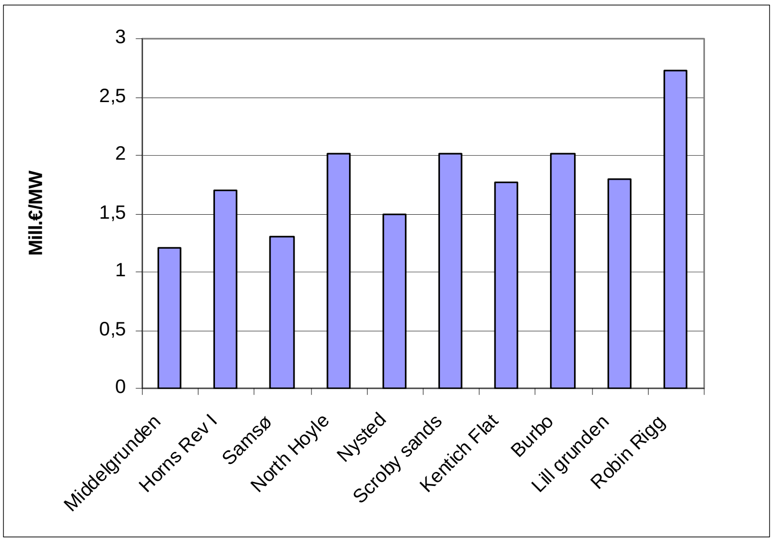

Figure 4.1: Investments in offshore wind farms, mill.€/MW (Current prices)

To illustrate more thoroughly the economics of offshore wind turbines, the two largest Danish offshore wind farms are chosen as examples. The Horns Rev project located approximately 15 km off the west coast of Jutland (west of Esbjerg) was finished in 2002. It is equipped with 80 2 MW machines and thus have a total capacity of 160 MW. The Nysted offshore wind farm is located south of the isle of Lolland. It consists of 72 2.3 MW turbines and have a total capacity of 165 MW. Both wind farms have their own transformer station located at the sites, which through transmission cables are connected to the high voltage grid at the coast. The farms are operated from onshore control stations and no staff is required at the sites. The average investment costs related to these two farms are shown in Table 4.4.

	Investments 1000 €/MW	Share %
Turbines ex work, including transport and erection	815	49
Transformer station and main cable to coast	270	16
Internal grid between turbines	85	5
Foundations	350	21
Design, project management	100	6
Environmental analysis etc.	50	3
Miscellaneous	10	<1
Total	1680	~100

Note: Exchange rate 1 € = 7.45 DKK.

Table 4.4: Average investment costs per MW related to offshore wind farms at Horns Rev and Nysted.

In Denmark all of the above costs components have to be born by the investors except the costs of the transformer station and the main transmission cable to the coast, which is born by the TSO’s in the respective areas. The total cost of each of the two offshore farms is close to 260 mill. €.

Compared to land-based turbines the main differences in the cost structure are related to two issues [ref.0]:

- Foundations are considerably more costly for offshore turbines. The costs depend on both the sea depth, and the chosen principle of construction[12]. For a conventional turbine sited on land, the share of the total cost for the foundation normally is approx. 4-6%. As an average of the two above mentioned projects this percentage is 21% (cf. Table 4.4), and thus considerably more expensive than for on-land sites. But it should be kept in mind that considerable experiences are gained in establishing these two wind farms and therefore a further optimization of foundation can be expected in future projects.

- Transformer station and sea transmission cables. Connections between the turbines and to the centrally located transformer station and from there on to the coast generate additional costs compared with on-land sites. For Horns Rev and Nysted wind farms the average cost share for the transformer station and sea transmission cables is 21% (cf. Table 4.4), of this is a minor share of 5% to the internal grid between turbines.

Finally, in relation to the two projects a number of environmental analysis, including an environmental impact investigation and visualizing the wind farms, and also additional research and development were carried out. The average cost share for these analyses for the two wind farms account for approximately 6% of total costs, but part of these costs are related to the pilot character of these projects and is not expected to be repeated next time an offshore wind farm will be established.

Though the costs are considerable higher for offshore wind farms this is to a certain degree moderated by a higher total electricity production from the turbines due to higher offshore wind speeds. For an on-land installation utilization time is normally around 2000-2300 hours per year, while a typical offshore installation has an utilization time of 3000 hours per year or above. The investment and production assumptions used to calculate the costs per kWh are stated in Table 4.5.

	In operation	Capacity MW	Mill.€/MW	Full load hours per year
Middelgrunden	2001	40	1.2	2500
Horns Rev I	2002	160	1.7	4200
Samsø	2003	23	1.3	3100
North Hoyle	2003	60	2.0	3600
Nysted	2004	165	1.5	3700
Scroby sands	2004	60	2.0	3500
Kentich Flat	2005	90	1.8	3100
Burbo	2007	90	2.0	3550
Lillgrunden	2007	110	1.8	3000
Robin Rigg	2008	180	2.7	3600

Table 4.5: Assumption used for economic calculations. Note that Robin Rigg is expected to be in operation in 2008

In addition the following economic assumptions are used

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[12] At Horns Rev monopiles have been used, while the turbines at Nysted are erected on concrete foundations.

- Over the lifetime of the wind farm annual operation and maintenance costs are assumed to 16 €/MWh, except for Middelgrunden where O&M costs based on existing accounts are assumed to be 12 €/MWh for the entire lifetime. These assumptions on O&M-costs are subject to high uncertainty.

- The number of full load hours is assumed for a normal wind year, corrected for shadow effects in the farm and for unavailability and losses in transmission to the coast.

- The balancing of the power production from the turbines is normally the responsibility of the farm owners. According to previous Danish experiences balancing requires an equivalent cost of approx. 3 €/MWh. Also balancing costs are subject to high uncertainty and might differ substantially between countries.

- The economic analyses are carried out as simple national economic ones, using a discount rate of 7.5% p.a. over the assumed lifetime of 20 years. No taxes, depreciation, risk premium etc are taken into account.

Figure 4.2 shows the total calculated costs per MWh for the wind farms stated in Table 4.5.

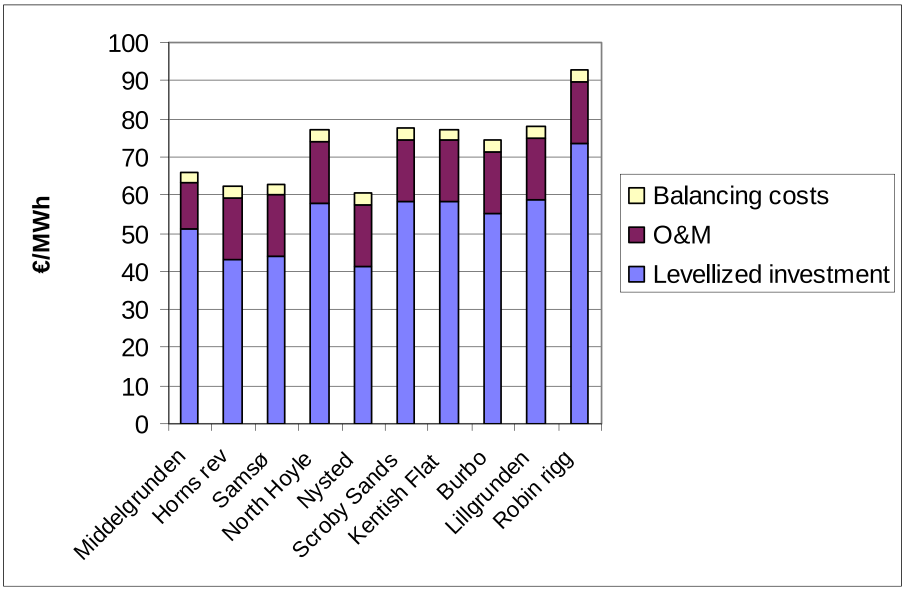


Figure 4.2: Calculated production cost for selected offshore wind farms, including balancing costs (2006-prices).

As shown in Figure 4.2 total production costs differ significantly between the illustrated wind farms, Horns Rev, Samsø and Nysted being among the cheapest, while especially Robin Rigg in UK appears to be expensive. Partly differences can be related to depth of sea and distance to shore, partly to increased investment costs. Observe that O&M-costs are assumed to be at the same level for all wind farms (except Middelgrunden) and are subject to considerable uncertainty.

Costs are calculated as simple national economic ones, thus these costs will not be those of a private investor, which will have higher financial costs, require a risk premium and a profit. How much a private investor will add on top of the simple costs will among other things depend on the perceived technological and political risk of establishing the offshore farm and, on the competition between manufacturers and developers.

4.3 Environmental factors for offshore projects

The shallow waters around the North European coasts of the North Sea, the Baltic Sea and the English Channel offers good conditions for offshore wind farms. These areas combine shallow water with a good wind resource. At the same time these areas host millions of breeding, migrating and wintering water birds, with large congregations occurring in specific areas. With present plans to develop more large offshore wind farms in especially Denmark, UK, Sweden, Germany and Holland, it is increasingly important to study how this development can be taken forward with minimum impact upon the environment.

4.3.1 The Danish experience

Like wind farms and other infrastructure projects on land it is obvious that offshore wind farm projects will have an impact on their natural surroundings. However, the Danish experience from the past 16 years shows that offshore wind farms, if placed right, can be engineered and operated without significant damage to the marine environment. Since 1991 a total of 8 offshore or near-shore wind farms have been commissioned with a total installed capacity of 423 MW from 213 wind turbines in the range from 450 kW to 2.3 MW – and one 3 MW.

4.3.1.1 The Danish Offshore Monitoring Programme 1999-2006

Before, during and after the construction of the two large wind farms Horns rev (160 MW) and Nysted (165 MW) an environmental monitoring programme was launched to investigate and document the impact of these two wind farms. The results were published on 27-28 November 2006 at an international conference in Ellsinore [ref.0}.

The studies and analyses have dealt with:

- Benthic fauna and flora, with particular focus on the consequences of the introduction of a hard-bottom habitat, which is the turbine foundation and scour protection, this also included a survey of the in-fauna community in the wind farms.
- The distribution of fish around the wind turbines and the scour protection, and the effect of electromagnetic fields on fish.
- Studies of the numbers and distribution of feeding and resting birds, performed by aerial surveys, and of the food choice of scoters.
- Migrating birds, including study of the risks of collision between birds and wind turbines.
- The behaviour of marine mammals – porpoises and seals – and their reaction to wind farms.
- Sociological and environmental-economic studies.
- Coastal morphology.

Below the findings on benthic communities, fish, marine mammals, birds and people are summarised.

Benthic communities and fish

For both wind farms new artificial habitats developed quickly. At Horns Rev, the new habitats have increased diversity and biomass in the area, whilst in the Nysted offshore wind farm, monocultures of common mussels have developed due to the low salt content in the area and the absence of such predators as starfish. The artificial habitats are expected to have positive effects on fish populations, both with regard to the number of species and the quantity of fish, once the artificial reef is fully developed.

Marine mammals

During construction every effort was made to frighten seals and harbour porpoises away from the area before the extremely noisy work of inserting piles and sheet pile walls began, so as to avoid harm being done to them. After completion the seals have returned to both areas and have generally seemed unaffected by offshore wind farm operations both at sea and on land.

During the construction phase, the number of porpoises at the farms decreased immediately when noisy activities commenced, alleviating fears that marine mammals would remain in the area and so might be hurt by the intense pressure waves generated by pile driving. At Horns Rev the porpoise numbers very quickly returned to “normal” once construction was completed, although data on porpoises at Nysted are different and more difficult to interpret.

Birds

Potential hazards to birds include barriers to movement, habitat loss and collision risks. Radar, infrared video monitoring and visual observations confirmed that most of the more numerous species showed avoidance responses to both wind farms, although responses were highly species specific. Birds tended to avoid the vicinity of the turbines and there was considerable movement along the periphery of both wind farms.

The study confirmed that the sea birds and divers are good at avoiding the offshore wind farms either by flying around them or by flying low between the wind turbines, and therefore the risk of collisions is small. Of a total of 235,000 common eiders passing Nysted each autumn, predicted modelled collision rates were 0.02% (45 birds). The low figure was confirmed by the fact that no collisions were observed by infra-red monitoring.

Concerning loss of habitat post-construction studies initially showed almost complete absence of divers and scoters within the Horns Rev wind farm and significant reductions in long-tailed duck densities within the Nysted wind farm. Other species showed no significant change or occurred in too few numbers to permit statistical analysis.

The fact that no common scoters were observed inside the wind farm area lead to the perception that they had been forced out of their previous feeding grounds, even though this had only insignificant effects on the level of population. Then in late 2006 and early 2007 Vattenfall A/S maintenance crews and helicopter pilots reported increasing numbers of common scoters present within the wind farm site. On that background a series of four surveys of water bird distribution in the area was programmed during January to April 2007 (ref.0).

The results from these four aerial surveys carried out in 2007 show that, in contrast to the earlier years post construction, common scoter were present in significant numbers between the turbines at Horns Rev 1. It can therefore be conclude that Common Scoter may indeed occur in high densities between newly constructed wind turbines at sea, but this may only occur a number of years after initial construction.

Public acceptance

Public attitudes to offshore wind farms have also been examined. This part of the study consisted of a sociological survey with in-depth interviews with local residents both in the Horns Rev and Nysted areas and an environmental economy survey, in which local questionnaire surveys were supplemented by surveys among a national reference group.

The Horns Rev offshore wind farm is located 14 km west of Blåvandshuk in an area dominated by holiday homes with only 3,300 permanent residents. The offshore wind farm is only visible from just a few houses. The Nysted offshore wind farm is located 10 km from the coast and some of the approximate 4,300 permanent residents in the area can see the wind farm from their homes. The wind farm is also visible from Nysted harbour.

The environmental economy survey shows that more than 80% of the respondents are either positively or extremely positively disposed towards offshore wind farms. The greatest support is to be found in the area around Horns Rev, whilst there were most negative reactions in the Nysted area, though opposition here was restricted to a mere 10% of the respondents. The latter may relate to the fact that the township of Nysted is located close to the shore and thereby to a higher degree exposed to aviation warning lights placed on the nacelles of the turbines on the outer edges of the wind farm.

A clear willingness to pay (via electricity bills) to reduce visual impact was found. In the Horns Rev sample, respondents were willing to pay 261 DKK/household/year to have the distance from the shore extended from 8 to 12 km and 643 DKK/household/year to have the distance extended from 12 to 18 km. There was no extra willingness to pay to have wind farms moved from 18 to 50 km from the shore. In the Nysted area, respondents were willing to pay nearly twice as much as in the Horns Rev sample.

Furthermore the sociological survey showed that the original opposition in the Blåvandshuk area has gradually diminished after the Horns Rev offshore wind farm was commissioned, and by 2004 the general attitude was neutral or even slightly positive.

4.3.1.2 Important results from the Danish environmental programme.

The comprehensive environmental monitoring programmes of Horns Rev and Nysted wind farms confirm that, under the right conditions, even big wind farms pose low risks to birds, mammals and fish, even though there will be changes in the living conditions of some species by an increase in habitat heterogeneity.

The technological tools developed in the Nysted and Horns Rev studies, especially for the study of behavioral responses of marine mammals and birds, will be very useful for researchers working on new offshore wind farms in other locations. Among others these involve the so-called T-POD system, which measures the supersonic activities of harbour porpoises within the offshore wind farms and in the test areas, and TADS technology, which measures bird collisions. These technologies can readily be transferred to estuarine or open sea sites and applied for study of a wide range of focal species.

The results of the environmental monitoring programme in general show that it is possible to adapt offshore wind farms in a way which is environmentally sustainable and which causes no significant damage to the marine environment. Territorial planning, which identifies the most suitable locations, is crucial in this context. In the light of the programme, offshore wind farms now in many ways stand out as attractive options for the development of sustainable energy, as long as authorities and developers respect the marine environment.

4.3.2 Natura 2000

Natura 2000 is an ecological network in the territory of the European Union designed to protect the most seriously threatened habitats and species across Europe. Natura 2000 is founded on two EU directives, the Habitats Directive and the Birds Directive adopted in 1979. Each EU Member State must compile a list of the best wildlife areas containing the habitats and species listed in the Habitats Directive and the Birds Directive. These lists are then be submitted to the European Commission, after which an evaluation and selection process on European level will take place in order to appoint the Natura 2000 sites. Natura 2000 protects 18% of land in the 15 countries that formed the EU before the expansion in 2004.

4.3.3 UK, Sweden and Holland

The Swedish Energy Authority (Energimyndigheten) launched an environmental monitoring program (Vindval) in 2004 with a total budget of 35 mio. SEK. The program includes monitoring of effects on fish, mammals and birds as well as a sociological survey. The program is due at the end of 2007.

For the wind farm Utgrunden and Yttre Stengrund both located in Kalmar sound extensive monitoring of bird migration were carried out in 1999 to 2003. This is a very busy area for migration of sea birds. Each year approximately 1.3 million birds are passing by. A calculation of collision risk based on the observations shows that 1-4 birds in spring and about 10 birds in autumn run the risk of colliding with the existing 12 wind turbines. The waterfowl that make an evasive maneuver due to the wind turbines extend their total migrating distance and time by only 0,2 – 0,5 %.

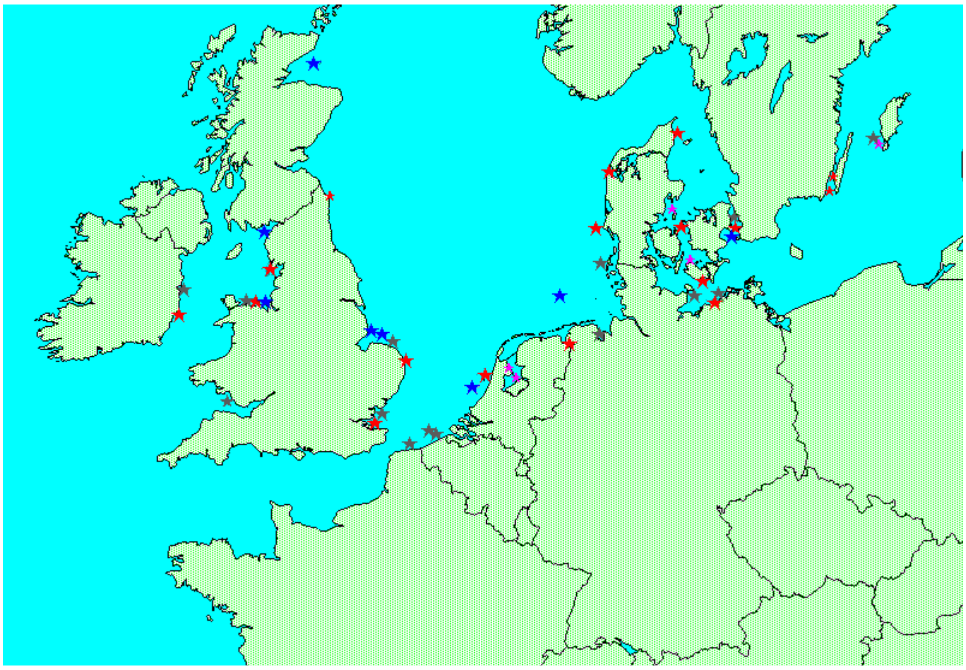
For the wind farm North Hoyle (60 MW) in the UK commissioned in November 2003 Jamie May PMSS Ltd, at the Copenhagen Offshore conference October 2005 ended his presentation on the environmental impact assessment with the conclusion that for a wind farm placed away from sensitive species and habitats basically no negative impact were found.

In the Netherlands a large monitoring program has been launched to monitor effects from the first Dutch offshore wind farm Egmond an Zee (108 MW) completed in April 2007. The first results are due in 2008.

4.4 Offshore wind power prospects in 2015, 2030 and 2050

4.4.1 Offshore wind **farms under construction and in planning stage**

At present several offshore wind farms are under construction in UK waters (Robin Rigg, Rhyl Flats, Inner Dowsing and Lynn) and in Dutch waters the second offshore farm Q7-WP consisting of 60 2 MW turbines will be operational in spring 2008. And much more offshore capacity is in the planning stages. In the United Kingdom, for example, London Array Limited received consent in December 2006 for the world’s largest offshore wind farm to be built in the London Array. At 1,000 MW of capacity, it will be capable of powering one-quarter of the homes in London. In Denmark another 2 times 200 MW will be installed in 2009 and 2010.



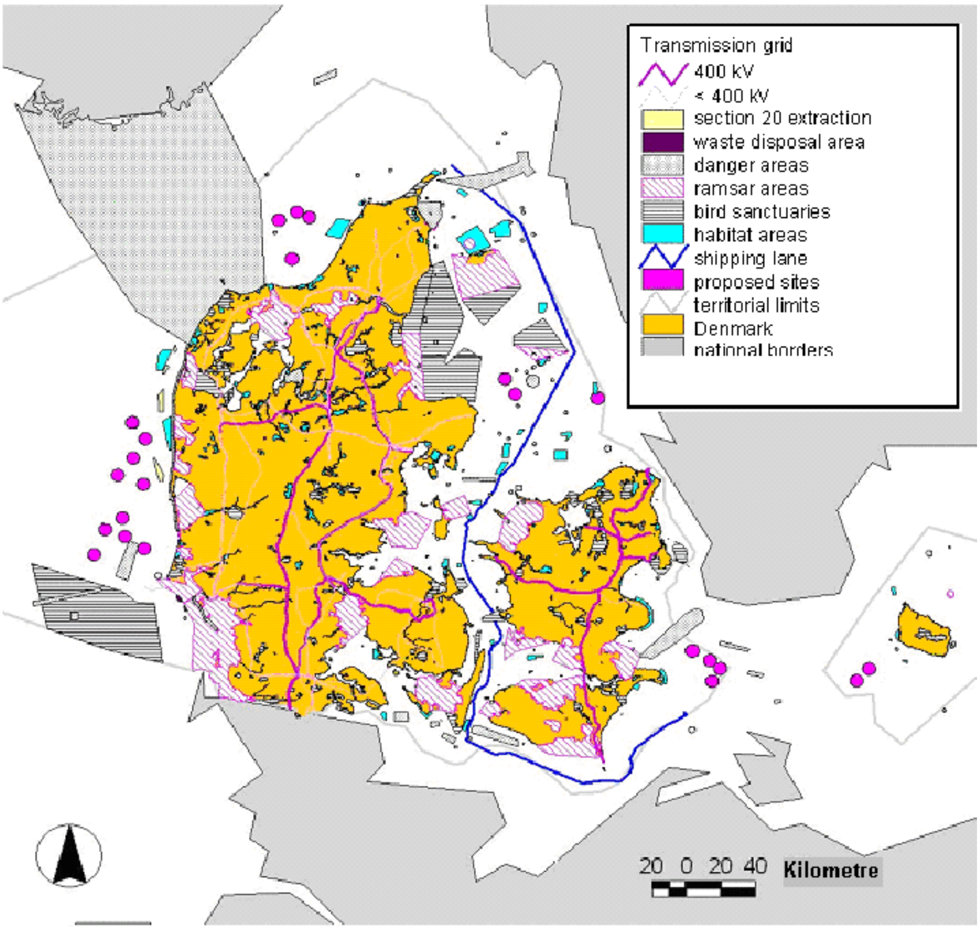
© 2002 www.offshorewindenergy.org. “Stars”: red = (built MW wind turbines), purple = (built small wind turbines), blue = (under construction), grey = (planned)

Figure 4.3. Map of existing and planned offshore wind farms in North-West Europe

4.4.1.1 Future Danish offshore projects

The Committee for Future Offshore Wind Turbine Locations published the report: ”Future Offshore Wind Turbine Locations – 2025” in April 2007. The report charts a number of possible offshore areas where offshore turbines could be built to an overall capacity of some 4,600 MW. Offshore wind turbines with a capacity of 4600 MW could generate approximately 18 TWh, or just over 8% of total energy consumption in Denmark. This corresponds to approximately 50% of Danish electricity consumption. The committee has examined in detail 23 specific possible locations each of 44 square kilometers to an overall area of 1012 square kilometers divided between 7 offshore areas.

The committee has assessed society’s interests in relation to grid transmission conditions, navigation, the marine environment, the landscape, raw material exploitation etc. The committee has also assessed options for connecting major offshore wind farms to the national grid, including examining the engineering, economic and planning options for landing power and the consequences for the underlying grid of the various potential areas for construction. At the same time the committee described scenarios for technological development of wind turbines capable of installation at greater sea depths. The committee attached importance to a planned and coordinated expansion of wind power and the transmission network with a view to obtaining the greatest possible economic benefits.



4.4.2 Scenarios for the future offshore development of wind power

In the last two decades wind power has developed rapidly. For 15 years annual growth rates in total accumulated capacity has ranged within 20 to 35%. At present the wind power market is characterized by a strong demand implying supply constraints within the turbine manufacturing industry and no signs indicate that demand will diminish within the coming years (BTM market world market updates ref.0). Turbine manufacturers and sub suppliers are expanding their manufacturing capacity and new companies are entering the arena. In the light of a growing concern for climate change and security of energy supply - increasing prices for fossil fuels, high crude oil prices - expectations are that the wind power industry also in coming years will witness a rapid growth.

To some degree offshore development will follow the picture outline for the total wind power development outlined in chapter 3.6, but a few exceptions do exist. The following specific assumptions are made for offshore wind power development:

- Mainly based on existing plans offshore wind power development is assumed to grow by approx. 34% p.a. until 2015. Growth rates are expected to fall after 2015 to approx. 27% in the period 2015-20, to 20% in 2020-30 and, to a little more than 5% in 2030-50.
- The capacity factor will on average be 37,5% for offshore turbines (3300 full load hours) for the whole period until 2050, covering that new wind turbines will have a higher production being moderated by a lower availability of sites with high wind speeds.

Based on the assumptions, the future scenario for offshore wind power development is given in Table 4.6.

	Offshore wind GW	Yearly growth offshore wind %	Offshore of total wind power, %	Production from offshore wind, TWh	Expected electricity consumption TWh	Penetration of offshore wind, %
2006	0.9		1.2	3	15500	0.0
2015	12.8	34	2.6	42	21300	0.2
2020	42.4	27	4.0	140	23800	0.6
2030	251.1	19.5	9.5	829	29750	2.8
2050	773.8	5.5	18.4	2559	40100	6.4

Table 4.6: Scenario for global offshore wind power development.

As shown in Table 4.6 total offshore wind power production is calculated to 2,559 TWh in 2050, offshore wind power supplying a little more than 6% of global final electricity consumption and constituting approx. 18.4% of total wind power capacity. The assumed growth implies that the accumulated global offshore wind power capacity will double each 2nd to 3rd year until 2015, each 3th year from 2015-20, and, finally, each 5th year from 2020-30.

4.5 Long-term cost perspectives for offshore turbines

Until 2004 the cost of wind turbines in general followed the development of a medium-term cost reduction curve (learning curve) showing a learning rate of approximately 10% that is each time wind power capacity was doubled the cost was reduced by approx. 10% per MW-installed. This decreasing cost-trend was interrupted in 2004-6 where the price of wind power in general increased by approx. 20%, mainly caused by increasing material costs and a strong demand for wind capacity implying scarcity of wind power manufacturing capacity.

A similar increase in price is witnessed for offshore wind power, although a fairly small number of realized projects in combination with a large spread in investment costs make it difficult exactly to identify the price level for offshore turbines. On average expected investment costs for a new offshore wind farm will today be in the range of 1.9 to 2.2 mill.€/MW.

In the following the long term cost development of offshore wind power will be estimated using the learning curve methodology. However, learning curves are not developed to be applied for that long a time period and for this reason the estimated figures are mainly to be seen as the results of a long term scenario development.

The long term cost perspectives for offshore wind power is shown in Table 4.7 given the following conditions:

- The total capacity development of wind power (Section 3.6, Table 3.4) is assumed to be the main driving factor also for the cost development of offshore turbines, because the major part of turbine costs are related to the general wind power industry development. However, a faster development of offshore capacity is expected and also a number of cost issues (foundation, transmission cables etc.) are specific for offshore, which by now are expected to have considerable cost reduction potentials. For that reason the total wind power capacity development is used in combination with higher learning rates for offshore development than seen for onshore.

- The existing manufacturing capacity constraints for the wind turbines will persist until 2010. Although we gradually will see an expanding industrial capacity for wind power, a continued increasing demand will also continue to strain the manufacturing capacity and not before 2011 increasing competition among wind turbine manufacturers and sub suppliers will again imply unit reduction costs in the industry.
- For the period 1985 to 2004 a learning rate of approx. 10% was estimated (ref.**Error! Reference source not found.**). With the return of competition in the wind industry again in 2011 this learning rate is again expected to be realized by the industry. Because offshore wind power is a relatively young and immature area, this learning rate is assumed to persist until 2030, where after the learning rate is assumed to fall to 5% until 2050.

Given these assumptions minimum, average and maximum cost-scenarios are reported in Table 4.7.

	Investment costs, Mill. €/MW			O&M	Cap. factor
	Min	Average	Max	€/MWh	%
2006	1.8	2.1	2.4	16	37.5
2015	1.55	1.81	2.06	13	37.5
2020	1.37	1.60	1.83	12	37.5
2030	1.20	1.40	1.60	12	37.5
2050	1.16	1.35	1.54	12	37.5

Table 4.7: Scenarios for cost development of offshore wind turbines, constant 2006-€.

As shown in Table 4.7 average cost of offshore wind capacity is calculated to decrease from 2.1 mill.€/MW in 2006 to 1.35 mill€/MW in 2050 or by approx. 35%. A considerable spread of costs will still exist, from 1.16 mill. €/MW to 1.54 mill.€/MW. A capacity factor of constant 37.5% (corresponding to a number of full load hours of approx. 3300) is assumed for the whole period, covering an increasing production from newer and larger turbines moderated by sites with lower wind regimes and increasing distance to shore and thus increasing losses in transmission of power.

A study made in UK [ref.0] has estimated the future costs of offshore wind generation and the potential for cost reductions. It identified the cost of raw materials - especially steel, which accounts for about 90% of the turbine and a primary cost driver. The report emphasized that major savings can be realized if turbines are made of lighter, more reliable materials and if major components are developed to be more fatigue resistant. A cost model based on 2006 costs predicted that costs will rise from approximately 1.6 million £/MW to approximately 1.75 million £ (2.37 to 2.6 million €/MW) in 2011 before falling by around 20% of the cost by 2020.

5 Novel Technologies

5.1 New wind turbine technologies

While a significant consolidation of the wind turbine design took place in the 80'ies and 90'ies a large development effort continue today. The main drivers for the current technology development are:

- cost of power
- reliability
- grid compatibility
- visual appearance
- acoustic performance

Many of the issues are addressed in the UpWind project - the largest EU-supported initiative in wind energy R&D to date. UpWind looks towards future wind turbine design, including the design of very large turbines (8–10 MW) and wind farms of several hundred MW, both on- and offshore. The challenges inherent in the creation of such power stations necessitate the highest possible standards in design; complete understanding of external design conditions; the use of materials with extreme strength to mass ratios; and advanced control and measuring systems—all geared towards the highest degree of reliability, and, critically, reduced overall turbine mass. Wind turbines larger than 5 MW and wind farms of hundreds of MW necessitate the re-evaluation of the core unit of a wind energy power plant, the turbine itself.

UpWind will develop the concepts, tools and components the industry needs to design and manufacture this new breed of wind turbines. The project will focus on design tools for the complete range of turbine components.

In the USA the Department of Energy (DoE) has laid out a five-year plan for wind energy R&D that follows three paths:

- Land-based electricity path: Here the focus is on low wind speed technology and machines in the range 2–6 MW. The main barriers are transmission capacity, and the goal for 2012 is \$0.03/kWh at 13 mph (5.8 m/s) sites.

- Offshore electricity path: The focus is on both shallow and deep water with turbine sizes of 6 MW and larger. The main barriers are cost and regulation, and the goal for 2012 is \$0.05 /kWh.

- Emerging deployment paths: Here the focus is not on wind alone, but also on hydrogen and clean water. The barriers are cost and infrastructure, and the 2020 goals are custom turbines for electricity, hydrogen production and desalination.

5.2 Superconducting generators for wind turbines

At DTU/Risø a project is launched towards development of a 10 MW generator based on so-called high-temperature superconductor (HTS) materials (operating at 77K – the boiling point of Nitrogen). Traditionally superconducting materials used in e.g. hospitals Magnetic Resonance Imaging scanners are based on low temperature superconductors requiring liquid helium. The new wind turbine generator can be kept at 77K by an advanced cryogenic refrigeration plant and is expected to contribute the following advantages:

- A 50 – 60 % reduction in weight and size compared to today's generator
- A multi-pole design makes direct drive possible and avoids the use of gear-boxes
- Removing the gear-box is expected to give less maintenance of the generator
- Reduced operation and maintenance costs

5.3 New offshore concepts

Although the offshore market is only 1.3% of the world market (installed MW in 2006) many new technology developments are first seen offshore. There are many reasons for this. The development offshore started much later than on-shore development and is not as mature. At the same time offshore is the most challenging environment for application of wind power with a harsh environment and difficult access, which calls for autonomous designs with very high reliability. Furthermore the relatively high cost for foundations and grid connection drives the size of the wind turbines towards larger units in order to reduce generation costs. In some countries e.g. USA and Norway locations outside the visibility zone are considered in order to eliminate possible conflicts with people living near the coast. The water depth outside the visibility zone (> 25 km) in these waters is significant and leads to new challenges.

Figure 5.1: The Beatrice wind farm consisting of two 5 MW wind turbines

in 42 m deep water. The wind farm is connected to an existing oil production facility. Source www.beatricewind.co.uk

As offshore oil and gas runs low the production facilities are likely to be transformed from pure fossil fuel based towards hybrid/renewable energy facilities adding wind, wave and solar devices for generation of electricity and later also fuels for the transport sector. A first sign of this development is seen in the North Sea at the Beatrice oil field off the cost of Scotland. The prototype installation consist of two 5 MW wind turbines at water depths of 42 m and the power from the wind turbines can cover approximately one third of the needs of the nearby oil production platform (Figure 5.1).

In the US in 2004, the Offshore Wind Energy Consortium financed by the US Department of Energy, General Electric and the Massachusetts Technology Collaborative announced a project to consider technology for water depths from 50 ft to 100ft (20-35 m). Same year a company called Atlantis Power LLC launched a financing scheme for $2 million for 3 x 2MW wind turbines to be operated in 120 m water depth. In March 2006, GE announced a $27 million partnership with the U.S. Department of Energy to develop 5 to 7 MW turbines by 2009, supplanting the company's current 3.6-megawatt turbines.

Japan has also been investigating offshore wind development [ref.0]. Japan has a national target of 3000 MW by 2010 (current status is 1500 MW total on and offshore) which will be the equivalent of 0.5% of national electricity consumption. There are several areas within wind speeds above 8 or 9 m/s at 60 m height but the contour of 20 m water depth is only about 2 km from the coastline. Ryukyu University has developed the ‘hexa-float’ system made of concrete with 10 m sides and a 10 kW prototype is planned. Also under consideration is a stable floating platform for two turbines in a diamond shape which has been tested in a water tank as has the spar type floating structure.

Figure 5.2: The floating wind turbine

concept Hywind. Source: Norwegian Hydro and Solberg production

In Norway two competing projects, Hywind (Norwegian Hydro, Statoil) and Sway (Statoil, Statkraft, Lyse Energi, Shell) both are developing floating offshore wind farm concepts for deep water (200-300m). Both are based on wind turbines rated at 3-5 MW or larger and the sub-sea structure is made of concrete. The main difference between the two concepts is the mooring principle. Recently Hywind has received 59 mill NOK financial support from the Norwegian Government for their prototype off the cost of Norway to be installed in 2009 while the companies behind Sway have managed to raise the necessary funds for the prototype from private investors.

5.3.1 Offshore wind and wave

Poseidon’s Organ is a hybrid power plant transforming waves and wind into electricity – a floating offshore wave power plant which also serve as foundation for wind turbines. The concept has been tested in wave tanks in scales up to 1:25. Late in 2007 a 1:6 scale model rated at 80 kW wave power and measuring 25 by 37 m will be launched off the coast of Lolland, Denmark in connection with the first offshore wind farm in Denmark at Vindeby The full size plant (**Error! Reference source not found.**) is designed to be 230 m by 150 m and is expected to be placed off the cost of Portugal, and will be characterized by:

- 35 percent of the energy in the waves is transformed to electricity

- 30 MW generation capacity including three 2 MW wind turbines

- 28GWh annual generation if located in the Atlantic Ocean off the Portuguese west coast

- 22GWh annual generation from the three wind turbines

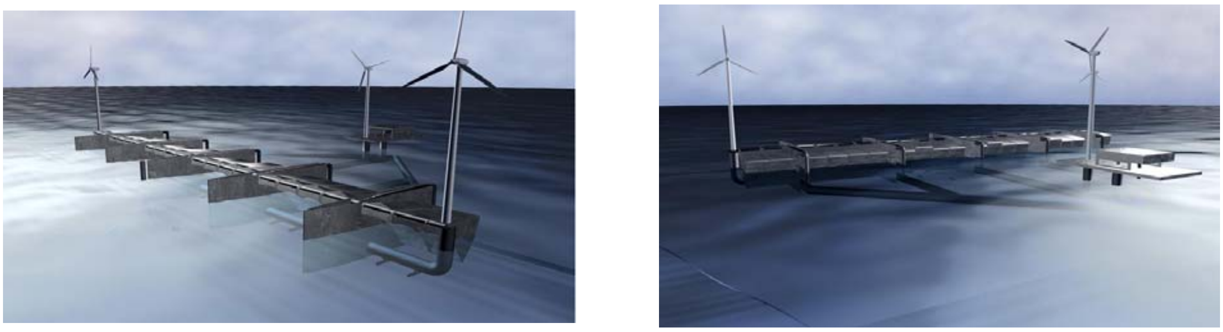


Figure 5.3: Computer image of Poseidon’s Organ. The front of the full size wave power plant is 230 metres wide and consists of 10 floats. The floats absorb the energy inherent in the waves. A double functioning pump transforms the wave energy into a water flow driving a turbine producing electricity. Source www.poseidonorgan.com

5.4 Small wind turbines

In the decentralised energy societies of the future the large (but distant) centralised energy facilities will be supplemented by an extensive integration of renewable energy in everyday life (micro-generation). Examples of this is facades and other building elements integrated with solar photovoltaic elements and small wind turbines designed and optimised for use at the point of energy demand. Two examples of this trend is the small 6 kW wind turbine from Quietrevolution Ltd. and a combined solar PV and a small wind turbine integrated with a outdoor lightning system (Figure 5.4 and Figure 5.5). The idea is that the pole and the grid connection for the lamp are needed anyway. Both are then designed to serve the wind turbine as well as a solar PV installation.

Figure 4

Figure 5.4: Quietrevolution wind turbine for integration in cities and on buildings .Ref. www.quietrevolution.co.uk

Figure 5

Figure 5.5: The Hybrid Tower Wind & Solar Power Outdoor lighting System from Matsushita, Japan. Ref www.panasonic.co.jp

6 System aspects

6.1 Overview

Electricity grids, and the physical markets that they underpin, evolved to link relatively few large, centralized, 'utilities Dispersed, variable wind electricity is a departure from this pattern. Nonetheless, low wind energy share has nominal impact.

In contrast, large wind energy shares will require further evolution. A long term view on design and planning, better communications, and greater interconnection and flexibility are essential if the full value of wind is to be recognised, while safeguarding overall system reliability.

In 2006, 17% of Danish electricity demand was met by wind energy[13], facilitated by international trade. Variable generation need not compromise system reliability, although it may increase costs. Additional costs relate to grid connection and reinforcement; and to system balance.

Wind energy integration should not be considered in isolation from other objectives that also necessitate infrastructure investment, such as security of supply and free

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[13] IEA Wind 2006 Annual Report. See Table x.4 above

trade. Up to 2030, some $6 trillion are expected to be invested in renewing power systems.

The concept of a general ceiling for wind energy share is overly simplistic, as it fails to take into account the diversity of resources and constraints in different systems. Moreover, assessments made at the national level may fail to take into account increasing cross border trade.

6.2 Variability and predictability

Variability of supply is not in itself a threat to system security. Nor is it a new challenge per se - demand fluctuates continually.

Wind variability can be ‘smoothed out’ to a degree by aggregating output over a wider area and with other variable technologies, such as solar PV, biomass CHP, and run-of-river hydro, which vary on different timescales. But large shares of variable output do add complications.

Nonetheless, the key to maintaining a balanced system remains that of forecasting - predictability. Short term forecasting of wind power production is in its infancy compared to demand forecasting, and the level of accuracy will never be as high as for the latter. While the overall shape of production can be predicted most of the time, significant deviations will occur. Accuracy can be improved by combining predictions over larger areas. Recent West Denmark results point to an average prediction error in day ahead forecasts of 6.2% of installed capacity.

6.3 Flexibility

Nonetheless, the variability of wind plant – sometimes expressed as a low ‘capacity value’ – does mean that the system as a whole will need to be flexible enough to respond to periods of low winds. Similarly, when more electricity is generated than forecast, the system must absorb it.

A range of options for greater flexibility exist. The combination of measures depends on the nature of the system. Parameters governing system flexibility include presence of dispatchable plant in the generation portfolio, ‘gate closure’ times in trading, interconnection for larger balancing areas, improved communication across the market, demand side response for peak shaving, and storage to reduce impact of variability.

6.4 System evolution

Power system infrastructure and operation can be modified to enable greater penetration of wind energy. Today technology is not a constraint in itself. A number of new developments, mainly at the demonstration stage, hold considerable promise.

These developments include re-wiring existing lines with high temperature conductors; dynamic line rating with temperature monitoring; HVDC cabling; and power electronic devices for load flow control. Storage technologies, which can act as a buffer between demand and variable supply, are still at the demonstration phase, but have great potential. Large-scale, system integrated electricity storage would have wider benefits also, such as reducing requirements for new generation capacity by meeting demand peaks.

Early co-ordination and action is necessary to avoid a time lag between the installation of a wind farm and availability of transmission. Public antipathy to new transmission corridors has stretched planning periods to as long as 10 to 15 years.

It may also be necessary to enable a number of generators to share transmission capacity according to forecast output, in order to avoid excessive transmission capacity. Care would be needed to ensure sufficient capacity and to avoid congestion.

Grid codes exist to ensure the reliability of the power system and appropriate requirements must be met by wind farm operators.

6.5 Costs

The additional costs of integrating wind energy broadly fall into two categories: grid connection and reinforcement, to physically enable output to reach the consumer; and those related to ensuring instantaneous balance of supply and demand.

6.5.1 Grid reinforcement costs

Direct comparison of reinforcement costs on a country-for-country basis is misleading, as it greatly depends on the distance from windfarm to load. Reported results to date, derived from detailed load flow analyses prepared by national system operators in the United Kingdom, the Netherlands, Portugal and Germany, show reinforcement costs for onshore wind in the region of 100 € / kW. For offshore wind, reported costs are around a factor five higher. The length of (expensive) marine cable is decisive.

6.5.2 System balancing costs

System balancing costs comprise the impact of minute-to-hour fluctuations in production, and that associated with maintaining ‘adequacy’ of the system – meeting peak load. Cooperation among system operators and interconnection of balancing areas can reduce cost by enabling imbalance to ‘flow’ to where it costs least. At penetrations of around 20%, recent estimations of additional balancing costs range from 1-4 €/MWh.

The capacity value of wind energy – which can be expressed as its ability to displace conventional plant – is lower than for the latter due to its variable output. Nonetheless values of 20-30% for onshore wind at low penetrations are accepted. Capacity value reduces as penetrations increase, and increases with larger balancing areas.

While the cost of wind energy is the subject of much debate, its value is often overlooked. Wind farms can contribute to balancing and power quality, although at present limited markets exist for these services. Moreover, wind electricity has no fuel or CO_2 costs.

6.6 Large scale grid integration and transmission aspects

Developments of importance to turbine technology, control systems and power transmission will include:

- gearless direct-drive turbine designs based on variable-speed and direct-drive multi-pole generators;

- high-voltage direct current (HVDC) transmission systems, energy storage technologies, compensation units and control technology for wind power plants;

- ‘intelligent’ wind turbines that use computer controls to optimise their operation to suit local conditions and interact with other energy sources;

- systems to control variables such as rotational speed and power output according to wind, grid or market conditions; and

- control systems for large-scale integration of wind turbines into the grid.

In full, system aspects have to be address by a large number of perspectives such as the following:
- grid integration – variability and reliability
- grid codes
- transmission and distribution networks, HVDC
- voltage control
- frequency control
- fault ride through
- planning and building of new infrastructure
- back up
- operational costs
- grid costs onshore and offshore
- wind power technology to be complete as power station – storage, combined systems
- forecasting, 6 to 48 hours
- accounting tools
- control and loads measurements, power electronics
- market and business mechanisms
- storage (examples from Japan, Norway, Switzerland)

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