RESEARCH REPORT

VTT-R-08358-09

Nord-Vind Windpower technology: history, status and vision

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Confidentiality: Public

Report's title **Nord Vind. Windpower technology: history, status and vision**	
Customer, contact person, address Nordisk Energiforskning Mikael Forss Stensberggata 25, N-0170 Oslo, Norge	Order reference VTT offer VTT-V-38207-09
Project name Nordvind Vision	Project number/Short name 38207
Author(s) Hannele Holttinen, Esa Peltola	Pages 26/
Keywords wind power, wind turbine, technology trends	Report identification code VTT-R-08358-09

Summary

The global wind power capacity surpassed 100 GW in early 2008 and is increasing by 28 GW/year with increasing growth rate. According to market estimates, global wind power wapacity could be more than 300 GW in 2013 and 500–700 GW in 2020.

Land based wind power plants built today are usually 1–3 MW in size, investment cost range is 1200–1500 €/kW and average production is 20–35 % of installed capacity. The investment costs of offshore wind farms are high compared to land based wind farms, and this is (partly) compensated by better production. The cold climate/arctic turbines are still few, and the modifications required can raise the total cost 10–20 % in comparison to on-land turbines. There are niche markets for small wind turbines, with a small contribution in fulfilling renewable targets but market size in number of turbines large enough for commercial activity.

Main trends in wind turbine technology are increasing size of turbines (although at slower pace), increasing wind farm size and increasing use of smart materials and controls in the turbines. Moving to offshore applications, and other remote areas, brings technological solutions like condition monitoring and prediction, preventive maintenance and controllability to improve the reliability. The trends in network connection will enhance controllability of wind farm output and support to power systems. There is still potential to further cost reductions from mass production benefits and increased load managing in design.

The basic concept – a 3-bladed turbine with a horizontal axis – has dominated the market and seems to remain dominant also in the foreseeable future. There are some other innovative new concepts emerging, but they have a long way to show their reliability and cost effectiveness. There is a lot of development work and innovations still to be seen in the basic 3 bladed concept to improve reliability, load management, control and material use. Innovations offshore are expected in future: for the foundations and floating concepts. In future we expect to see large, meshed offshore grids connecting wind farms, ocean energies and countries.

Confidentiality	Public

Espoo 13.11.2009

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Distribution (customer and VTT)

Preface

This report is compiled as a basic introduction to wind power technology, its history, development and trends. The focus is on issues that are relevant for the Nordic countries.

The assignment was ordered in June 2009, written in August-September 2009, and commented by the NordVind-group, which is a Nordic working group under the Nordic Council of Ministers, in October. The updated version to cover for the comments was made in November.

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1 Historical development of wind power and status 2009

This section describes historical development and status of wind power (from 1980s to now). First the development in turbine types, evolution of turbine size, siting (offshore, onshore), grid connection as well as driving force of renewable targets in European countries are described. Then the status of current technology and evolution of market size globally and building in European and Nordic countries is presented.

1.1 Development and drivers for wind power

Early development

The modern wind power age began in the late 1970s, in part spurred by spiking oil prices. The pioneering companies were small industry, starting out with 10-20 kW turbines and gradually designing larger machines. There was also a European research effort backed by large aircraft and construction industry aiming at megawatt turbines. This effort, however, did not produce commercial turbines. The Californian wind rush started the wind industry in early 80s, with 50-100 kW turbines. When it stopped due to end of subsidy scheme, most of the European companies producing the wind turbines went bankrupt. But slowly the European demand for wind turbines started in some countries. Denmark was the pioneer, Netherlands, Germany and Spain followed.

Early wind turbines borrowed heavily from agriculture, boat building, and aircraft design. The largest manufacturer previously manufactured agricultural vehicles, marine intercoolers and cranes. The industry has overcome many challenges. Early machines were heavier (relative to their output); basic components such as yaw drives often failed; structural loads were little understood; availability (for operation) was lower, and the need for O&M higher. Turbines were mechanically noisy, and wind farms arrays were not designed to minimise visual impact or wind shadow (wake effect).

The 3 bladed, horizontal axis, upwind turbine has become the basis for the industry. Vertical axis turbines are not cost effective in large turbines (more than 100 kW), simply because they need more material to cover the same rotor swept area. Their benefits (no yaw mechanism needed, possibility to place generator on ground) can be used in smaller machines. Two bladed machines have nearly vanished from the market. This is mostly due to the visual impact being more disturbing when seeing the turbine from the side (directly from the front/back they look similar to three bladed ones but moving even a little bit will produce an asymmetric rotating movement). Two bladed machines may still be considered for offshore turbines.

From small single turbines to large turbines in wind farms

Increasing size of turbines has been the main trend for the last two decades. Wind turbines have grown 100-fold in rated power from less than 50-100 kW turbines in the 80s to the 5-6 MW turbines available now. At the same time the typical dimensions have increased almost 10-fold from 15 m in diameter to about 120-130 m at present.

In the end of 2008, the average rated capacity of all wind turbines in the world was 1.1 MW. Turbines built in 2008 had an average rated power of 1.6 MW. This development can also been seen in the shift of market share from turbines in MW-scale to turbines around 2 MW in rated power (Table 1).

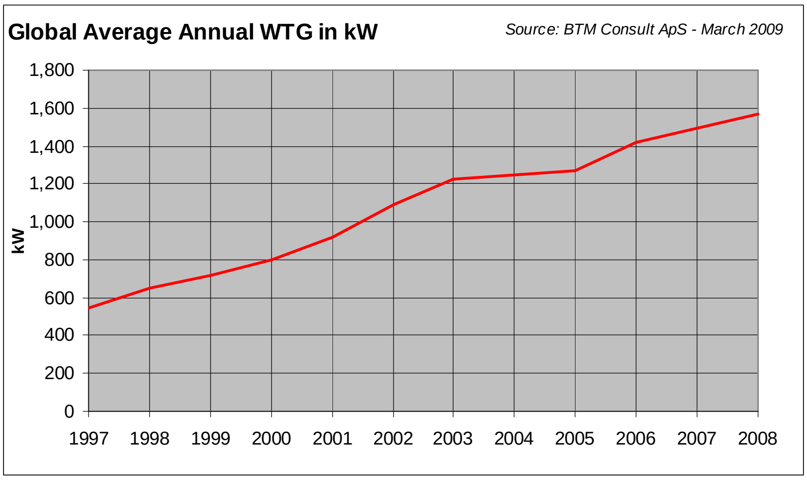


Figure 1. The development of average capacity of new wind turbines installed globally.

Table 1. The MW size turbines are increasing their market share.

Year	**2006**	**2007**	**2008**
Total MW supplied	**16,007**	**22,181**	**31,281**
Product (Size range)	**% of total MW**		
"Small WTGs" <750 kW	2.4%	1.3%	0.5%
"One-MW " 750-1499 kW	31.0%	29.8%	13.1%
"Mainstream" 1500-2500 kW	62.2%	63.7%	80.4%
"Multi-MW Class" >2500 kW	4.3%	5.3%	6.0%
Total	**100.0%**	**100.0%**	**100.0%**
Source: BTM Consult ApS - March 2009			

The first single wind turbines were coupled in the distribution network (10…30 kV voltage level). In case of grid faults, it was important that the turbines were tripped off and stayed shut down until the grid was recovered. This had to do with protection, to make sure that while making any work at the lines/cables, there was no electricity. As wind turbines have become larger and they are built in wind farms, more and more wind power has been connected to transmission grid (110…400 kV). Grid codes for especially wind power plants have emerged in recent years, requiring for example that the turbines have the capability to stay connected to the grid during short faults.

Drivers and barriers

Drivers for wind power are CO_2 emission reduction targets and overall environmental benefits from an emission free electricity production form as well as decreasing dependence on fossil fuels, also as a hedge to increasing gas and oil prices.

Barriers to wind development have been acquiring site permits, due to public acceptance or environmental impacts. In some countries also grid permits has or is becoming a barrier for future growth.

Planning and siting the turbines is important to decrease the negative impacts that wind turbines can have. Some people can deem the visual impact of wind turbines as negative especially in some landscapes. Bird collisions to turbines can be decreased avoiding sites that are critical due to the species or nesting nearby. Birds will collide with all man made structures, however, with wind turbines in most cases the collisions are less than for static structures, as the birds more easily notice the turbines with moving blades. Noise from the turbines can reach 1 km distance from the turbines so can be a negative impact close to the turbines. Wind turbines require in general large areas, however, the turbines cover about 2 % of the area so the space between the turbines is free for other use (for agriculture etc). Wind turbines can be built 9-15 MW/km^2, offshore perhaps 4-8 MW/km^2 due to larger wake effects (offshore the wind has less turbulence and thus the wakes recover more slowly).

Some sort of subsidy is needed for wind power investments as the generation costs are in most sites above conventional power generation costs (exception New Zealand where the wind resource is excellent): a generation or investment subsidy or a green certificate scheme.

Costs

The investment cost of wind power was steadily decreasing in the 80’s and 90’s, reached about 1000–1200 €/kW level in the early 2000’s and has now risen in recent years due to increasing material costs (mainly steel) as well as a somewhat heated market (lack of production capacity for the turbines and components in 2006–2008).

Investment cost is dominated by the turbine (70–80 % of the total cost). O&M costs are generally estimated to be around 12 to 15 € per MWh of wind power produced, over the total lifetime of a turbine. The production cost of wind power is highly sensitive to the wind resource. For example, with investment cost of 1400 €/kW, the production cost will be more than 100 €/MWh in a low wind site (full load hours 1500 h/a) and less than 70 €/MWh in a good wind site (almost 3000 h/a).

Offshore, the foundation and grid connection will become more dominant in the investment costs, and the turbine itself will be 20–30 % more expensive as on land. The investment costs of existing, near shore, offshore wind farms have been 1200–2700 €/kW. Estimated costs especially for deeper waters further away from shore are higher. The O&M costs are estimated to be 16–30 €/MWh. This will be compensated by better wind resource (3000–5000 h/a). The production costs of near shore wind power plants has been reported to be 60–90 €/MWh. For the projected wind farms further offshore, the range is 90–150 €/MWh.

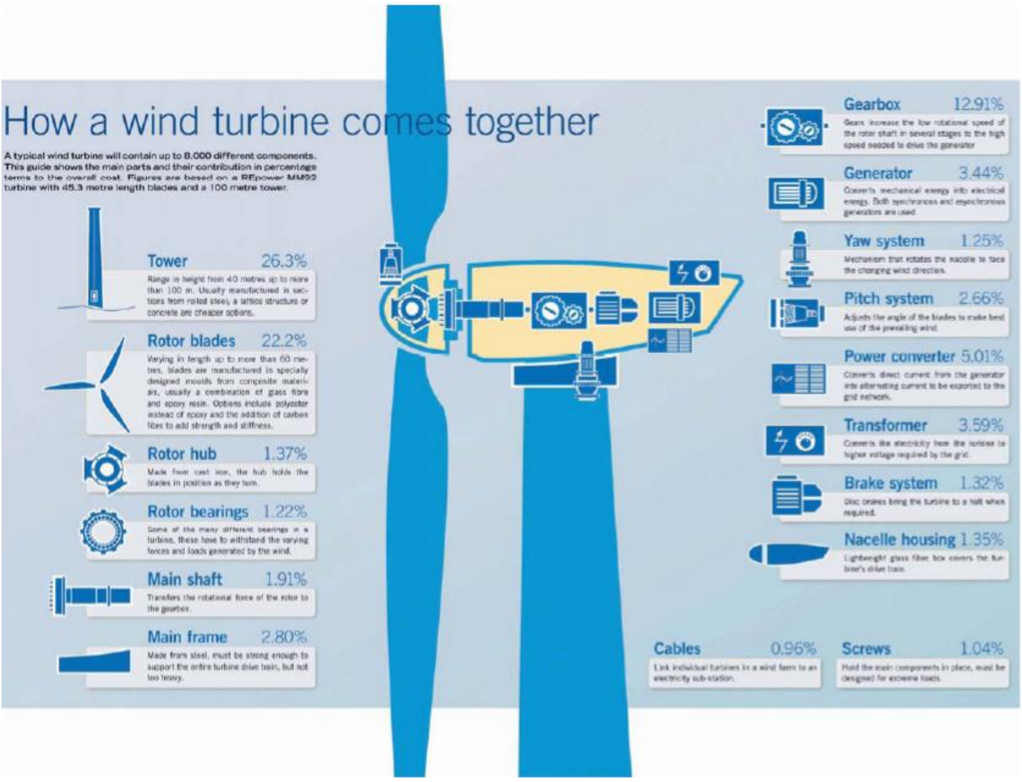


Figure 2. Components of a wind turbine. Estimated cost breakdown of a modern wind turbine. (Source: EWEA, 2009, originally from Wind directions, January/February, 2007).

The production cost of wind power is still at a higher level than for conventional power sources, and some incentives are needed for building. The most successful subsidy programmes have been based on production subsidy: feed-in tariff or production premium (Denmark, with tendering for offshore projects; Finland to start from 2010). Green certificate systems are in use in some countries (Sweden, together with production premium for some years; Norway to start in 2012). Investment subsidies have not proved to be a very efficient incentive (Norway, Finland).

The overall R&D and demonstration budget for wind power has been quite moderate compared with expenditure on other energy sources. The support from European Commission during FP5 and FP6 programmes was 24.4 and 31.6 Million € (about 7 Million €/year). The total national R&D funding for wind power in 19 European countries has been in between 40 and 100 Million €/year in 1980-2006 (EWEA, 2009).

1.2 Status of wind power technology and market

Technology

Today, the average grid connected turbine has a rated capacity of about 2 MW. Largest commercial turbine available is 6 MW. It extracts energy from the wind by means of a horizontal rotor, rotating upwind of the tower, with three blades that can be pitched to control speed of rotation. Two-blade, and direct-drive (without a gearbox) variations, are also found. Wind turbines generate electricity between speeds of 3–4 m/s to 20 –25 m/s.

Land based wind power plants built today are usually 1–3 MW in size. They can be built at a cost in the range of 1200–1500 €/kW and produce energy corresponding to peak load hours between 2000–2400 h/a. The technical availability is generally high, about 95–98% of the time. The average investment costs increased to about 1500 €/kW in 2008 (Milborrow, 2009a) due to increases in material costs and undercapacity for production of turbines and components in the market. First information from 2009 projects show a decrease of turbine and total investment costs, due to decreases in material prices.

Today's offshore wind turbines are essentially marinised versions of land turbines with, for example, enhanced corrosion protection (Figure 3). The investment costs of offshore wind farms are high compared to land based wind farms, and this is only partly compensated by better production. Estimated investment costs in 2009 range in between 2000–4000 €/kW – installing to deep water and long distance to shore will increase the costs by 40 % and 20 %, respectively (Milborrow, 2009b). Availability of offshore turbines at present is around 80–95%. At the end of 2008 there were nearly 1500 MW offshore turbines installed, about 550 MW in the Nordic countries (414 MW in Denmark and 134 MW in Sweden). There are more than 3000 MW offshore wind farms under construction in Europe, most of them in UK.

The cold climate/arctic turbines are still few (Figure 4). Icing of turbine blades occurs in the Northern parts of Nordic countries (Lapland) on the arctic fells. In Norway, icing is frequent on heights of more than 500 m.a.s.l. Icing also occurs in the Alpine regions, in Canada and US (IEAWIND Task 19). Wind turbines used in these areas require modifications to the standard solutions used in the turbines. These modifications and other site specific costs can raise the total cost 10 – 20 % in comparison to standard conditions. Also the expectation for production is higher because of the better wind resource provided that functional solutions for eg ice prevention are used. They are not widely available at the moment.

Figure 3. Example of an offshore wind farm from Sweden (Lillgrund 110 MW, 48 times 2.3 MW).

Figure 4. Example of an arctic wind farm from Finland (Olos 3 MW, 5 times 600 kW).

There are niche markets for small wind turbines. So far the market has been very limited in size. The application is mainly for professional off-grid use, where turbines are used for loading up batteries (10–100 W), and for providing electricity for a single household or farm (1–10–50 kW), where they can also be grid connected. In the latter market segment there is need for standardization, which has started recently.

The investment cost relative to installed capacity is higher and the production relative to installed capacity is lower for small turbines than for large grid connected machines. Average costs for current stand-alone wind turbines vary from 2500 to 6000 € per installed kW, while in distributed generation, a small wind turbine can vary from 2700 to 8000 € per installed kW, the additional cost mainly due to the power converter required for grid connection. Both these figures contrast with the specific costs of large wind turbines, which are in the region of 1300–1500 €/kW.

Figure 5. Example of a small wind turbine (Eagle 2 kW).

Smaller machines usually are installed in lower towers and also can be used in sites with limited wind potential, compared to typical sites for large wind turbines. The state of the art for small wind turbines is still far from technological maturity and economical competitiveness, however, development work is on-going in several countries. The technology of small wind turbines is clearly different from that used in large wind turbines.

These differences affect all of the subsystems: mainly the control and electrical systems, but also the design of the rotor.

Many of the small turbines existing on the market today are machines that have developed in an almost ‘hand crafted’ way, with lower maturity compared to that achieved by large wind turbines.

Demand and markets

The global wind power capacity surpassed 100 GW in early 2008 and is increasing by 28 GW/year with increasing growth rate. The installed capacity in recent years as well as the growth rates are presented in Figure 6 and Table 2. Europe, USA and China+India all installed about 8 GW in 2008. The largest markets in Europe are Spain, Germany, France, Italy, UK and Portugal, adding 0.7 to 1.7 GW in 2008. Looking at the cumulative capacity, US has 25 GW, Germany 24 GW, Spain 16 GW, China 12 GW and India 10 GW. There are several European countries having 3–4 GW installed (Italy, France, UK, Denmark, Portugal)

In 2009–10, the global recession will impact the growth rate of wind power. The expected capacity increase in Europe will be close to 8 GW (little less than in 2008), in USA 6–7 GW and in China 9–10 GW. It is expected that the global installed capacity will be close to 150 GW at the end of 2009.

Table 2. Installed wind power capacity (annual and cumulative) and growth rates of wind power market in 2003-2008.

Year:	Installed MW	Increase %	Cumulative MW	Increase %
2003	8,344		40,301	
2004	8,154	-2%	47,912	19%
2005	11,542	42%	59,399	24%
2006	15,016	30%	74,306	25%
2007	19,791	32%	94,005	27%
2008	28,190	42%	122,158	30%
Average growth - 5 years		**27.6%**		**24.8%**

Source: BTM Consult ApS - March 2009

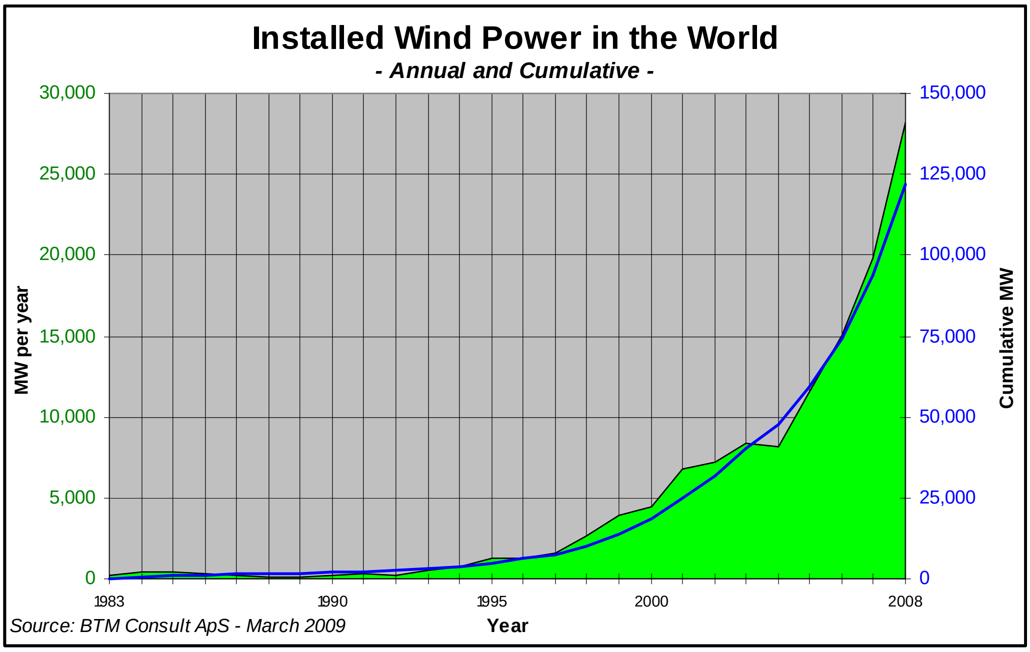


Figure 6. Installed wind power capacity annually and cumulative (line) from 1983 to 2008.

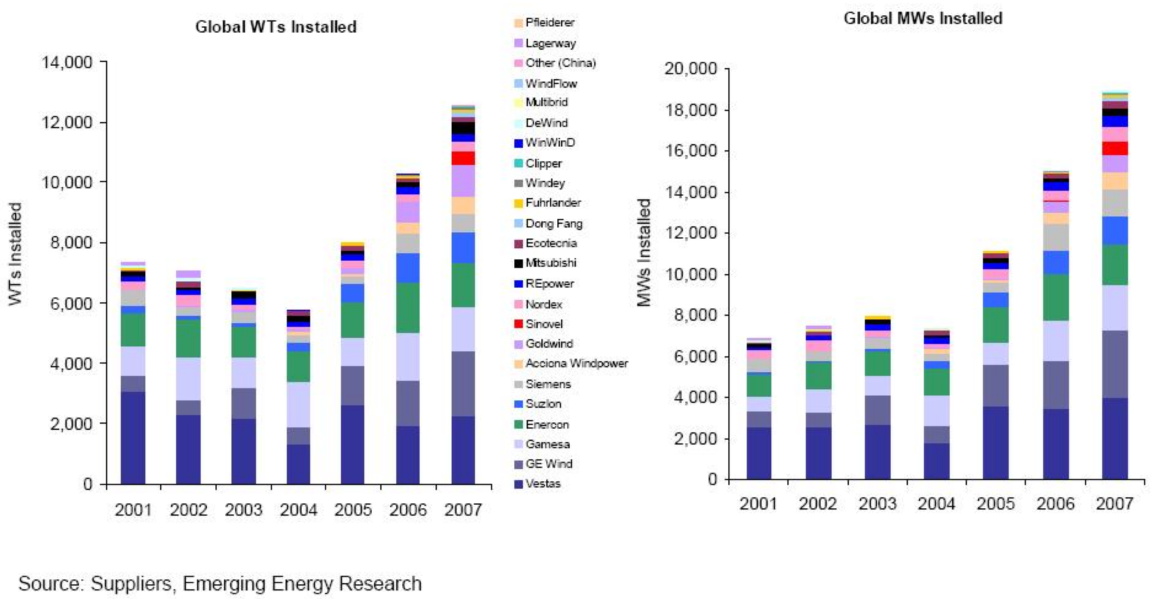


Figure 7. Wind turbine manufacturers, global market shares in number of turbines and installed capacity in MWs. The rapid shifting to MW size turbines made the number of installed turbines decrease in 2001–03 even if the MW installed was increasing.

Wind industry

Danish wind technology has been a success – still in the beginning of the 2000's the Danish wind turbine manufacturers made 50 % of turbines sold in global markets. In 2008 the Danish manufacturer Vestas was the largest manufacturer globally. Larger energy sector players like GE, Siemens and Areva have acquired smaller German and Danish turbine manufacturers to achieve an increasing role in the markets (Figure 7). There are about 10 larger manufacturers covering more than 80 % of the market, as well as about 20 smaller ones in the global markets. Increasing demand in global markets has resulted in large manufacturing capacity increases in recent years and room for newcomers in the market. The Chinese market has been growing with more than 100 % per year and the target is to reach 100 GW in China in 2020 making China one of the busiest markets.

The manufacturers have several different concepts: the mainstream “Danish design” turbine having 3 blades, gearbox and asynchronous generator directly coupled to the grid was dominating the smaller size turbines but now there are an increasing number of other concepts in the MW class turbines. Gearless turbines and turbines that have a single stage gearbox with a slowly rotating generator, with full power frequency converter have an increasing market share. Almost all MW-class turbines use both pitch control (turning the blades to control the power produced) and speed control to limit power and loads.

Most turbines are installed onshore. The offshore market is growing in Europe. There are large offshore projects ongoing in UK, NL, Germany, Denmark and Sweden and the offshore market it expected to increase to 3000 MW/year in 2012…2014, bringing the total installed offshore wind power capacity from the current 1.5 GW to 11–12 GW in five years time (Milborrow, 2009a).

The size of turbines is still increasing, although at a slower pace. The trend in size increase is depicted in Figure 8.

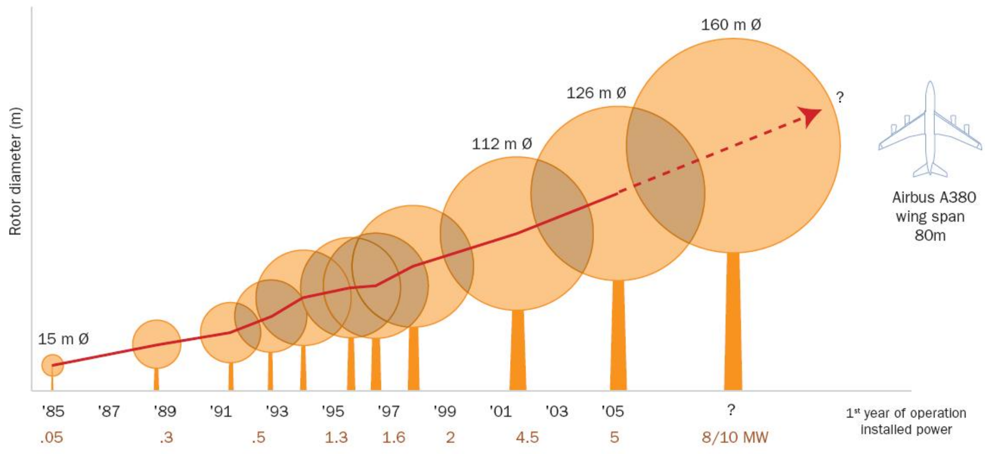


Figure 8. Increasing size of wind turbines from 1985 forward. The largest turbines commercially available in 2009 are 5 and 6 MW turbines. The 8-10 MW are under planning.

Wind energy in Nordic countries

Development of installed wind power capacity in Europe and Nordic countries is presented in Figure 9. Denmark was Europe’s largest wind power nation in the early 90s, number 3 in 2001–07 and is still now number 6 in EU countries. Sweden is now number 9, Norway 14 and Finland 18 in installed wind power capacity in European countries.

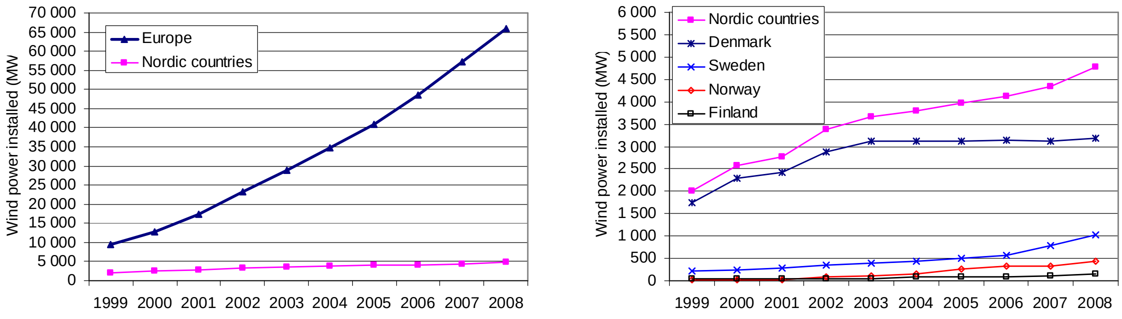


Figure 9. Installed capacity in Europe and in Nordic countries.

Wind energy in the energy system

Important difference between wind plants and fuel-based plants is that the wind can not be stored, so wind plants do not operate at full power all of the time. A capacity factor (average power as percentage of rated/installed power) on land of 25–30% is common (it can be as low as 18% in weaker resource areas, and as high as 40 % in best areas). Wind turbines operate 80–90 % of the time, but most of the time at part load.

The variability of wind output means that power system operation and design need to be modified as penetrations rise to a significant level. There are ways to increase flexibility in power systems so variability does not impose technical limits. However, the increase of flexibility will come at a cost, especially at higher penetration levels, so this can impose economic limits on wind power penetration. Globally wind power produces roughly 1 % of all electricity consumption. In Europe the share is about 4 %, in the Nordic countries about 2 %. Denmark is the leading nation with 20 % of its electricity demand covered by wind power production. Spain and Portugal are at 11 %, Ireland at 9 % and Germany at 7 % wind power penetration.

In some areas there is already so much wind power in the grid that if the power plants shut off during grid faults this can make the recovery of the grid more difficult – and can even violate the security rules of the power system (for example, 3000 MW or more should not trip off instantaneously anywhere in the European UCTE grid, but if there is a grid fault and wind turbines are tripping off when producing at high power, this can already happen in regions of Germany and Spain). A fault-ride-through capability of wind power plants is therefore required in most Grid codes in Europe and USA. Also other capabilities can be supplied by wind power plants. Voltage control is one example that can be used in weaker grids, by determining the reactive power production of wind turbines according to the voltage level.

In the Nordic countries, the electricity market is in principle quite well suited for wind power. The balancing (frequency control) is done for the whole large balancing area. There is a lot of hydro power to bid for the common balancing market resulting in moderate balancing costs. The day-ahead market bidding results in considerable imbalances for wind power producers. In Nordic countries we have an intra-day market closing only one hour before delivery, which makes it in principle possible to correct larger forecast errors after more up-dated predictions for wind power production arrive. This is not used for wind power so far, as the balancing cost reported have been quite low (2–3 €/MWh wind power produced, compared with average market price of 30–50 €/MWh) (IEAWIND Task 25).

2 Vision and trends for wind power

In this section the vision for wind power technology, 10-20 years ahead is described: turbine types, technical solutions, turbine size trends (different markets for different size turbines including micro turbines), siting trends as well as grid connection in future. Also environmental challenges (cold weather, offshore), offshore foundations (shallow/deep water) and challenge of wind integration to achieve higher penetration levels of wind power are discussed. Market estimates for Nordic countries/Europe/global markets are presented.

2.1 Technology trends

Wind turbine technology is still evolving. Major trends are increasing turbine and wind farm size and increasing use of smart materials and controls in the turbines. Moving to offshore applications, and to more complex terrain like mountains, with more difficult access and harsh conditions, brings also new challenges and technological solutions. The trends in network connection will enhance controllability of wind farm output and support to power systems. There is still potential to further cost reductions from mass production benefits and increased load managing and smart structures in design process. There was recently (2007–08) increasing turbine prices in the global market due to raising steel prices and shortage of supply of turbines and components, this has somewhat decreased as the recession has pushed the steel prices back and the demand growth has decreased in 2009.

Early wind turbines borrowed heavily from agriculture, boat building, and aircraft design. Now wind power drives technology development, although scope for exchange still exists, particularly with the offshore oil and gas industry. Also manufacturing technology can learn from automobile and aircraft industries. New technological advances have the possibility to continue reducing the cost of wind energy and improving the manufacturing process can benefit from mass production. So far there have been new, larger turbine components every 3-5 years so the manufacturing automation has not had much possibility to evolve.

The basic concept – a three-bladed turbine with a horizontal axis – has dominated the market and seems to remain dominant also in the foreseeable future. Nordic Windpower, originally a Swedish company, has developed 2-bladed wind turbine concept with products in MW-class for utility projects. Vertical axis concepts exist only in small scale, up to about 10 kW in rated power. There are also some other innovative new concepts emerging, (see f.ex. wind energy facts in www.wind-energy-the-facts.org for some air-borne concepts with kites). The challenge for any new concept is to provide improvements to the current industry standard in efficiency, in investment cost, and in reliability (operating costs) and this is not easy to do as the efficiency is already at a high level and the current R&D is focused on further improving the cost effectiveness. Basic research has not a lot of funding for a totally new way of extracting energy from wind, however, national funding in f.ex. the Netherlands is given to small projects trying to prove the feasibility and viability of new concepts. So far no commercial applications have emerged from this work and the global industry of wind power technology with 30-50 billion euros annual turnover is proceeding to further improve the current 3-bladed concept. There is a lot of development work and innovations still to be seen in the basic 3 bladed concept to improve load management, control and material use. Innovations for the foundations offshore and floating concepts are still expected in future, as well as the offshore grid.

The key behind the evolution of wind turbines in rated power and size has been the increasing knowledge of wind turbine performance loads and the management of the loads by means of improved control, better knowledge of material properties and more efficient use of materials (Figure 10). This is also seen as the major motivation for the industry to pursue medium and long term research efforts in developing turbines in 10–20 MW size. These very large turbines are not necessarily needed in the global markets (except offshore where they have an advantage). However, pushing the technology to limits will provide new innovations that can be used in the 3–6 MW turbines.

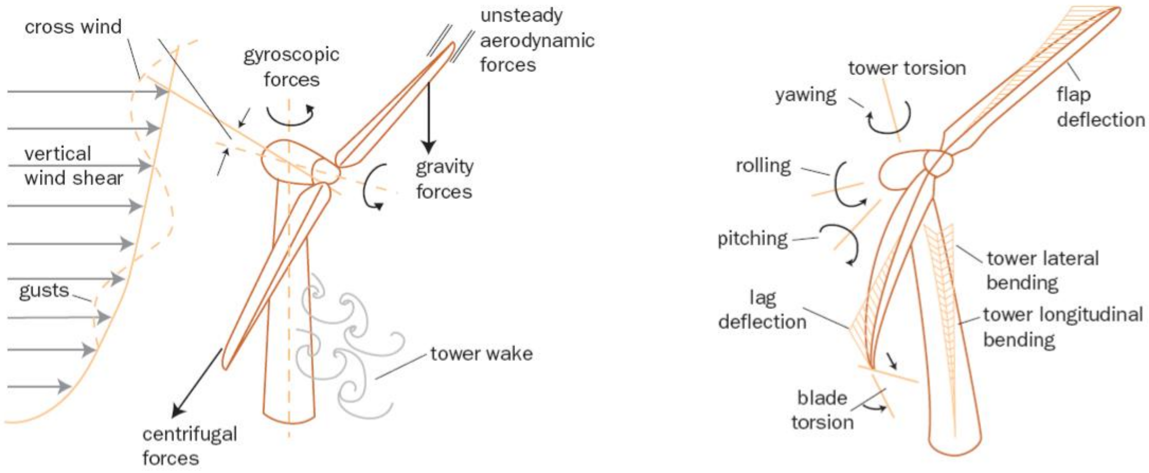
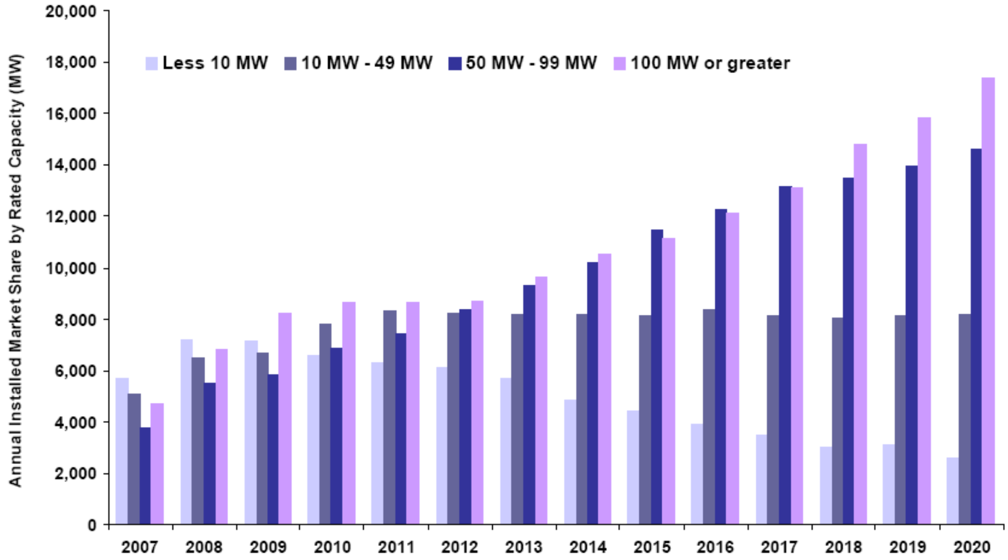


Figure 10. From the dynamic point of view a wind turbine is a complex structure to design reliably for a given service life time. On the left all external dynamic forces are indicated that expose a turbine to extreme fatigue loading. On the right the various vibration and deflection modes of a wind turbine can be seen. Source: EWEA

Wind turbine and wind farm siting is moving from smooth lowlands to new areas: offshore, mountains, complex terrain and cold and icing climates. This brings new challenges to turbine design. Remote sites with limited access (like offshore, mountains) together with increasing size of the turbines bring higher requirements for turbine reliability and maintenance free operation. New solutions based on condition monitoring and prediction, preventive maintenance and controllability are developed. Environmental challenges offshore mean designing for both wave and wind loads. Ice loads to foundations and towers has to be taken into account in Sweden and Finland, to some extent also in Denmark (the sea areas around Norway do not freeze due to Golf stream). The salty air demands for more corrosion protection.

Cold weather brings requirements for lubrication and materials. Icing of turbine blades means developing de-icing or anti-icing technologies for blades, or control strategies to stop the turbine when icing can occur in cases of security issues nearby the turbines due to ice throw.

Complex terrains and offshore bring also challenges to wind resource estimation. For the investments, a 5–10 % uncertainty in yearly production level is much for the financial risks. Development for better codes together with field tests aim to reduce the uncertainty to 3 % (TPWIND, 2008). Offshore the wind resource is more stable. Low turbulence of wind results in wake effects recovering more slowly, so the siting of turbines in the offshore wind farm needs to take this into account to reduce wake losses. Short term forecasting is also more challenging offshore, and large offshore wind farms experience higher variability and unpredictability in production compared to distributed wind farms onshore. New ways to measure wind, like Lidar and Sodar technologies for remote sensing, give new opportunities to measure larger wind fields and more high above winds. This can reduce the cost of wind resource estimation and bring new options to reduce loads by controlling wind turbines more precisely according to the wind field that large 100 m wide rotors experience.



Source: Emerging Energy Research

Figure 11. Wind power plants of 50 MW and larger are estimated increase and projects of less than 10 MW to decrease in the global markets.

As the unit size of commercial wind turbines increases further, on-line load monitoring, control and alleviation of loads by using smart structures become more important. Especially the requirements for both reliability and lifetime will increase as described especially for offshore and other remote area applications. In the future there will be special cold or icing climate turbines, and special offshore and on-shore wind turbines, instead of onshore turbines with offshore modifications in the market today. This requirement leads to considerations concerning the optimal drive train solutions like increase in gearless or otherwise optimized drive train concepts with variable speed operation.

The constant speed stall regulated turbine dominated the market up to about 1 MW rated power. Development of active stall concept in late 1990's enabled the use of stall regulation to about 1.5 or even 2 MW. In the modern MW-scale turbines the stall control is not anymore a competitive concept. Next to all new designs in the MW-scale seem to use pitch control of rotor blades combined with variable speed generators, either using double-fed induction generators with power converters for generator rotor circuit (DFIG) or permanent magnet generators with full power converter systems.

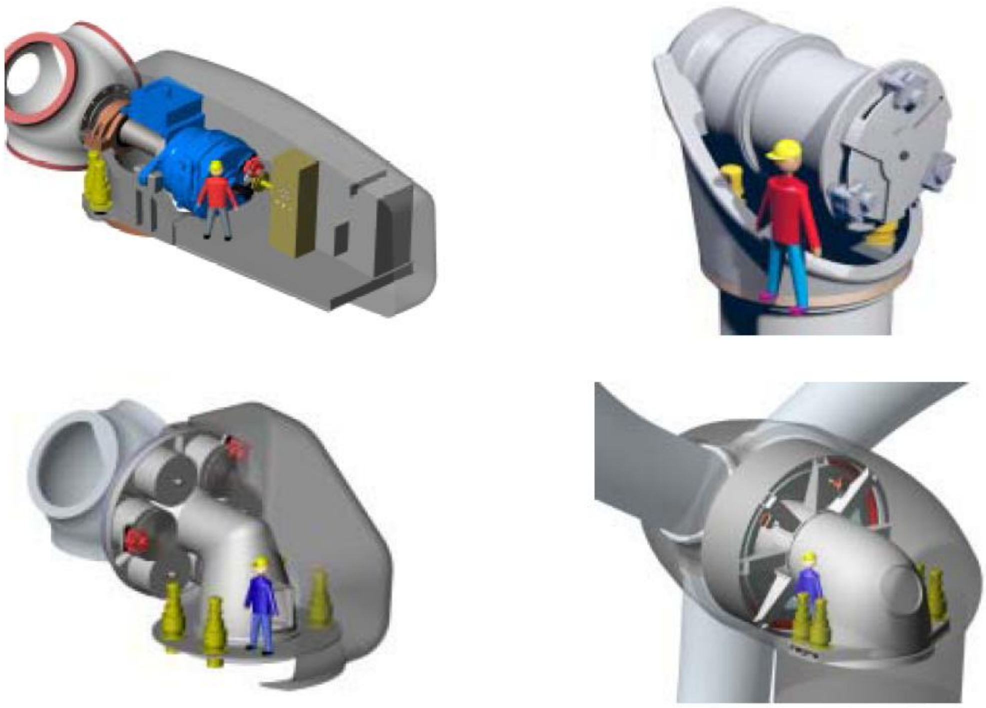


Figure 12. Some drive train concepts in MW-scale wind turbines. Planetary/helical gear boxes with 2-3 stages combined with high-speed, doubly-fed induction generator (above left), one stage planetary gear box integrated with a medium speed permanent magnet generator (above right), helical gear box with many permanent magnet or wound-rotor medium to high speed generator(below left) and low-speed gearless generator, either permanent magnet or with wound rotor (below right).

The further development of wind technology aims to cost reduction of the generated electricity. Controllability and adjustability will increase, for load management and maximising the performance. Minimising the mechanical loads for components will enable decrease of materials needed in huge MW turbines. Cost reductions are achieved by increased life-time efficiency (higher production at lower investment cost) as well as reliability and availability of wind turbines (reduced O&M costs). Design of components is also made to enable transport of larger machine components to remote areas. The following list examples of topics of development in this respect:

- Blades: new materials, blade vibration control using active materials, blade airfoil shape control, modular solutions (jointed blades to reduce the problems in blade handling and transport of more than 50 m long blades).
- Drive train: in parallel with the traditional 3-4 stage gear + generator there will be gearless low speed generators and designs with one-stage gear and medium speed generator. Permanent magnet generators and variable rotational speed will be used increasingly. The challenge is to realise the potentially better efficiency and reliability of a direct drive system without cost or weight penalties. The general trend towards more integrated nacelle systems (to reduce weight) means that bearing designs become more complex as they interact with the complete system. New, smart materials.
- Towers: managing loads and smart structures. More slender structures. Offshore wind power will bring about need to combine wind and wave loads in design as well as managing sea ice loads.

- Foundation and erection techniques: new designs for offshore foundations especially in deeper waters (>30m), new erection technologies offshore and in mountainous conditions, new installation vessels offshore.
- Network connection: increasing unit sizes, smart and controllable wind power plant concepts, wind farms providing active power and voltage control. Offshore grids linking offshore wind farms, ocean energy and different countries.
- Operation and maintenance: increasing importance as unit size and cumulative capacity increases, condition monitoring, preventive maintenance. Offshore, development of vessels for maintenance work.

Offshore turbines can still be optimised in the design process. The traditional design having rotor diameter of the same order as tower height may not be optimal offshore. The economic penalties of increased foundation loads and tower cost will typically outweigh any small energy gains from a much increased hub height. Larger rotor tip speed i.e. larger rotational speed for given rotor diameter may be utilized offshore.

Offshore foundation concepts used so far (monopiles, caissons) are working in shallow waters (5–25 m). For deeper waters tripods and jackets have been demonstrated (30–40 m). The offshore potential becomes vast when possibilities for deep waters (more than 100m) can be utilised. Developing floating turbines is one trend of offshore wind power. Three example structures are presented in Figure 13. The world's first full-scale floating wind turbine pilot (2.3 MW) is now operational in Norway (Hywind, 2009). It has a 65 m tower, and the floatation element stretches 100 meters below sea surface.

Figure 13. Floating concepts in Norway, from left: HyWind, SWAY and WindSea.

Larger generation units will require new solutions for regulation of the generation and the network. The technical requirements of wind turbines have increased from system operation point of view. Before, wind turbines were built with a "connect and forget" principle and they were demanded to disconnect from the network in case of any disturbances. Modern wind farms are required to be able to operate more like power plants and their capabilities in providing support to voltage and ancillary services are demanded in latest Grid Codes for connection.

High voltage direct current-transmission (HVDC) becomes an option for the grid connection of large offshore wind farms. The technology is evolving and the visions for future envisage offshore networks, a meshed network built offshore to link offshore wind farms, other offshore electricity production (wave/tidal) and consumption (oil/gas) as well as different countries. The first pilot for this concept is planned for Krieger's Flak, in between Sweden, Denmark and Germany.

Larger penetrations of wind power planned for Europe (15–30 % of electricity consumption) will be challenging for the power system. Both grid planning (extending and reinforcing the grid) and balancing the energy will require more cooperation between the system operators as well as new planning and operational tools. Integrating short term forecasting to system operation, operating the systems as flexibly as possible using interconnections between countries, and ultimately building new flexible generation and storages will be needed.

2.2 Market estimates for wind power development

Future drivers are CO_2 emission reduction targets as well as decreasing dependence on fossil fuels, also as a hedge to increasing gas and oil prices. Many countries have set targets to increase the use of renewable sources of energy, however, not all specify the targets for wind power.

There are several market estimates for wind power growth. Capacity could be more than 300 GW in 2013 and 500–700 GW in 2020 (GWEC, 2008; BTM, 2009). At present cost level 1.3 million €/MW and by assuming all the present capacity to be replaced by 2030 this represents an investment market of about 1700–2300 billion € in about 20 years.

European Wind Energy Association EWEA has a target of 300 GW wind in Europe in 2020. In US, a 20 % Vision has been made where 300 GW wind in US in 2025 is seen feasible, producing 20 % of all electricity consumption (USDoE, 2008). In US there are Renewable Portfolio Standard (RPS) targets in more than half of the states, most of which are foreseen to be realised by wind power. Global wind power penetration could reach 8–10 % in 2020, from roughly 1 % level of today.

Several market studies predict the market within 5–10 years time frame. Two forecasts of yearly installed capacity are presented in the graphs below (Emerging Energy, 2009; BTMConsult, 2009). These estimates are based on national targets for wind power. Europe remains the biggest market but market growth is strongest in USA and Asia. Offshore market remains marginal in 5-10 years time but is increasingly important for countries like Denmark, UK, the Netherlands, Germany, Sweden and Finland. Also Norway will probably see some offshore wind power installed even before the floating foundations for deep water will be commercialised.

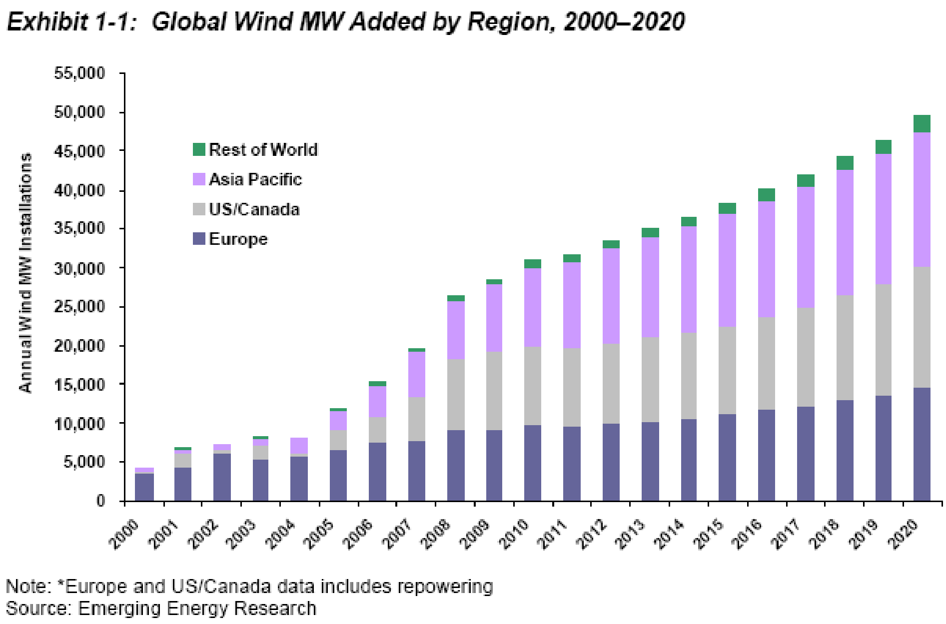


Figure 14. Market growth estimate by Emerging Energy Research, from 28 GW/year in 2008 to 50 GW/year in 2020.

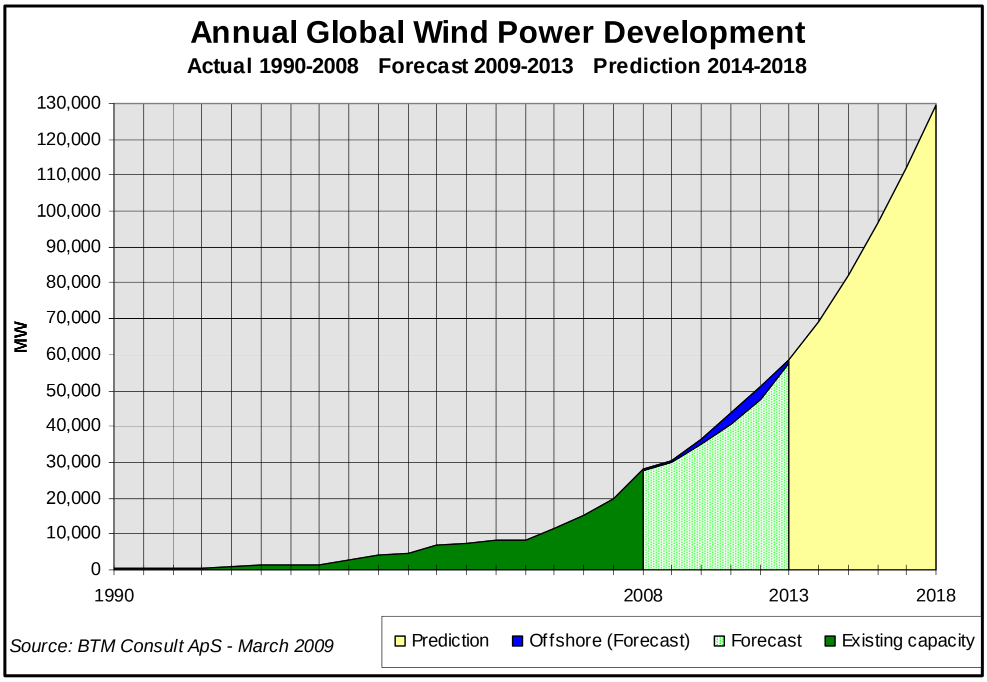


Figure 15. Market growth estimate by BTM consult, from 28 GW/year in 2008 to 58 GW/year in 2013, and 138 GW/year in 2018.

2.3 Nordic countries

Markets and policy

The market and demand for wind turbines depends on the national policy objectives and targets in each country. Denmark aims at 50 % of its electricity needs coming from wind power (currently 20 %). Sweden has a planning target of 30 TWh/a wind power production in 2020, of which 10 TWh/a offshore. Norway aims at 3 TWh (~1000 MW) in 2010 and Finland 2000 MW in 2020 (IEAWIND, 2009).

All Nordic countries have had a different approach to subsidies. Feed-in tariffs were used in Denmark to achieve the first 2000 MW wind power capacity. Now a production bonus is used, especially enhancing repowering projects to modernise the fleet of less than 500 kW turbines currently installed (the 3163 MW installed is from more than 5000 turbines). Most of the new capacity is coming from tendering processes for offshore wind farms, where government has identified the sites.

Green certificates have been used Sweden, where wind power has got an extra bonus production subsidy, to enable the investments with lower certificate prices due to many cost effective biomass projects. It is estimated that changes in quotas for the certificate system or other economic support will be needed to reach a level substantially larger than 8 TWh/a in 2020.

Investment subsidies have been used in Finland and Norway, with limited funding resources. Finland is starting a premium tariff in 2010, with a 83.5 €/MWh price level (90.5 €/MWh during first years), where the producers get the difference of average spot price in the market and this price level for 12 years. Norway is planning to join the Swedish green certificate system in 2012.

For the Nordic wind turbine market the main demand onshore is in Sweden and Norway and offshore Sweden and Denmark. Offshore is relatively important in the Nordic countries, and cold climate market is significant. The Nordic wind power market could exceed 1000 MW/year in 2010 and 3500 MW/year in 2015 (Figure 16). However, the current subsidy schemes only support offshore wind farms in Denmark where there is a long term plan of building large offshore wind farms, with selected sites and tendering process by the government. In all other Nordic countries, the current or foreseen subsidy system will not provide enough incentive to build offshore, unless some other extra support is given.

Public acceptance can be a barrier to wind energy deployment in the Nordic countries. reducing the available sites for wind power production. Overall, the land use requirements and putting together conflicting land use criteria to accommodate more and more wind power will be a challenge. The permitting process can still be tedious, even if some improvements have been made. The smoother running of permit system is identified as one important support needed for wind power in Sweden. Impacts to radar, especially for the defence, still needs to be evaluated and measures to reduce the impacts developed. This is one issue currently putting a halt to many projects in Finland. Reducing the requirements for safety zones will bring more sites available for wind power.

Basically the Nordic grid is quite strong, however, wind power means reinforcements of the transmission network f.ex. from North Norway to South, and along the Finnish west coast.

Finnish system operator Fingrid foresees the reinforcement of the existing interconnections to Sweden as one way of coping with increased balancing needs due to wind power.

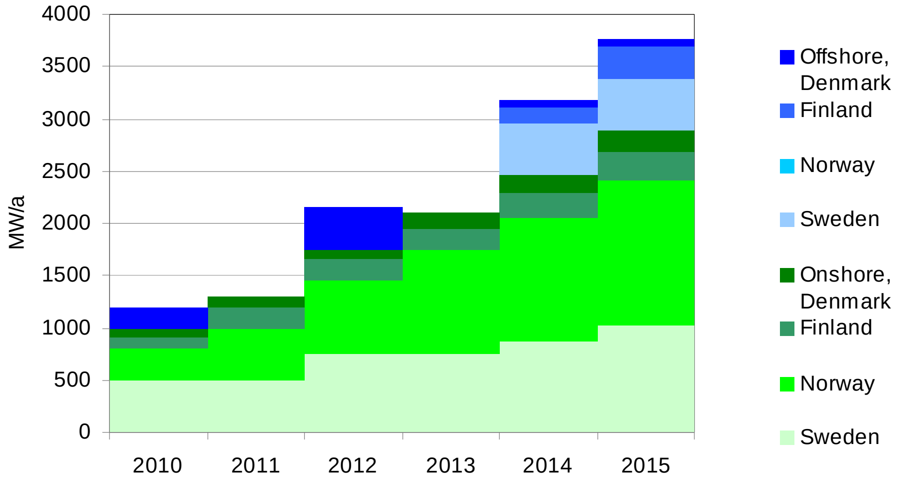


Figure 16. Nordic wind turbine market, divided to onshore and offshore markets in the four countries.

Large grid connected wind turbines

Major part of wind turbines in Nordic countries have been built onshore. In Denmark and southern part of Sweden the location of individual turbines and small wind farms are usually open and flat landscapes. In Norway the turbines are located mostly on hills whereas in Finland the major part of wind turbines are located in coastal sites as near the shore-line as possible.

Since in every country there is a limitation in the availability of the most economic sites, more demanding areas have and will be taken in use. In Denmark further increase in wind energy comes mainly from large offshore wind farms. Denmark has since early 1990's been a global forerunner in development and deployment of offshore wind energy. Sweden has also taken first steps in offshore wind energy but growing number of activities has emerged in forested areas and in hill and fjell areas. In Finland first projects in fjell areas and semi-offshore have been built. There is growing interest in developing other inland sites. Norway has still large untapped resource base onshore, with more than 6000 MW of projects in NVE's list of applications (more than 2000 MW have received approval). Some part of it is located areas with cold climate conditions. Norway also has a vast offshore wind resource requiring the development and deployment deep offshore solutions before deployment.

As the existing turbines come to towards the end of their age, most sites will be used by replacing older turbines new and usually bigger ones. In Denmark there are measures in use to promote and support this activity.

Small wind turbines

Small turbines will have only a marginal contribution in fulfilling the national targets for wind energy generation. However, the market size in number of turbines can be large enough for commercial activities in smaller scale, mainly directed into farmers, electricity for huts and other special use in smaller scale, such as electricity for the telecommunication infrastructure in remote areas. Policy measures suitable for small scale wind turbines are not in place Nordic countries (such as capital cost buy-down, feed-in tariffs and net metering) although was used in Denmark during the early years of wind energy development in 1980's. The market in developed countries is promising due to promotion policies, and even more so for developing countries with decrease in specific costs of the turbines and the increasing need for energy.

Industry

The supply side of wind turbine market has several large actors based in the Nordic countries:

- turbine manufacturers: Vestas, Siemens (global companies with Danish technology and roots, established market leaders), Winwind (emerging supplier with main office in Finland but activities also outside Nordic countries, ownership in India and Arab Emirates), Nordic Wind Power (company with Swedish roots, nowadays US), Scanwind (Norwegian-Swedish, acquired by GE Wind)
- globally important suppliers to turbine manufacturers like ABB (important supplier of generators, electrical drives for turbines and electrical systems of wind farms, Swedish and Finnish technology), LM Glasfiber (Danish blade manufacturer with global market and manufacturing facilities network), Moventas (Finnish gear box manufacturer, global activities), SKF (Main bearing company in wind business, Swedish), The Switch (emerging Finnish supplier of generator systems for wind turbines).

Several other Nordic companies have their place in wind energy market as suppliers of materials for towers and blades, castings, control systems, hydraulic etc. Some small turbine manufacturers also exist (Windside, Eagle, PEMEnergy,….).

R&D

The wind energy r&d-activities in the Nordic countries are following:

The topics in the Danish wind programme include larger projects with industrial interest on:

- wake effects in large wind farms
- aeroelastic design of blades
- control concepts for load reduction
- materials and manufacturing technology of blades

The Swedish Vindforsk-programme aims at

- better knowledge on wind resources both offshore and inland in forested and hill areas,
- to improve the cost efficiency of wind projects,
- to optimize the operation and maintenance in farms and
- to study the integration of wind energy into the energy system

There are two recently launched Norwegian research programmes for offshore wind power: NOWITECH and NORCOWE that concentrate in the precommercial r&d of

- integrated design tools for offshore wind turbine concepts
- new materials for blades and generators
- deep offshore foundations (both floating and sea bottom based)
- strategies and technologies for operation and maintenance
- evaluation of new concepts by modelling and testing.

Norway is in the forefront of developing floating offshore wind turbines. The world's first full scale floating pilot plant (Hywind) was installed in June 2009, 10 km off the west coast of Norway. It has a 2.3 MW Siemens turbine (65 m tower), and the floatation element stretches 100 meters below sea surface.

The major part of r&d funding in Finland is directed to industrial development projects. Publicly funded r&d includes research in wind energy in cold climate and integration of wind energy in energy system. The preparatory work for a new wind energy research programme under CLEEN strategic top research centre for energy is starting.

Important issues for Nordic research are

- Nordic wind atlas including as part of the new European wind atlas,
- Resource and environmental conditions' database and modelling tools for offshore as well as for in complex terrain and cold climate,
- Wind integration for the Nordic electricity market and grid,
- Offshore and cold climate specific development needs.

3 Conclusions /Summary

Drivers for wind power are CO_2 emission reduction targets as well as decreasing dependence on fossil fuels, also as a hedge to increasing gas and oil prices. Barriers to wind development have been acquiring site permits, due to public acceptance or environmental impacts. In some countries also grid permits has or is becoming a barrier for future growth.

The global wind power capacity surpassed 100 GW in early 2008 and is increasing by 28 GW/year with increasing growth rate. There are several market estimates for wind power growth. Capacity could be more than 300 GW in 2013 and 500–700 GW in 2020.

The investment cost of wind power was steadily decreasing in the 80's and 90's, reached about 1000–1200 €/kW level in the early 2000's and has now risen in recent years due to increasing material costs (mainly steel) as well as a somewhat heated market (lack of production capacity for the turbines and components in 2006–2008). The production cost of wind power is still at a higher level than for conventional power sources, and some incentives are needed for building. The most successful subsidy programmes have been based on production subsidy.

Land based wind power plants built today are usually 1–3 MW in size. They can be built at a cost in the range of 1200–1500 €/kW and produce energy corresponding to peak load hours between 2000–2400 h/a. The investment costs of offshore wind farms are high compared to land based wind farms, and this is only partly compensated by better production. The cold climate/arctic turbines are still few. The modifications required for the standard solutions together with other site specific costs can raise the total cost 10–20 % in comparison to standard conditions. There are niche markets for small wind turbines. So far the market has been very limited in size. Small turbines will have only a marginal contribution in fulfilling the national targets for wind energy generation. However, the market size in number of turbines can be large enough for commercial activities in smaller scale.

Wind turbine technology is still evolving. The size of turbines is still increasing, although at a slower pace. Other major trends are increasing wind farm size and increasing use of smart materials and controls in the turbines. Moving to offshore applications, and to more complex terrain like mountains, with more difficult access and harsh conditions, brings also new challenges and technological solutions like condition monitoring and prediction, preventive maintenance and controllability to improve the reliability and decrease operational costs of wind energy. The trends in network connection will enhance controllability of wind farm output and support to power systems. There is still potential to further cost reductions from mass production benefits and increased load managing and smart structures in design process.

The basic concept – a three-bladed turbine with a horizontal axis – has dominated the market and seems to remain dominant also in the foreseeable future. Nordic Windpower, originally a Swedish company, has developed 2-bladed wind turbine concept with products in MW-class for utility projects. Vertical axis concepts exist only in small scale, up to about 10 kW in rated power. There are also some other innovative new concepts emerging, (see f.ex. wind energy facts in www.wind-energy-the-facts.org for some air-borne concepts with kites) but they have a long way to show their reliability and cost effectiveness. There is a lot of development work and innovations still to be seen in the basic 3 bladed concept to improve reliability, load management, control and material use. Innovations offshore are expected in future: for the foundations especially to deeper waters and floating concepts to water depths of 100 m and more. In future we expect to see large, meshed offshore grids connecting wind farms, ocean energy and several countries in Baltic and North Sea.

Important issues for Nordic research are

- Nordic wind atlas including as part of the new European wind atlas,
- Resource and environmental conditions' database and modelling tools for offshore as well as for in complex terrain and cold climate,
- Wind integration for the Nordic electricity market and grid,
- Offshore and cold climate specific development needs.

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