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Published in:
DTU International Energy Report 2014

Publication date:
2014

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Morthorst, P. E., González, J. M., & Schröder, S. T. (2014). Wind economics. In H. Hvidtfeldt Larsen, & L. Sønderberg Petersen (Eds.), DTU International Energy Report 2014: Wind energy — drivers and barriers for higher shares of wind in the global power generation mix (pp. 79-85). Technical University of Denmark.

Chapter 11

Wind economics

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Accumulated global installed capacity of wind energy has increased from approximately 48 GW in 2004 to more than 321 GW at the end of 2013, an annual growth of more than 20%. A large part of this development is of course driven by national and regional incentive schemes and subsidies. However, onshore turbines are to an increasing extent becoming economically competitive with conventional power production, especially when sited at locations with high wind speeds and in countries with comparatively high power prices.

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 installed turbines.

Renewables targets and support

Thanks to its abundant resources and cost-competitiveness among renewable energy technologies, wind power will be a cornerstone of the future energy sector in the EU. Installed wind capacity across all the EU member states is expected to quintuple, to more than 200 GW, between 2005 and 2020 (Beurskens *et al.*, 2011). The historical development pathways of wind power in different EU countries have varied considerably: early movers like Denmark had already achieved relatively large installed onshore capacities by 2005, whereas most other countries plan to carry on building new onshore wind farms until 2020 (*Figure 31*).

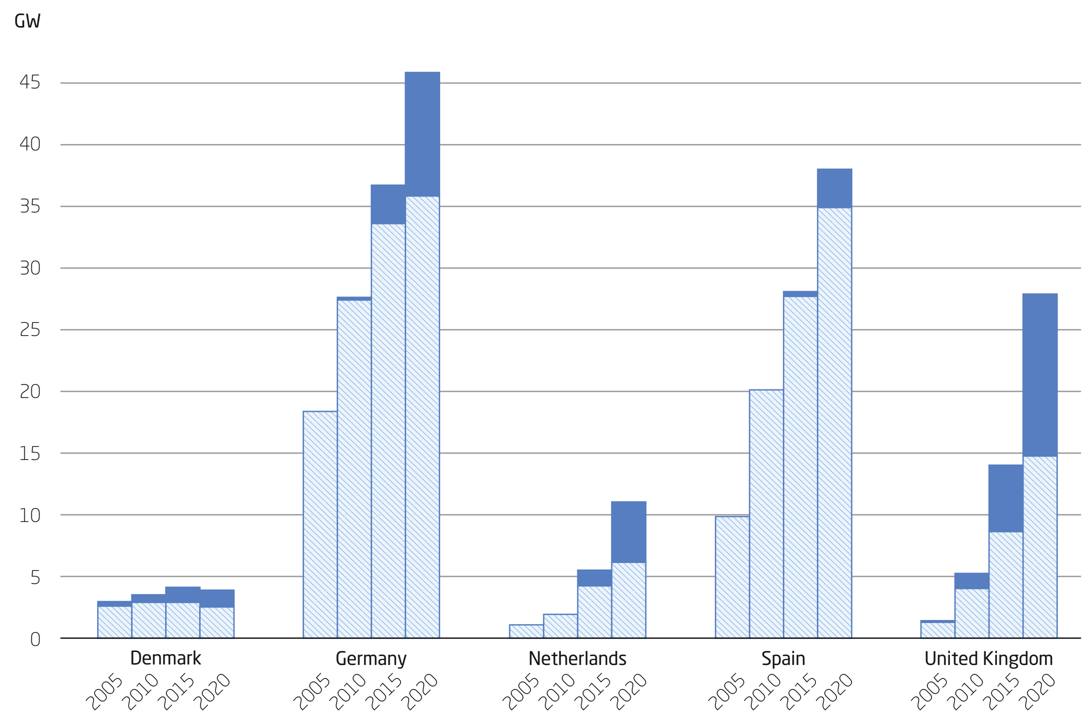
A similar development can be observed for offshore wind power, although again it differs between countries. Denmark, which has been a forerunner, envisages the erection of a single new offshore wind farm by 2020, whereas the other countries bordering the North Sea plan to install dozens of GW between 2015 and 2020. These plans reflect both the space occupied by onshore wind power in these densely populated countries and the cost decreases expected for offshore wind power in the future. In summary, these factors are leading to a shifting ratio between

Figure 31 – Development of installed capacity in selected countries.

Development of installed capacity in selected countries.

2005/2010/2015/2020
Offshore
Onshore

Data: Beurskens *et al.* (2011)



onshore and offshore installations. Offshore is expected to increase from about 2% of total installed capacity in 2005 to about 20% by 2020.

For wind power, a number of EU countries have now abandoned the classic feed-in tariffs that paved the way for cost reductions in the past. One of the main reasons is the increasing market share of wind power, which now has to interact better with the remainder of the power system and respond to market signals. A number of major EU wind markets – notably Germany and soon the UK – use feed-in premiums[8] with guaranteed total income levels.

The EU's current legislative plans point towards a stronger focus on cost reductions and competition (European Commission, 2014), which might be achieved through a more widespread use of tendering as a support tool. Tendering is currently used to determine offshore support rates in France, for example.

Moreover, cross-border cooperation as established by EU Directive 2009/28/EC is beginning to see the light of day. An existing example of this is the green quota scheme shared between Norway and Sweden. An example of possible project-based cooperation in wind power would be large wind farms that could be built in Ireland, yet connected to the UK grid and treated as UK-based projects (MoU, 2013).

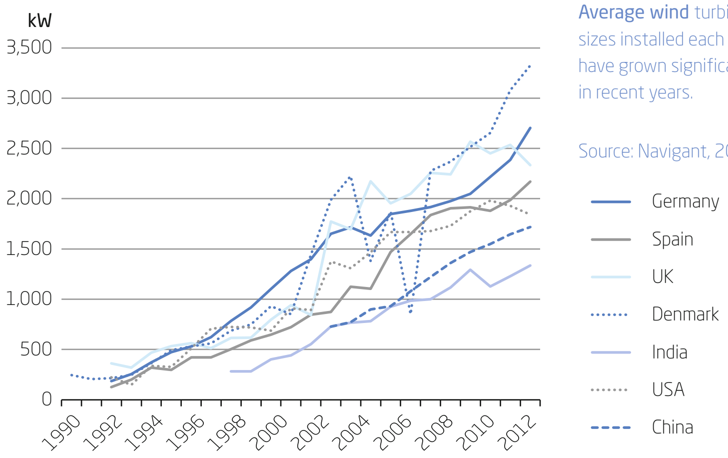
Onshore costs

The main parameters governing wind power economics include:

- investment costs, including auxiliary costs for foundations, grid connection, etc.;
- operation and maintenance costs;
- electricity production / wind farm capacity factor (strongly driven by the average wind speed);
- turbine lifetime; and
- discount rate.

Of these, the most important are the turbines' electricity production and their investment costs.

Figure 32 - Average wind turbine sizes.



Average wind turbine sizes installed each year have grown significantly in recent years.

Source: Navigant, 2014.

As electricity production is highly dependent on wind conditions, choosing the right site is critical to achieving economic viability. In general, three major trends have dominated the development of grid-connected wind turbines in recent years:

1. Turbines have grown larger and taller, and the average size of turbines sold has increased substantially.
2. The efficiency of the turbines' production has increased steadily.
3. In general, investment costs per kW have fallen, although a steady trend has not been observed in recent years

Figure 32 shows the growth in the average size of wind turbines sold each year for a number of the most important wind power countries. The average size has increased from approximately 200 kW in 1990 to more than 3 GW in Denmark and 2.5 GW in Germany in 2013, with the UK and Spain lagging only a little behind. The spikes seen for Denmark are caused by offshore wind turbine installations, which are generally larger than turbines installed onshore.

The wind regime at the chosen site, the hub height of the turbines and the efficiency of production are the main factors determining power production from the turbines. Thus, increasing the height of the

8. A Fixed feed-in tariff covers a total fixed payment per MWh to the owner of the plant for an agreed period (20 years or lifetime of project).

   A fixed feed-in premium covers an extra fixed payment on top of the day-ahead power price, both as a payment per MWh.

turbines has by itself yielded higher power production. Similarly, methods for measuring and evaluating the wind speed at a given site have improved substantially in recent years, so the siting of new turbines has improved. Thanks to better equipment design, electricity production efficiency has also improved significantly over recent years.

Capital costs of wind energy projects are dominated by the cost of the turbines themselves.[9] Of the other contributors, the most important are typically grid connection, electrical installation and foundations, though road construction and financial costs may also account for substantial fractions of the total. For onshore turbines, the auxiliary costs add up to 20–30% of the total turbine costs, depending on the country of installation and the size of the turbines.

9. **i.e. the "ex works" cost:** this includes the cost of the turbine itself, blades, tower, and transport to the site, but excludes site work, foundations, and grid connection costs.

The total cost per kW of installed wind power capacity differs between installations and between countries, as exemplified in *Figure 33*. The cost of land-based turbines today is typically in the range 1,200–1,400 €/kW, and is very similar in the US (1,260 €/kW) and Denmark (1,350 €/kW). *Figure 33* is based on a limited amount of data, however, so the results might not be representative.

Operations and maintenance (O&M) costs relate to a limited number of cost components: insurance, planned maintenance, repairs, spare parts and administration. Some of these cost components can be estimated with relative ease. For insurance and regular maintenance, for example, it is possible to obtain standard contracts covering a considerable portion of the wind turbine's total lifetime. On the other hand, the costs of repairs and related spare parts are much more difficult to predict. Although all the components of O&M costs tend to increase with the age of the turbine, this trend is especially noticeable for repairs and spare parts.

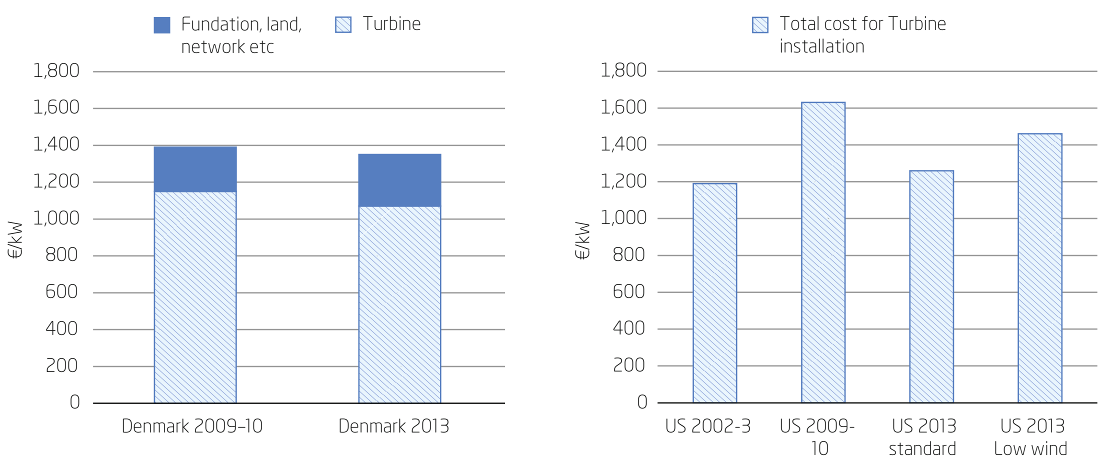
O&M costs constitute a sizeable share of the total annual costs of a wind turbine. For a new turbine, O&M costs might easily average 20–25% of the total levelized cost per kWh produced over the lifetime of the turbine. On an annual basis, O&M costs might start at 10–15% for a new turbine, rising to at least 20–35% by the end of the turbine's life.

O&M costs are attracting increasing attention. Manufacturers are attempting to lower them significantly by developing new turbine designs that are more reliable and require fewer, shorter, regular service visits.

Offshore costs

Offshore wind power is experiencing a steep rise in installed capacity, primarily via projects in northern European waters. The European dominance in the worldwide offshore market is illustrated in *Figure 34* only from 2010 onwards, the first Asian

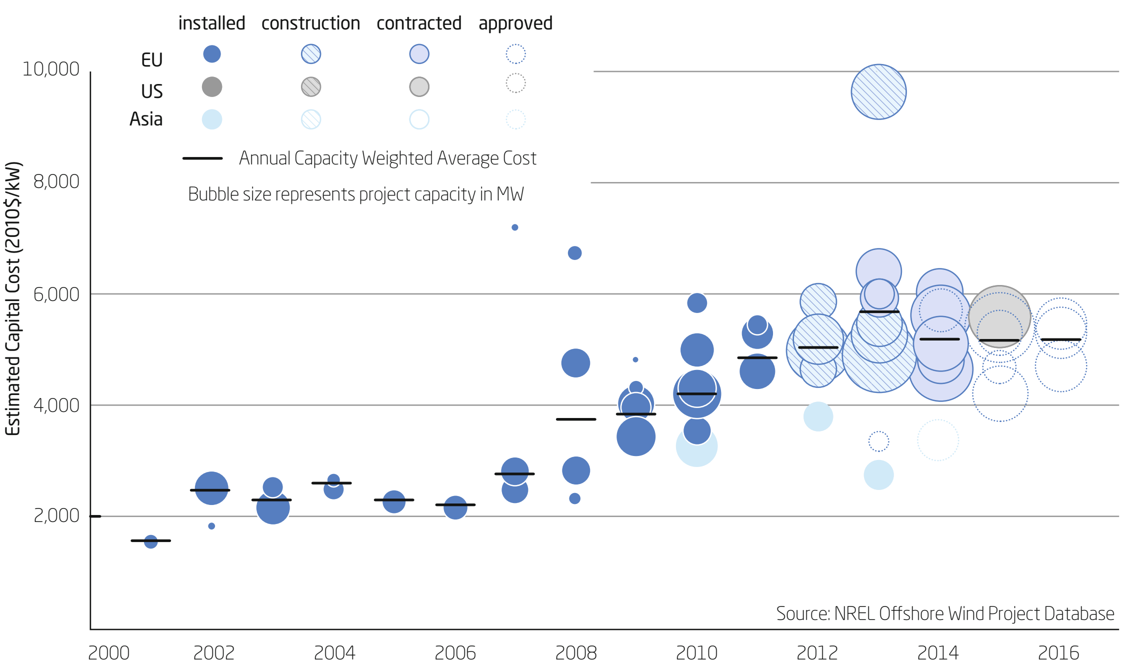
Figure 33 – Total investment cost.



Total investment cost, including turbine, foundation, grid connection etc., for selected projects in Denmark (**left**) and the US (**right**).

Source: Danmarks Vindmølleforening (2014) and Wiser *et al.* (2012b). Updated to 2013 prices.

Figure 34 – Reported capital costs for offshore wind projects (2000–2016).



Source: Tegen *et al.*, 2013

and US offshore projects emerged, while costs increased considerably around this year. They depend heavily on water depth and distance to shore, which is why a progress towards cost reductions cannot be observed yet. After a fairly small number of small offshore projects close to the coast, the larger projects being built from 2010 onwards are located in deeper waters are require longer cables to shore. More specifically, the Danish Energy Agency and Energinet.dk (2012) estimate that foundation costs rise by 0.3 Mill. Euro/MW for every 10 meters of additional water depth. At distances beyond typically 50 km from shore, the connection is done by an HVDC system instead of AC systems for technical reason. The required installations lead to considerably higher costs. For these reasons, general conclusions about cost components of offshore wind projects are to be handled with care. The mentioned factors should be remembered when looking at average prices.

Cost of energy

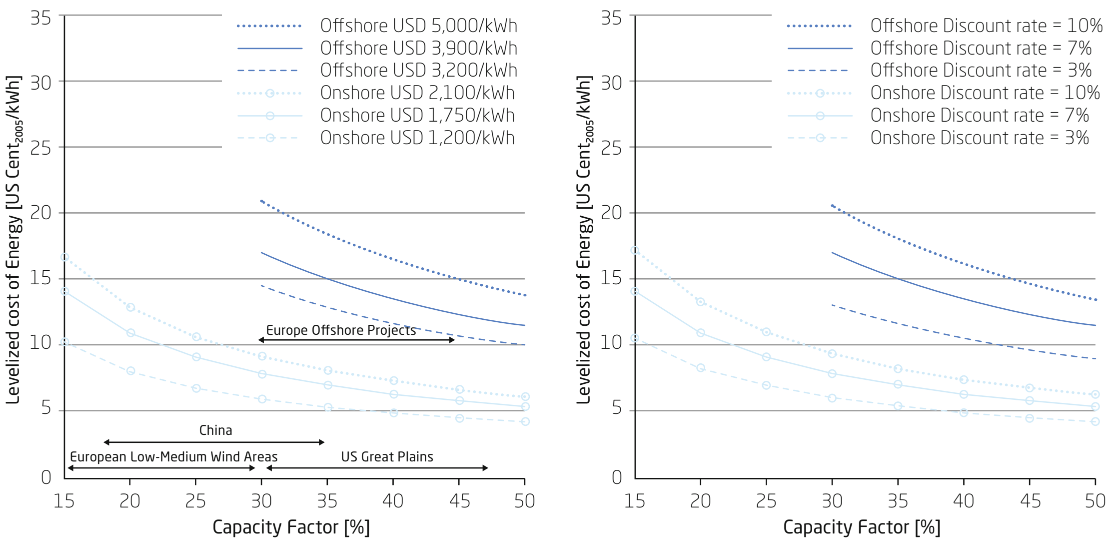
The turbine's power production is the single most important factor in the unit cost of power. *Figure 35* shows the calculated cost per kWh as a function of the prevailing wind regime.[10] These costs range considerably depending on the capacity factor and thus how windy the chosen site is.

For a standard onshore installation with an investment cost of $1,750 /kW (€1,330/kW) the cost ranges from approximately 7–9 US cent/kWh at sites with medium average wind speeds to approximately 6–7 US cent/kWh at good coastal positions. In Europe, good coastal sites are mostly to be found on the coasts of the UK, Ireland, France, Denmark and Norway. Medium wind areas are mostly located inland in central and southern Europe – Germany, the Netherlands, France, Spain and Italy – but also in the north, in inlands parts of Sweden, Finland and Denmark. In many cases local conditions significantly influence the average wind speed at a specific site, so big differences in the wind regime are to be expected even for neighbouring areas.

As *Figure 35* shows, energy from offshore turbines is considerably more expensive than that from onshore turbines. At a high-wind offshore position

10. The figure uses the capacity factor to represent the wind regime. The capacity factor is defined as the number of full load hours per year divided by the total number of hours per year (8760). Full load hours are calculated as the turbine's average annual production divided by its rated power. The higher the capacity factor (and hence the number of full load hours), the higher the wind turbine's production at the chosen site.

Figure 35



How the estimated levelized cost of onshore and offshore wind energy varies with capacity factor for different project costs (**left**) and discount rates (**right**) (Wiser *et al.*, 2012a).

with a capacity factor of 50%, corresponding to wind conditions at the Danish Horns Reef 1 wind farm, the calculated cost of electricity is close to 12 US cent /kWh for a standard offshore installation with an investment cost of $3,900/kW (€3,000/kW).

Wind and the power market

Grid-connected wind turbines in general sell their power to the market. As wind resources are inexhaustible and free, the marginal production cost of power from a wind turbine is close to zero. On the other hand, the availability of wind resources is strongly contingent on short-term weather conditions. Consequently, any attempt to plan the operation of an electric energy system containing wind farms must cope with the variable and uncertain nature of wind power production.

The effect of wind power production on spot prices can largely be attributed to the so-called merit-order effect: since its marginal cost is virtually zero, wind power production enters the aggregated supply curve in the spot market from the left-hand side, pushing the spot price down. In fact, in spot markets with a high penetration of wind power, zero or even negative prices are no longer uncommon. In parallel, the variability of wind power production naturally increases price volatility. Furthermore, this direct cause-and-effect relationship is exacerbated by the fact that accommodating the fluctuating wind commits the system to extra operational costs, as conventional power plants operate at part load for more of the time and are subject to more cycling and start-ups.

Since wind power production cannot be perfectly predicted in advance, backup power resources are required to cover wind power forecasting errors at short notice. The operating costs associated with these backup resources are referred to as regulation costs. It is generally expected that as the penetration of wind in a power system increases, so do the regulation costs. These costs are passed on to the wind power producers through the balancing market. It is therefore critical for the integration of wind power to keep regulation costs bounded and low.

Employment and wind power

The wind power industry is an important driver in the creation of new jobs. In the EU as a whole, and in most of its member states, an expanding wind industry is one of the promising options to cope with current high levels of unemployment. Jobs are to be found in manufacturing, installing, operating and maintaining wind turbines.

According to the International Renewable Energy Agency, the global wind industry employed 834,000 people at the end of 2013 – a rise of 11% compared to 2012. The highest growth is seen in emerging countries such as China, where 365,000 people were employed in the wind industry by the end of 2013, an increase of 37% compared to 2012.

The EU had 328,000 wind industry workers by the end of 2013, an increase of 21% compared to 2012. In the offshore wind industry Europe accounts for most global employment, with 58,000 workers; most of these are in the UK, followed by Germany. By 2013 approximately 27,000 people were employed in the wind industry in Denmark.

Employment expectations for the wind industry are large. According to the European Commission a big expansion of renewables could generate more than 3 million jobs by 2030.

Conclusions and recommendations

- Most important for the development of wind power, including competitiveness with power from conventional sources, are continuing and reliable policies with stable support frameworks and fixed long-term targets for wind capacity development.

- The share of wind power in the energy system is increasing fast. Thus it is increasingly important to pay attention to the system integration of wind power. This also needs to be reflected in the design of support mechanisms (e.g. feed-in premiums instead of tariffs) and of markets for ancillary services.

- Special attention has to be paid to offshore wind power development, where considerable cost reductions are still needed. The good news is that significant potential for savings seems to exist; analysis is required to show how this potential can best be exploited.

- In many cases tendering procedures are used for new offshore wind farms. It is important that these procedures are designed to attract a large number of bidders, increasing competition and lowering the cost of energy produced. More international coordination is also needed so that member states do not drive up the cost of new offshore wind farms.

- Other barriers, such as public acceptance, do exist for wind power. It is increasingly important that such barriers are addressed if member states want to develop strong wind power industries.