Renewable Energy Essentials: Wind

- World generating capacity of wind energy is growing at 20-30% per year, and surpassed 90 Gigawatts (GW) in 2007 – 50 times installed capacity in 1990. Approximately 152 teraWatt hours (TWh) of wind electricity were generated in 2006.
- Annual investment topped USD 50 billion in 2007. The global wind industry employs around 200 000 people.
- Turbine costs have decreased by a factor of four since the 1980s. Since 2004, however they have increased by 20-80%, due to tight supply of turbines and components, and high commodity prices. In 2007, onshore turbine costs ranged from USD 1.2m – 1.8m per MW.
- Recent production costs onshore range from USD 75/MWh to 97/MWh at high to medium quality wind resource sites. Onshore wind is competitive at sites with good resource and grid access.
- The IEA *Energy Technology Perspectives 2008* publication suggests that in 2050 wind power could supply up to 12% of global demand for electricity – with concentrated effort and technology innovation.
- Barriers to growth include capital cost, uncertainty regarding policy support and impacts of variability on power systems, limited grid capacity and visual impact.

Market status

Wind power in total generated 152 TWh of electricity in 2006. In 2007, wind power plants provided for 20% of electricity consumption in Denmark, 10% in Spain, and 6% in Germany. More than 20GW of capacity were installed in 2007 alone, led by the United States, China and Spain. Cumulative installed capacities are shown in the map below. The largest individual wind power plant operating in 2007 (in Texas) had a capacity greater than 700 MW, the same order of magnitude as conventional power plants.

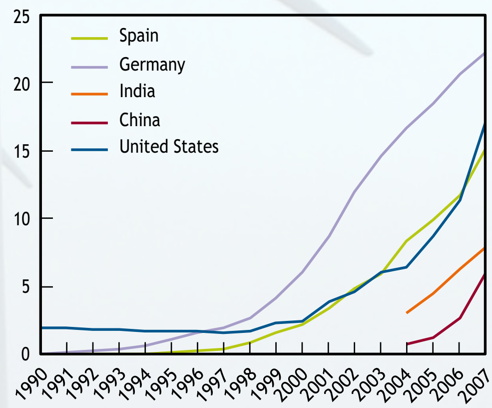


Figure 1. Cumulative installed gigawatts of wind power in leading countries, 1990 – 2007

Offshore

Offshore installed capacity topped 1.1 GW in 2007, located in just six countries, including Denmark (420 MW), United Kingdom (300 MW), Netherlands (130 MW), Ireland (25 MW), and Sweden (135 MW). Several large projects are planned in other countries. Offshore wind power plants can produce up to 50% more electricity than their onshore cousins, due to higher and steadier wind speeds. Other advantages include greatly reduced visual impact, less turbulence, and lower noise constraints – allowing higher rotor speeds. On the other hand, with current technology the hardware and its installation are more expensive.

Small wind

Small and micro wind turbines have in the past been considered mainly for off-grid applications. Recently a number of countries have shown renewed interest, including Canada, Ireland, Italy, Portugal, Spain, United Kingdom and United States. However, reliability problems persist, and markets remain small.

The wind resource

The global resource map below illustrates approximate, average global wind speeds on- and offshore. The energy content of the wind is proportional to the cube of the wind speed, so a slighter faster average speed yields significantly greater output. This has major bearing on the financial viability of a project. A good wind speed site for an average development is around 7m/s (25 kmph, 16mph) and above, at a hub height of around 80 metres. The importance of a high quality wind regime is illustrated by the fact that the US produced more wind electricity in 2007 than any other country, even though it does not have the largest installed capacity. Similarly, offshore wind energy represented 1.8% of total installed capacity (in 2006) but produced 3.3% of total wind electricity. High quality wind resources are distributed throughout the globe.

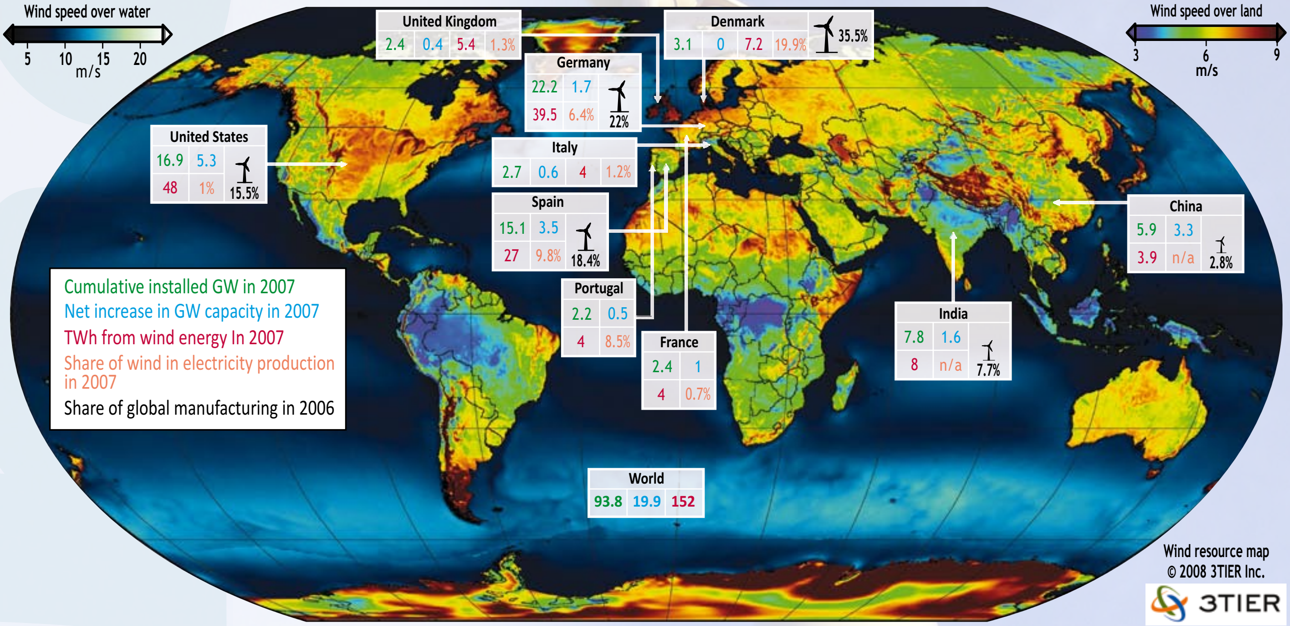
Manufacturing and employment

Six countries worldwide account for almost all wind turbine manufacturing (see Figure 2). Although Denmark contains only a little over 3% of global installed wind capacity, it was the birthplace of modern wind energy and still produces over a third of all turbines sold worldwide. Other principle manufacturing countries are Germany, Spain, the USA, India and China. The global wind industry employs around 200 000 people.

New investment

Investment reached USD 50.2 billion in 2007, accounting for 43% of new investments in renewable energy. Wind raised USD 11.3 bn in public markets, 60% of which through a single Initial Public Offering.

Figure 2. World onshore and offshore resource map at 80m height and 15 km resolution, with installed capacity, production and manufacturing data for leading countries



Map notes: Figures for 2007 capacity increase for India and China are gross. TWh produced in India and China are for 2006. Most Danish activity in 2007 was in re-powering. Leading states in the Unites States, in terms of share of national electricity production, include Minnesota (5%), Iowa (5%), New Mexico (4%) and Oregon (3.5%).

Economics

Investment costs

Turbine costs have decreased by a factor of four since the early 1980s. Since 2004, however, they have risen by around 20-80% (2006), driven by supply tightness (turbines, gear boxes, blades, bearings and towers) and higher commodity prices (particularly steel and copper). Industry sources expect supply tightness to loosen by 2010. In 2007, onshore turbine costs ranged from USD 1.2m per MW in the United States to USD 1.8m in Italy. Total installed costs (inc. turbine) ranged from USD 1.4m in the UK to USD 2.7m in Ireland (Figure 3).

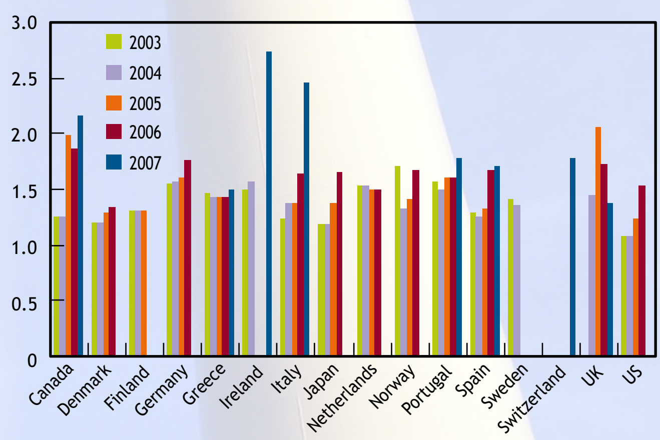


Figure 3. Evolution of investment costs in selected countries: 2003 to 2007 (USD millions per MW)

Operation and maintenance (O&M)

The annual operating cost for large onshore turbines in 2006, including insurance, regular maintenance, spare parts, repair and administration was in the range of USD 14/MWh to USD 26/MWh. O&M costs are considerably higher for offshore wind turbines.

Production costs

At sites with the best available wind resource as well as nearby grid access, wind power plants can be competitive with conventional electricity producers. The cost per unit of electricity generated depends on the quality of the wind resource (represented by the number of full load hours of operation) investment cost, O&M cost, and turbine longevity. Wind power plants are capital-intensive so the cost of capital (discount rate) is a decisive factor in wind cost estimation. Typical production costs, levelised over turbine lifetime, with a discount rate of 7.5% and investment costs of USD 1.6m per MW, for example, range from USD 75/MWh to 97/MWh, at high to medium quality wind resource sites, as illustrated in Figure 4.

Offshore costs

Costs are largely dependent on water depth and distance from shore. Foundations, installation, and grid connection are significantly more costly offshore. Turbine cost is typically 20% higher, and towers and foundations perhaps 150% more. However, offshore wind plant output can be up to 50% greater, due to higher wind speeds. Installations in the United Kingdom and Sweden in 2007 – 2008 cost between USD 2.5m per MW and USD 3.7m per MW, and production costs at these locations ranged from USD 85 – 105/MWh.

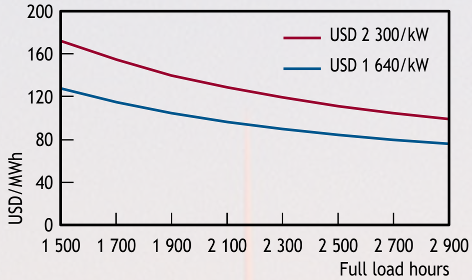


Figure 4. Wind power production costs as a function of the wind resource and investment cost

Cost reductions

Drivers for cost reductions include increased performance and reliability, technology advances, larger turbines (when installed offshore), and increased manufacturing capacity. The use of "learning rates" to gauge future cost reductions is based on the assumption that existing trends will persist. In essence, this methodology yields a percentage reduction in costs for each doubling of production. For wind energy, recent IEA analysis suggests a learning rate of around 10-20%. With a 10% learning rate, costs in 2015 would be about USD 53/MWh at high wind, onshore sites.

Outlook

Growth drivers

Strategies to mitigate anthropogenic climate change, and other negative environmental effects of conventional power production, have given rise to a range of supportive government policies for renewable energy, some of which are specific to wind energy, as well as carbon markets. Other drivers include technology advances, fossil fuel scarcity and increasing price, growing concern regarding energy independence, electricity market liberalisation, and rising electricity demand particularly in emerging economies. Off-grid and rural energisation, and poverty reduction are important developing country drivers.

Barriers

Barriers to wind energy development include uncertainty relating to the future of/lack of incentive schemes (*e.g.* annual renewal of the Production Tax Credit in the USA), concerns about the impacts of variability on power system reliability, access to transmission, perceived visual and ecological impacts, and the structure of conventional electricity markets. The latter evolved around conventional generation and utilities, and in many cases could be optimised to facilitate wind power participation.

Long-term scenarios

The outlook is for continued double-digit percentage annual growth in wind energy. IEA Energy Technology Perspectives (ETP) 2008 suggests that wind technology could feasibly provide 9% (approx. 2 700 TWh) of global electricity in 2030[1]. By 2050, the IEA's advanced "BLUE" Scenario, which requires significant technology innovation, suggests that as much as 12% (approx. 5 200 TWh) could be feasible[2]. These amounts are plotted in Figure 5, as a range. The Global Wind Energy Council has prepared an Advanced Scenario that suggests that, if stronger early action is taken, wind electricity production could reach still higher: 5 200 TWh in 2030 and 7 200 TWh in 2050. The IEA scenarios are generated by a model which also takes into account competing generation technologies.

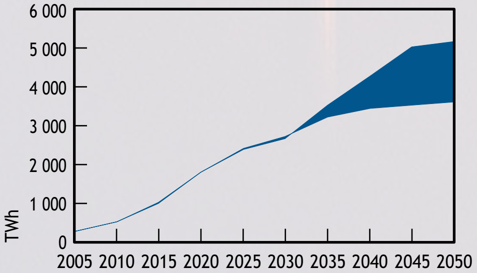


Figure 5. IEA ETP Scenarios: range of potential global wind electricity production (TWh)

1. "ACT" Scenario, in which CO_2 emissions stabilised at present levels by 2050, and measures are taken with a cost of up to USD 50/tonne CO_2.
2. "BLUE" Scenario, in which present CO_2 emissions halved by 2050, and measures are taken with a cost of up to 200/tonne CO_2.

System related aspects

Variability

Wind power plants – like wave, tidal, and solar plants – depend on a variable resource; the wind does not blow all the time in any one place. Consequently, the capacity factor[3] of wind turbines ranges from 20% to 40%, lower than for conventional base-load technologies. Variability is commonly perceived to be challenging at high shares, but there is no intrinsic, technical ceiling to variable renewables' potential. Nonetheless, as variable electricity inputs to the system increase, so the flexibility of the power system must increase also, to provide for times when wind power output is low. In electricity system terms, flexible power plants are those in the generation portfolio that can quickly ramp production of electricity up or down as required. But the system can also respond to fluctuating wind power output through the use of stored energy, import from other areas and through enabling demand side response. A number of *operational* measures exist also, particularly relating to the operation of transmission capacity and electricity markets.

Environmental impacts

External costs

The costs relating to social and environmental damage caused by pollution – are rarely taken into account in assessment of the costs of power technologies. Wind power plants require no fossil fuel and produce little environmental pollution during their manufacture, operation and decommissioning. CO_2 emissions for wind energy are small, (around 10g of CO_2 per kWh). If external costs were taken into account in normal cost assessments, studies suggest that wind energy would already be competitive with most power technologies.

Local impacts

Although public support for wind power is often high, wind turbines may be considered by some to be visually intrusive. Micro-siting techniques can be used to reduce visual impacts. Issues relating to aerodynamic noise are largely resolved with suitable codes relating to the allowable distance from residential areas. Following concern about potential avian, bat and marine impacts, most environmental assessments have suggested that these are easily minimised through careful siting of turbines.

Technology status and development

Turbine technology

Wind turbines extract kinetic energy from moving air flow (wind) and convert it into electricity via an aerodynamic rotor connected by a transmission system to an electric generator. Today's standard turbine has three blades rotating on a horizontal axis, upwind of the tower, with a synchronous or asynchronous generator connected to the grid. Two-blade, and direct-drive (without a gearbox) turbines are also found.

Larger turbines

The electricity output of a turbine is roughly proportional to the rotor area, so fewer larger rotors (on taller towers) use the wind resource more efficiently than more numerous, smaller machines. The largest wind turbines today are 5-6 MW units with a rotor diameter of up to 126 metres. Turbines have doubled in size approximately every five years, but a slowdown in this rate is likely for onshore turbines, due to transport, weight and installation constraints.

Lifetime and availability

The estimated lifetime of an individual wind turbine is 20 to 25 years. Life spans may stretch as the technology continues to mature. However, due to the youth of the industry and the re-powering of plants with the latest turbine technology, few turbines have been around long enough to test this assumption. Due to extensive testing and certification, the reliability of wind turbines – the proportion of the time they are technically available for operation – is around 99%.

Technology advances

Technology efficiency gains are ongoing. More efficient blades and drive trains, lighter nacelles (rotor plus generator) and fewer components mean a higher electricity output per unit of materials required in the manufacturing process. Such efficiency gains will to some extent counter rising capital costs associated with higher commodity prices (*e.g.* copper and steel).

Offshore/deep offshore

To a large extent, the move offshore can be said to be driving wind energy technology development generally. Most offshore wind at present is installed in shallow water. Floating turbines, for the deep offshore environment, are at the demonstration phase with a 2.3 MW prototype scheduled to be deployed in 2009 off the coast of Norway in the North Sea, and another 2.5 prototype scheduled to be installed in 2009 off the Apulia region in Italy.

R&D priorities

Subjects for further research, specific to wind energy technology, include more refined resource assessment; materials with higher strength to mass ratios; advanced grid integration & power quality and control technologies; standardisation and certification; development of low-wind regime turbines; improved forecasting; increased fatigue resistance of major components such as gearboxes; better models for aerodynamics and aeroelasticity; generators based on superconductor technology; deep-offshore foundations; and high-altitude "kite" concepts.

3. The amount of output a power plant produces, divided by the amount it would have produced, had it been in operation 24h, 365 days.

Resource map from 3Tier; capacity and production figures from IEA Wind and Wind Power Monthly; manufacturer data from BTM Consult. Photos: © EWEA, 2008.