QUALITY OF WIND POWER

How does quality affect the cost of electricity generation from wind power?

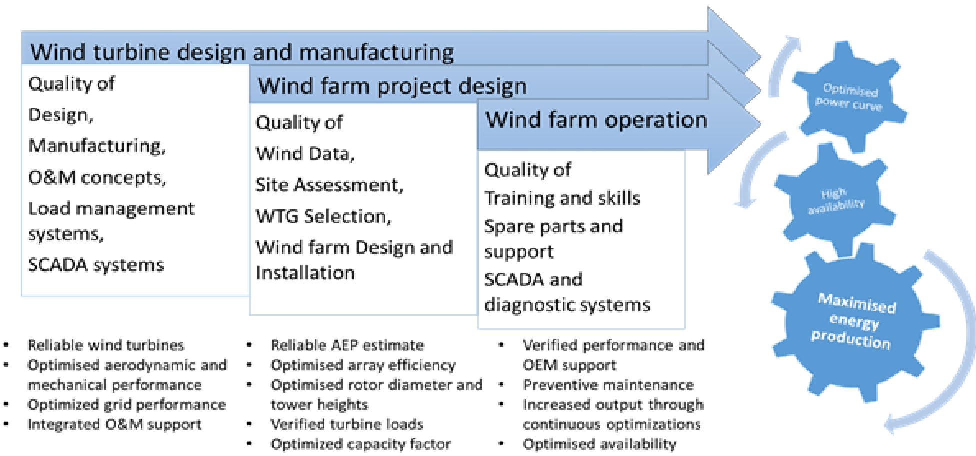
Danish Energy Agency

QUALITY OF WIND POWER

Wind power is a cornerstone in the green transition of the power sector, and onshore wind power is in many cases competitive with power production based on fossil fuels. Nevertheless, it is evident that many wind farms do not perform optimally. This paper illustrates how a consequent focus on quality can help to optimize wind farm energy production by a combination of quality in wind turbine design and manufacturing, wind farm project design, and wind farm operation. This is done by calculating the impacts on LCoE (Levelized Cost Of Energy) for a number of examples with assumptions chosen in cooperation with industry experts.

LCoE: LEVELIZED COST OF ENERGY

LCoE includes both the investment and the operational costs of an energy technology to calculate the average cost of energy during the lifetime. It also includes external costs such as emissions, system integration costs, etc. LCoE is often used as a simple way to compare different generation technologies' socio economic energy production costs. The Danish Energy Agency has prepared an international LCoE-calculator that can be freely downloaded and used. The tool allows the user to adapt all input data to a local or national context.



ABBREVIATIONS

O&M: Operation and Maintenance, i.e. the necessary works to keep the wind farm in operation, including daily supervision, planned and unplanned maintenance, repairs, administration, etc.

WTG: Wind Turbine Generator, i.e. the individual wind turbine units, which together with foundations, cables, etc. forms a wind farm.

OEM: Original Equipment Manufacturer, i.e. the company that originally manufactured the wind turbine or its components.

AEP: Annual Energy Production, i.e. the expected energy production of the wind turbine/wind farm in a year with normal wind conditions.

SCADA: Supervisory Control and Data Acquisition, i.e. the systems used to monitor and control the wind turbines and the wind farm, and to collect information about the operation statistics.

PC: Power curve, i.e. the relation between wind speed in the turbines´ hub height (in m/s) and the power output (in kW).

CFD : Computational Fluid Dynamics, i.e. numerical methods used to simulate the flow over a modelled surface by computer calculations, for example to determine wind speed and turbulences at each planned turbine position in a wind farm. Especially important in mountain areas.

QUALITY IN WIND TURBINE DESIGN AND MANUFACTURING

Wind turbines and their components are exposed to high dynamic loading for many hours in rough climates. Quality in design is a main driver for cost effectiveness over the lifetime. Continuous technical development over decades has led to more efficient, reliable, and yet lighter turbines. Among the key quality issues in design are:

• Optimization of aerodynamic and mechanical performance

Reduced loads and weight, and increased yields are obtained through the use of advanced methods for load simulations and integrated design of drive train components and control systems. For instance, turbines of a given platform can have many different optional rotor diameters and tower heights to allow for an optimal choice for various site conditions. Similarly, a higher power rating can be obtained by optimization of existing turbine platforms.

• Optimized grid performance

Optimized grid performance of wind farms by use of power electronics in combination with wind farm control systems. For instance, wind farms can provide active grid support through abilities for ´fault ride through´, active power factor regulation, and gradual ramp-out at high wind speeds. This increases the value of wind in the grids and minimizes down time.

• Solutions for improved reliability and operation and maintenance

Design for improved reliability and cost-effective operation and maintenance include use of full-scale accelerated testing, statistical fault analysis, condition monitoring (vibrations, temperatures etc.), and improved SCADA facilities. This can help to adapt the design to minimize breakdowns and facilitate preventive maintenance.

QUANTIFICATION OF QUALITY IN WIND TURBINE DESIGN AND MANUFACTURING FOR LCOE CALCULATION

The calculation assumes that the combination of turbine optimizations result in more efficient turbines that leads to 10 percent higher energy yields in average. However, a price increase of the turbines for adding more advanced options is expected to increase the overall investment costs by 10 percent.

In manufacturing, a high focus on quality control and factory testing of components and complete turbine nacelles reduces down time due to teething and component failures over the lifetime. Test run and certification of new turbine models helps to prevent teething problems and obtain a high availability.

QUALITY IN WIND FARM PROJECT DESIGN

Quality in wind farm design is obtained through experience, good planning, and application of best available methods. Among the most important issues are:

• **Site assessment and wind data**

Sufficient and high quality wind data will provide the basis for assessing the wind resource and determine the specific load basis for the site, i.e. the wind class according to IEC 61400-1. This ensures that the optimum turbines can be selected and that the turbine loads and energy production can be estimated with good accuracy.

• **Selecting the optimal wind turbines for the site**

Turbines are designed and certified to IEC Class that defines the allowable mean and extreme wind speeds and turbulence levels. For a specific site turbines shall be selected to optimize rotor diameters and tower heights relative to generator rating, and thereby maximize the energy production and capacity factor without compromising safety and lifetime. This must be seen in connection with costs of other project elements such as transport, installation and foundations. Customization by calculation of loads at individual turbine positions allows for a further optimization of rotor diameters and tower heights than a conservative selection by IEC class.

• **Optimization of the layout of turbines in the wind farm**

The wind farm layout shall be optimized to ensure the highest possible array efficiency (i.e. minimize wake losses), and at the same time ensure that none of the turbines become overloaded.

The main tools to obtain quality in wind farm design are state of the art experience and specialist knowledge in wind measurement and resource estimates, wind farm lay out, and turbine load calculations. To assist the design

QUANTIFICATION OF QUALITY IN WIND FARM PROJECT DESIGN FOR LCoE CALCULATION

The calculation assumes an improvement of array efficiency from 85 percent to 90 percent due to optimizations of site layout. Further, an average increase of the annual energy production of 5 percent is expected because of optimizing the turbines to the site.

and planning a number of advanced software solutions exist for wind analysis, dynamic load modelling, CFD models, and lay out optimization, which can help to maximize energy production and tailor the turbines to the actual sites.

QUALITY IN WIND FARM OPERATION

The competitiveness of wind power most directly depends on the performance in the operation phase. The term 'Availability' expresses the share of the total time for which the turbines are able to generate. Today, state of the art wind farms obtain availabilities above 98%, whereas others fall far below such levels due to continuous problems of both technical and organizational nature. However, even when a high availability is reached, the energy production can be further improved by prioritizing low wind periods for the planned and necessary service works. A high quality in operation and maintenance includes among other things:

- **Proven performance at taking over**

  It is vital that the individual turbines, as well as the overall wind farm control- and SCADA systems, are duly tested and free of defects when the owner takes over the wind farm. Experience shows that even minor initial faults and shortcomings can limit the performance for several years.

- **Training and skills of the service provider**

  Wind turbine technology of today is advanced and complex. The quality in operation and maintenance directly relies on the staff's theoretical and practical skills, both in terms of basic education and specialist training with wind turbines. For long-term service agreements, it is essential that service providers have full technical capabilities demonstrated by a proven record. Here counts both the ability to operate the wind farm and solve problems efficiently on a daily basis, as well as the capability to plan and carry out major operations.

- **Spare parts and OEM support**

  A well-integrated spare parts and support strategy plays a key role to keep a wind farm in operation. The lack of even smaller parts can be critical to operation. Since all parts cannot be stored on site it becomes crucial to have agreements that secure availability and short lead times of strategic main components.

- **Load management systems and PC optimization**

  In operation, continuous improvement of the wind farm energy production can be obtained by using analyses of operational records, e.g. of load- and wind data to verify and optimize the power curve for each individual turbine. At the same time load management systems ensure that lifetime is not compromised. For example, an overall PC uprating can be combined with automatic down regulation of turbines in wind directions with high turbulence loads. In addition, turbines can be allowed to operate at reduced output beyond the normal stop-wind.

- **Use of SCADA and diagnostic systems**

  Turbine faults and breakdowns often lead to consequential damage and repairs, which take time to plan and carry out, during which no energy will be generated. Best practice use of SCADA systems, including diagnostic systems based on condition monitoring and statistical methods, allows the O&M staff to prioritize and plan preventive maintenance instead of reacting on problems with stopped turbines. This can both limit the costs and increase the availability.

Further, it is evident that, besides the technical and organizational competencies, a high commitment and focus on continuous improvement by both the management and staff involved with wind farm O&M is essential.

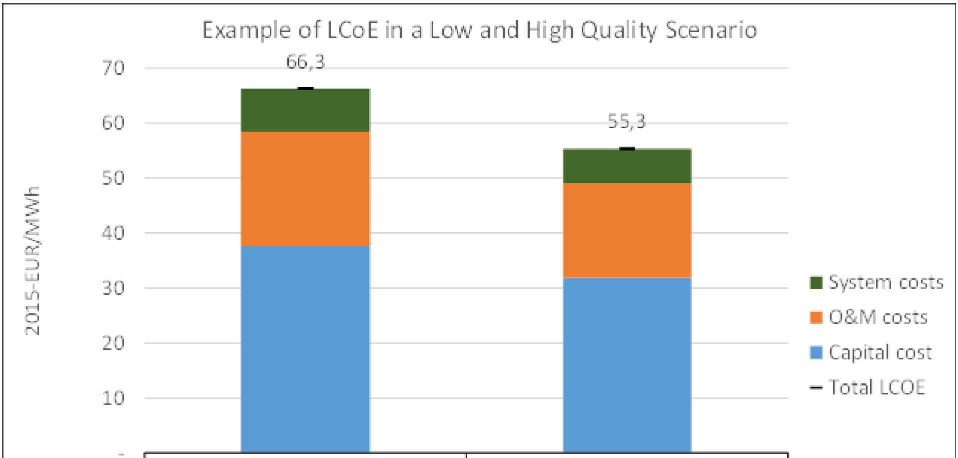
COST IMPACTS OF QUALITY OF WIND POWER

The table below summarizes the impacts of quality improvements and optimizations in each of the three stages of a wind farm project, where the starting point (base case) is a wind farm with poor, but not unrealistically low, performance, and the endpoint is a combination of optimization efforts in all stages. In this example it is found that a significant improvement of the energy yield expressed as the yearly full-load hours can be achieved.

QUANTIFICATION OF QUALITY IN WIND FARM OPERATION FOR LCOE CALCULATION

The calculation assumes that a best-in-class O&M performance combined with power curve optimisations can improve wind farm availability by 3% and improve the overall wind farm power curve by 3%. Since the energy production is higher, the total yearly O&M costs is expected to increase by 7%.

		Base case	Design optimizations	Project design optimization	O&M Performance optimization
Wind Farm Availability	%	95%	95%	95%	98%
Wind Farm Array efficiency	%	85%	85%	90%	90%
Power curve improvements	%		10%	5%	3%
AEP (Full load hours)	Hours/year	2309	2540	2823	3000
Life time	Years	20	20	20	20
Discount rate	%	4%	4%	4%	4%
Investment cost	MEuro/MW	1,25	1,37	1,37	1,37
Yearly O&M costs	Euro/MW/year	48.117	49.226	50.590	51.438
O&M costs	Euro/MWh	20,84	19,38	17,92	17,15



	Wind onshore	Quality Wind onshore
System costs	7,8	6,3
O&M costs	20,8	17,1
Capital cost	37,7	31,9
Total LCOE	66,3	55,3

In the calculated example the combined improvements due to quality in turbine design, wind farm project design, and in operation will mean a LCoE reduction of 17 percent even though more expensive turbines were assumed to increase the investment costs by 10 percent and the overall yearly O&M costs were assumed to increase by 7 percent.

However, at the same time a more expensive turbine is selected and the overall yearly O&M costs are higher.

The corresponding effects of the combined quality of wind optimizations can be calculated using the LCoE-calculator available at the Danish Energy Agency's website www.ens.dk, and the result appear in the graphic on the next page:

The graphic shows how the improved performance of the wind turbines decreases the LCoE considerably in the Quality Wind scenario, even though the Investment and the O&M costs are higher in absolute terms.

The LCoE calculator also values the system properties of the quality wind turbines. Wind power has a reduced value in the energy system due to its fluctuations and unpredictable nature. These system costs will vary depending on the actual power system and the share of wind energy. However, with more full-load hours and thereby higher capcity factor, the system integration costs will decrease, so wind power has more value. Based on Danish model studies, an increase of full load hours as shown in the example would reduce the integration costs from 5.8 EUR/MWh to 4.3 EUR/MWh. Further system costs are the balancing costs estimated to 2 EUR/MWh.

The content of this document is prepared by EA Energianalyse in cooperation with industry experts. The Danish Energy Agency is not responsible for any content or assumptions presented in this document.

The Danish Energy Agency's Centre for Global Cooperation supports emerging economies to combine sustainable future energy supplies with economic growth. The initiative is based on four decades of Danish experience with renewable energy and energy efficiency, transforming the energy sectors to deploy increasingly more low-carbon technologies.

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www.ens.dk/global-cooperation

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