Wind Energy Project Analysis

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Velimir Lackovic, Char. Eng.

Continuing Education and Development, Inc.
9 Greyridge Farm Court
Stony Point, NY 10980

P: (877) 322-5800
F: (877) 322-4774

info@cedengineering.com

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Wind Energy Background

The mechanical energy within the wind could be a promising supply of renewable energy. Its potential is significant worldwide. The energy that may be captured by wind turbines is extremely dependent on the native average wind speed. Regions that usually present the foremost enticing potential are situated close to coasts, upcountry areas with open tract or on the sting of bodies of water. Some mountainous areas even have sensible potential. In spite of those geographical limitations for wind energy project siting, there's ample tract in most areas of the world to supply a major portion of the native electricity needs with wind energy projects.

Wind farms that use multiple turbines are being created within the multi-megawatt range. Over the last decade, typical individual turbine sizes have raised from around one hundred kilowatt to one MW or more of electricity generation capability, with several wind energy projects currently being developed offshore. The results of all this progress is that, in some areas of the globe, large-scale wind energy projects currently generate electricity at prices competitive with typical power plants (e.g. nuclear, oil and coal).

In addition to those larger scale applications, there are variety of alternative applications for wind turbines, like medium scale applications on isolated-grids and off-grid uses for pumping water and providing smaller amounts of electricity for complete battery charging applications. Wind energy projects are typically more financially viable in "windy" areas. This is often attributable to the actual fact that the facility potential within the wind is related to the cube of the wind speed. However, the power production performance of a sensible turbine is usually more proportional to the sq. of the typical wind speed.

The distinction is accounted for by the mechanics, mechanical and electrical conversion characteristics and efficiencies of the wind turbines. This implies that the energy that may be created by a turbine will increase by about 20% for every 100% increase in wind speed. Wind energy project siting is essential to a financially viable venture. It's vital to notice that since the human sensory perception of the wind is sometimes supported by short-run observations of climatical extremes like wind storms and wind chill impressions, either of those “wind speeds” can be incorrectly taken as representative of a windy site. Correct wind resource assessment could be a customary and necessary part for many wind energy project developments.

Description of Wind Turbines

Wind turbine technology has reached a mature standing throughout the past 15 years as a result of international industrial competition, production and continued technical success in analysis and development. Wind energy project prices have declined and turbine technical availableness is currently systematically higher than 97%. Wind energy project plant capability factors have conjointly improved from 15% to over 30%, for sites with a decent wind regime.

Modern wind energy systems operate automatically. The wind turbines rely upon the same aerodynamic forces created by the wings of a plane to cause rotation. An anemometer that continually measures wind speed is a component of most turbine management systems. Once the wind speed is high enough to beat friction within the turbine drivetrain, the controls permit the rotor to rotate, therefore manufacturing a really bit of power. This cut-in wind speed is sometimes a mild breeze of about 4 m/s. Power output will increase quickly because the wind speed rises. Once output reaches the utmost power the machinery was designed for, the turbine controls govern the output to the rated power. The wind speed at which rated power is reached is named the rated wind speed of the turbine, and is typically a powerful wind of about 15 m/s. Eventually, if the wind speed will increase more, the system shuts the turbine right down to stop harm to the machinery. This cut-out wind speed is sometimes around 25 m/s.

The major parts of recent wind energy systems usually contain the following:

- Rotor, with a pair of or three blades, that converts the energy within the wind into energy onto the rotor shaft;

- Gearbox to match the slowly turning rotor head to the electrical generator;

- Tall tower that supports the rotor higher to capture the upper wind speeds;

- Solid foundation to stop the turbine from processing over in high winds and/or icing conditions

- Control system to begin and stop the turbine and to watch correct operation of the machinery.

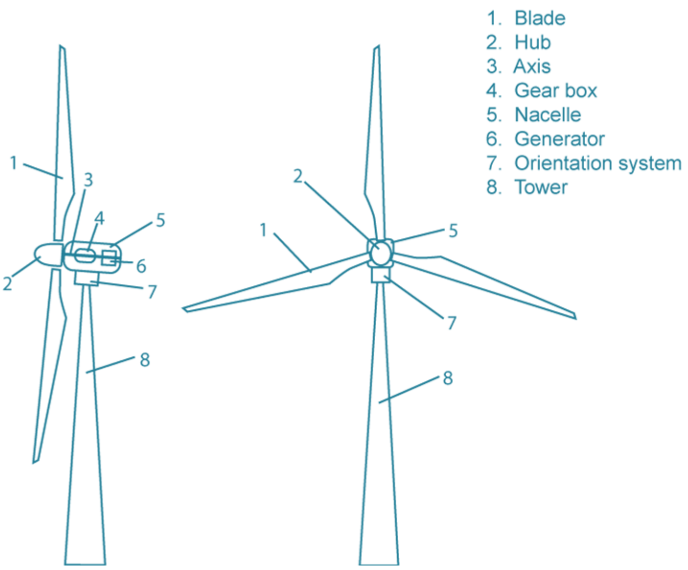

Figure 1. Wind Energy System Schematic illustrates the configuration of a typical "Horizontal Axis Wind Turbine" or HAWT wind energy system

Wind Energy Application Markets

Wind energy market is supported on the end-use application of the technology. Wind energy projects are common for off-grid applications. However, the biggest market potential for wind energy projects is with on-grid (or grid-connected) applications.

Off-grid applications

Historically, wind energy was best in remote sites, far away from the electrical grid and requiring comparatively tiny amounts of power, generally less than 10 kilowatt. In these off-grid applications, wind energy is often utilized in the charging of batteries that store the energy captured by the wind turbines and provides the user with power on demand. Water pumping where water (instead of energy) is stored for future use, is a typical historical application of wind energy. The key competitive space for wind energy in remote off-grid power applications is against electrical grid extension, primary (disposable) batteries, diesel, gas and thermoelectrical generators. Wind energy is additionally competitive in water pumping applications.

On-grid applications

In on-grid applications the wind energy system feeds power directly into the electrical utility grid. Two on-grid application varieties are distinguished:

- Isolated-grid electricity generation, with turbine generation capability generally starting from some 10 kilowatt to 200 kilowatt.

- Central-grid electricity generation, with turbine generation capability usually starting from some 200 kilowatt to 2 MW.

Isolated-grids

Isolated-grids are common in remote areas. Electricity generation is commonly comparatively costly as a result of the high value of transporting fuel to those isolated sites. However, if the location has smart native winds, a tiny low wind energy project may be put in to assist supply a portion of the electricity necessities. These wind energy projects are commonly remarked as wind-diesel hybrid systems. The wind energy system's primary role is to assist cut back the quantity of fuel consumption. A wind-diesel hybrid system is shown in Figure 2.

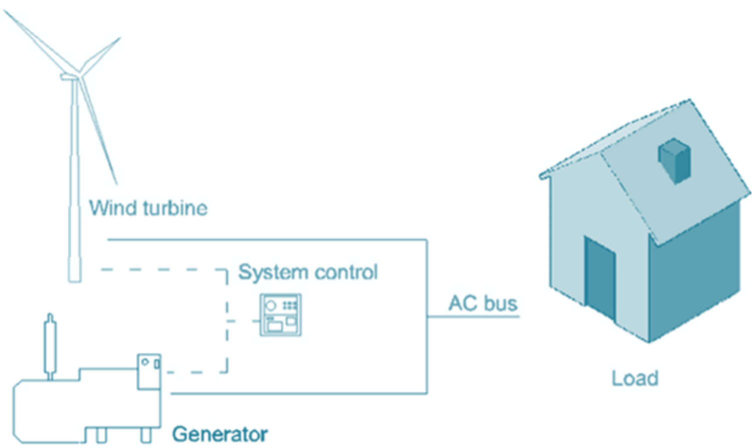

Figure 2. Wind-diesel hybrid system

Central-grids

Central-grid applications for wind energy projects have become more common. In comparatively windy areas, larger scale wind turbines are clustered along to form a wind park with capacities within the multi-megawatt range. The land inside the wind park is sometimes used for different functions, like agriculture or forestry. Another common approach for wind energy project development includes the installation of one or larger scale wind turbines by people, businesses or co-operatives.

A wind park consists of variety of wind turbines (which are usually put in in rows perpendicular to the wind direction), access roads, electrical interconnections and a substation, an observation system and a maintenance building for the larger farms. The development of a wind energy project includes the determination of the wind resource, the acquisition of all authorisations and permits, the planning and specification of the civil, electrical and mechanical infrastructure, the layout of the wind turbines, the getting of the instrumentation, the development and the empowerment of the installation. Construction involves preparing the site, grading the roads, building rotary engine foundations, putting in the electrical assortment lines and transformers, building the turbines and construction of the substation and building.

The wind resource assessment and approvals for a wind park are usually the longest activities within the development of the wind energy project. These will take up to four years within the case of a large wind park requiring a comprehensive environmental impact study. The development itself will commonly be completed inside one year. The precise determination of the wind resource at a given site is one of the foremost necessary aspects within the development of a wind energy project, because the obtainable wind resource at the project site will dramatically impact the price of wind energy production.

In the case where a pre-feasibility study indicates that a projected wind energy project can be financially viable, it's usually suggested that a project developer takes a minimum of a full year of wind measurements at the precise location where the wind energy project is proposed to be installed. For very small-scale projects (e.g. off-grid battery charging and water pumping), the price of wind observance may really be more than the price to obtain and install a little turbine. In this case, an in depth wind resource assessment would usually not be completed.

Wind Energy Project Model

A Wind Energy Project Model is employed to simply measure the energy production, life-cycle prices and greenhouse gas emissions reduction for central-grid, isolated-grid and off-grid wind energy projects, ranging in size from massive scale multi-turbine wind farms to little scale single-turbine wind-diesel hybrid systems. This section describes the assorted algorithms used to calculate, on an annual basis, the energy production of wind energy systems. A flow diagram of the algorithms is shown in Figure 3.

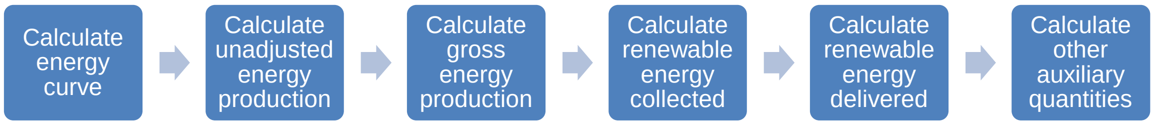

Figure 3. Wind energy model

Unadjusted Energy Production

The unadjusted energy production is the energy that one or additional wind turbines can turn out at normal conditions of temperature and air pressure. The calculation relies on the energy production curve of the chosen turbine and on the common wind speed at hub height for the projected site.

Wind speed distribution

Wind speed distribution, once needed for modelling, is calculated as a Weibull probability density function. This distribution is commonly utilized in wind energy engineering, because it conforms well to the determined long-run distribution of mean wind speeds for a variety of sites. In some cases the model additionally uses the Rayleigh wind speed distribution that may be a special case of the Weibull distribution, where the form factor is equal to 2.

The Weibull probability density function expresses the probability $p(x)$ to have a wind speed x during the year, as follows:

$$p(x) = \left(\frac{k}{C}\right)\left(\frac{x}{C}\right)^{k-1} exp\left[-\left(\frac{x}{C}\right)^{k}\right] \quad (1)$$

This expression is valid for k >1, x ≥ 0, and C > 0. k is the form factor, specified by the user. The form factor can generally vary from 1 to 3. For a given average wind speed, a lower form factor indicates a comparatively wide distribution of wind speeds around the average whereas a better form factor indicates a comparatively narrow distribution of wind speeds around the average. A lower shape factor can usually lead to a better energy production for a given average wind speed. C is the multiplier factor that is calculated from the subsequent equation:

$$C = \frac{\bar{x}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (2)$$

where $\bar{x}$ is the average wind speed value and Γ is the gamma function.

In some cases, the model can calculate the wind speed distribution from the wind generation density at the location instead from the wind speed. The relations between the wind generation density WPD and the average wind speed $\bar{v}$ are:

$$WPD = \sum_{x=0}^{x=25} 0.5\rho x^3 p(x) \quad (3)$$

$$\bar{v} = \sum_{x=0}^{x=25} x\, p(x) \quad (4)$$

where ρ is the air density and $p(x)$ is the probability to have a wind speed x during the year

Energy curve

The energy curve information is the total quantity of energy a turbine delivers over a range of annual average wind speeds. Energy curve is specific over the range of 3 to 15 m/s annual average wind speed.

Each point on the energy curve, $E_{\bar{v}}$, is calculated as:

$$E_{\bar{v}} = 8760 \sum_{x=0}^{25} P_x\, p(x) \quad (5)$$

where $\bar{v}$ is the mean wind speed considered ($\bar{v}$ =3, 4, …, 15 m/s), P_x is the turbine power at wind speed, and $p(x)$ is the Weibull probability density function for wind speed x, calculated for an average wind speed $\bar{v}$.

Unadjusted energy production

The unadjusted energy production is the energy delivered by the turbines at standard conditions of temperature and atmospheric pressure. The calculation is founded on the average wind speed at hub height for the site. Wind speed at hub height is usually higher than the wind speed measured at anemometer height due to wind shear.

The model uses the power law equation to calculate the average wind speed at hub height:

$$\frac{\bar{V}}{\bar{V_0}} = \left(\frac{H}{H_0}\right)^{\alpha} \quad (6)$$

where $\bar{V}$ is the average wind speed at hub height H, $\bar{V_0}$ is the wind speed at anemometer height H_0, and α is the wind shear exponent. Values of H, H_0, $\bar{V_0}$ and α are specified by the user.

Once the annual average wind speed at hub height $\bar{V}$ is calculated, the unadjusted energy production E_U is calculated simply by interpolating the energy curve from at the value $\bar{V}$.

Gross Energy Production

Gross energy production is the total annual energy produced by the wind energy equipment, before any losses, at the wind speed, atmospheric pressure and temperature conditions at the site. It is used to calculate the renewable energy delivered. Gross energy production E_G is calculated through:

$$E_G = E_U c_H c_T \quad (7)$$

where E_U is the unadjusted energy production, and c_H and c_T are the pressure and temperature adjustment coefficients. c_H and c_T are given by:

$$c_H = \frac{P}{P_0} \quad (8)$$

$$c_T = \frac{T_0}{T} \quad (9)$$

where P is the annual average atmospheric pressure at the site, P_0 is the standard atmospheric pressure of 101.3 kPa, T is the annual average absolute temperature at the site, and T_0 is the standard absolute temperature of 288.1 K.

Renewable Energy Delivered

Wind energy project model involves calculation of renewable energy delivered to the electricity grid, considering various losses. In the case of isolated-grid and off-grid applications, the amount of wind energy that can be used by the grid or the load is also considered.

Renewable energy collected

Renewable energy collected is equal to the net amount of energy produced by the wind energy equipment:

$$E_C = E_G c_L \quad (10)$$

where E_G is the gross energy production, and c_L is the losses coefficient, given by:

$$c_L = (1 - \lambda_a)(1 - \lambda_{s\&i})(1 - \lambda_d)(1 - \lambda_m) \quad (11)$$

where λ_a is the array losses, $\lambda_{s\&i}$ is the airfoil soiling and icing losses, λ_d is the downtime losses, and λ_m is the miscellaneous losses. Coefficients λ_a, $\lambda_{s\&i}$, λ_d , and λ_m are specified by the user.

Absorption rate and renewable energy delivered

The wind energy project model determines the wind energy delivered E_D according to:

$$E_D = E_C \mu \quad (12)$$

where E_C is the renewable energy collected and μ is the wind energy absorption rate.

The wind energy absorption rate is the percentage of the wind energy collected that can be used by the isolated-grid or the off-grid system. For central-grid applications, this rate is always equal to 100% since it is assumed that the grid is can absorb all the produced energy by the wind energy project. For isolated-grid and off-grid applications, the user defines the value of the absorption rate.

For isolated-grid and off-grid applications, the model calculates a suggested wind energy absorption rate. It is found by interpolation in Table 1, where the Wind Penetration Level (WPL) is defined as:

$$WPL = \frac{WPC}{PL}\,100 \qquad (13)$$

where WPC is the wind plant capacity and PL is the peak load defined by the user. WPC is determined by multiplying the number of wind turbines by their rated, or nameplate, capacity (power).

Average Wind Speed (m/s)	Wind Penetration Level (WPL)			
	0%	10%	20%	30%
0	100%	100%	100%	100%
4.9	100%	98%	96%	93%
5.6	100%	98%	94%	90%
6.3	100%	98%	93%	87%
6.9	100%	97%	92%	84%
8.3	100%	96%	90%	82%

Table 1. Suggested Wind Energy Absorption Rate for Isolated-Grid and Off-Grid Applications

As illustrated in Table 1, the suggested wind energy absorption rate varies according to the average wind speed and the wind penetration level. It is based on the wind speed at the wind turbine hub height. Table 1 values are derived from simulations conducted to establish the amount of wind energy delivered from wind farms installed in remote communities (i.e. isolated-grid and off-grid applications). The simulations considered combinations of wind regime, load profiles and equipment performance curves.

The model only provides suggested values for wind penetration levels less than 25%. However, if the wind penetration level is greater than 3% and the wind speed at hub height is 8.3 m/s or higher, then the model does not provide suggested values. Under these circumstances, the wind energy absorption rates will vary widely depending on the configuration of the system and on the control strategies adopted.

Excess renewable energy available

Excess renewable energy available E_x is the difference between the wind energy collected E_C and the wind energy delivered E_D:

$$E_x = E_c - E_D \tag{14}$$

Specific yield

The specific yield Y is calculated by dividing the renewable energy collected E_C by the swept area of the turbines:

$$Y = \frac{E_C}{N\,A} \tag{15}$$

where N is the number of turbines and A is the area swept by the rotor of a single wind turbine.

Wind plant capacity factor

The wind plant capacity factor PCF can be defined as the ratio of the average power produced by the plant over a year to its rated power capacity. It is calculated as follows:

$$PCF = \left(\frac{E_C}{WPC\,h_y}\right) 100 \tag{16}$$

where E_C is the renewable energy collected, expressed in kWh, WPC is the wind plant capacity, expressed in kW, and h_y is the number of hours in a year.

Different measures of cost and data limitations

Costs may be measured during a variety of various ways, and every method of accounting for the cost of power generation brings its own insights. The prices which will be examined embrace equipment prices (e.g. wind turbines, etc.), funding prices, total installation charges, fastened and variable operational and maintenance cost (O&M), fuel expenses, and also the levelised cost of energy (LCOE).

The analysis of costs is elaborate, but for comparison purposes and transparency, the approach used here could be a simplified version. This enables more scrutiny of the underlying information and assumptions, thereby enhancing transparency and the confidence within the analysis, and facilitating the comparison of prices so as to spot what are the key drivers in any variations.

The three (3) indicators selected are as follows:

- Equipment prices (factory gate FOB and delivered at site CIF);

- Total installation charges, together with fastened funding prices; and

- Levelised cost of electricity (LCOE).

The analysis in this chapter focuses on estimating the price of wind energy from the perspective of a non-public capitalist, whether or not they are a state-owned electricity generation utility, an independent power producer, or a private or community trying to invest in little scale renewables (Figure 4). The analysis could be a pure cost analysis, not a financial one, and excludes the impact of government incentives or subsidies, taxation, system equalization prices related to variable renewables, and any system-wide value savings from the advantage order. Similarly, the analysis doesn't take under consideration of any CO_2 rating, nor the advantages of renewables in reducing other externalities (e.g. reduced native air pollution, contamination of natural environments, etc.).

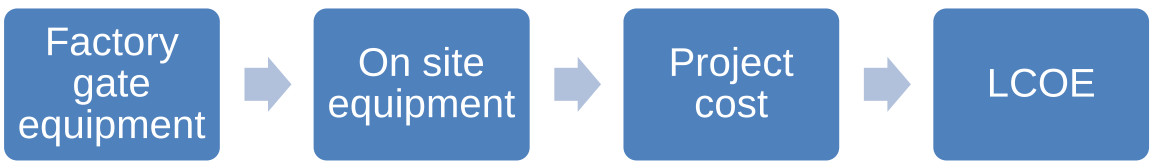

Figure 4. Wind power generation cost indicators and boundaries

Levelised Cost of Electricity Generation

The LCOE is the price of electricity required for a project where revenues would equal costs, including making a return on the capital invested equal to the discount rate. An electricity price above this would yield a greater return on capital, while a price below it would yield a lower return on capital, or even a loss.

The LCOE of renewable energy technologies varies by technology, country and project, based on the renewable energy resource, capital and operating costs, and the efficiency/performance of the technology. The approach used in the analysis presented here is based on a simple discounted cash flow (DCF) analysis. This method of calculating the cost of renewable energy technologies is based on discounting financial flows (annual, quarterly or monthly) to a common basis, taking into consideration the time value of money. Given the capital intensive nature of most renewable power generation technologies and the fact that fuel costs are low, or often zero, the weighted average cost of capital (WACC), also referred to as the discount rate in this report, used to evaluate the project has a critical impact on the LCOE.

There are many potential trade-offs to be considered when developing an LCOE modelling approach. More detailed LCOE analysis may result in more "accurate" absolute values, but also results in a significantly higher overhead in terms of the granularity of assumptions required and risks reducing transparency. More detailed methodologies can often give the impression of greater accuracy, but when it is not possible to robustly populate the model with assumptions, or to differentiate assumptions based on real world data, then the supposed "accuracy" of the approach can be misleading.

The formula used for calculating the LCOE of renewable energy technologies is:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (17)$$

where:

LCOE = the average lifetime levelised cost of electricity generation

I_t = investment expenditures in the year t

M_t = operations and maintenance expenditures in the year t

F_t = fuel expenditures in the year t

E_t = electricity generation in the year t

r = discount rate

n = economic life of the system.

As already mentioned, although different cost measures are useful in different situations, the LCOE of renewable energy technologies is a widely used measure by which renewable energy technologies can be evaluated for modelling or policy development. Similarly, more detailed DCF approaches, taking into account taxation, subsidies and other incentives, are used by renewable energy project developers to assess the profitability of real world projects.

A breakdown of the installed capital cost for wind

The installed cost of a wind power project is dominated by the upfront capital cost (often referred to as CAPEX) for the wind turbines (including towers and installation), and this can be as much as 84% of the total installed cost. Similarly to other renewable technologies, the high upfront costs of wind power can be a barrier to their uptake, despite the fact there is no fuel price risk once the wind farm is built. The capital costs of a wind power project can be broken down into the following major categories:

- The turbine cost: including blades, tower and transformer

- Civil works: including construction costs for site preparation and the foundations for the towers

- Grid connection costs: This can include transformers and substations, as well as the connection to the local distribution or transmission network

- Other capital costs: these can include the construction of buildings, control systems, project consultancy costs, etc.

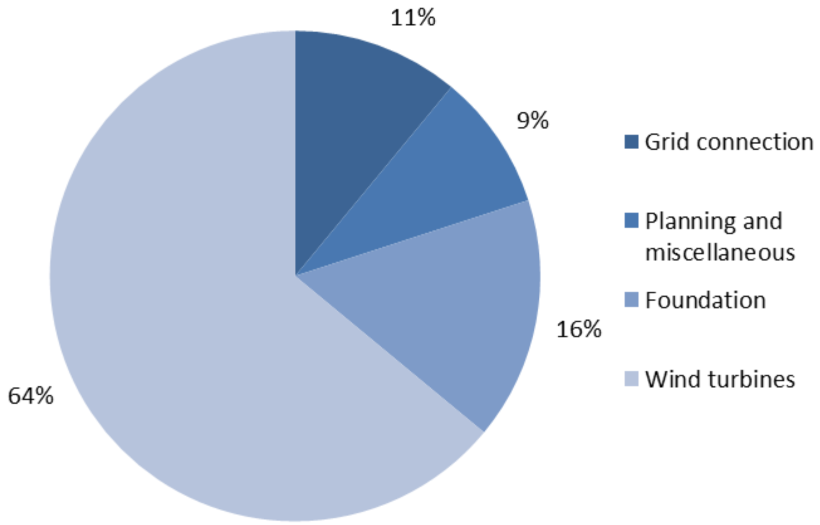

Figure 5. Capital cost breakdown for a typical onshore wind power system and turbine

For the turbine, the largest costs components are the rotor blades, the tower and the gearbox. Together, these three items account for around 50% to 60% of the turbine cost. The generator, transformer and power converter account for about 13% of the turbine costs, with the balance of "other" costs being made up of miscellaneous costs associated with the tower, such as the rotor hub, cabling and rotor shaft. Overall, the turbine accounts for 64% to as much as 84% of the total installation costs, with the grid connection, civil works and other costs accounting for the rest.

The reality is that the share of different cost components varies by country and project, depending on turbine costs, site requirements, competitiveness of the local wind industry, and the cost structure of the country where the project is being developed.

Wind Turbine Costs

The wind turbine is the largest single cost component of the total installation cost of a wind farm. Wind turbine prices increased steadily in recent years, but appear to have peaked in 2009. Between 2000 and 2002 turbine prices averaged USD 700/kW, but this had risen to USD 1500/kW in the United States and USD 1800/kW in Europe in

2009. Since the peak of USD 1800/kW for contracts with a 2009 delivery, wind turbine prices in Europe have declined by 18% for contracts with delivery scheduled in the first half of 2010. Global turbine contracts for delivery in the second half of 2010 and the first half of 2011 have averaged USD 1470/kW, down by 15% from peak values of USD 1730/kW.

The wind turbine prices quoted for recent transactions in developed countries are in the range of USD 1100 to USD 1400/kW. The recent decline in wind turbine prices reflects increased competition among wind turbine manufacturers, as well as lower commodity prices for steel, copper and cement.

Data for the United States market has followed a similar trend. Average wind turbine prices more than doubled from a low of around USD 700/kW between 2000 and 2002 to USD 1500/kW in 2008 and 2009. In the United States market, this increase in wind turbine prices accounted for 95% of the increase in total installed wind costs over the same period.

Analysis of different markets suggests that there is quite a wide variation in wind turbine prices, depending on the cost structure of the local market. China appears to have the lowest prices, with a turbine price of just USD 644/kW in 2010.

Grid Connection Costs

Wind farms can be connected to electricity grids via the transmission network or distribution network. In the former case, transformers will be required to step-up to higher voltages than if the wind farm is feeding into the distribution network. This will tend to increase costs. If the grid connection point is not far from the wind farm, the connection is typically a high voltage alternating current (HVAC) connection. Over longer distances it may make sense to use a high voltage direct current (HVDC) link, as the reduced losses over this link will more than offset the losses in converting to direct current and back again to alternating current. It has been estimated that HVDC connections will be attractive for distances over 50 km in the future.

Grid connection costs can also vary significantly by country depending on who bears what costs for grid connection cost. For example, in some regimes, it is the transmission system operator that bears the cost of any transmission system upgrade required by the connection of a wind farm; in other regimes, the wind farm owner will be required to pay for these costs.

Grid connection costs (including the electrical work, electricity lines and the connection point) are typically 11% to 14% of the total capital cost of onshore wind farms and 15% to 30% of offshore wind farms.

Civil Works and Construction Costs

The construction costs include transportation and installation of wind turbine and tower, the construction of the wind turbine foundation (tower), and the construction of access roads and other related infrastructure required for the wind farm. The main foundation type for onshore wind farms are a poured concrete foundation, while for offshore it is currently driven/drilled steel monopiles. However, other types of foundations are possible (e.g. suction, caisson, guyed towers, floating foundations and self-installing concepts using telescopic towers) and will be required for offshore developments in deep water. Foundations are material-intensive, with 45% to 50% of the cost of monopile foundations being attributable to the steel required.

Cost reductions for foundations can be made through economies of scale, reduced material consumption and reduced material cost.

The increase in the average size of wind turbines has increased the absolute cost per wind turbine, but transport and installation costs have not grown proportionately to turbine size, thereby reducing the relative importance of these costs in onshore wind farms. Offshore, these costs are much higher than onshore and a shortage of purpose-built vessels and cranes means that these costs are unlikely to decline rapidly in the near future until this constraint eases. Therefore, the construction of vessels and cranes specifically designed to install wind turbines offers an opportunity to reduce installation time and costs.

Operations and Maintenance Costs

The fixed and variable operations and maintenance (O&M) costs are a significant part of the overall LCOE of wind power. O&M costs typically account for 20% to 25% of the total LCOE of current wind power systems.

Actual O&M costs from commissioned projects are not widely available. Even where data are available, care must be taken in extrapolating historical O&M costs given the dramatic changes in wind turbine technology that have occurred over the last two decades. However, it is clear that annual average O&M costs of wind power systems have declined substantially since 1980. In the United States, data for completed projects suggest that total O&M costs (fixed and variable) have declined from around USD 33/MWh for 24 projects that were completed in the 1980s to USD 22/MWh for 27 projects installed in the 1990s and to USD 10/MWh for the 65 projects installed in the 2000s.

The data are widely distributed, suggesting that O&M costs, or at least their reporting, are far from uniform across projects. However, since the year 2000 O&M costs appear to be lower and to be more uniform across projects than was the case prior to 2000. This decline in O&M costs may be due to the fact more recent projects use larger, more sophisticated turbines and have higher capacity factors (reducing the fixed O&M costs per unit of energy produced).

Another important consideration for wind energy is the fact that O&M costs are not evenly distributed over time. They tend to increase as the length of time from commissioning increases. This is due to an increasing probability of component failures and that when a failure does occur it will tend to be outside the manufacturer's warranty period. Although the data to support this hypothesis are not widely available, data for a limited number of projects in the United States suggest that this could be correct.

Unfortunately, not all sources separate out fixed and variable O&M costs, and it is not uncommon for O&M costs to be quoted as a total of USD/kW/year. Fixed O&M costs typically include insurance, administration, fixed grid access fees and service contracts for scheduled maintenance. Variable O&M costs typically include scheduled and unscheduled maintenance not covered by fixed contracts, as well as replacement parts and materials, and other labor costs. Maintenance measures may be small and frequent (replacement of small parts, periodic verification procedures, etc.), or large and infrequent (unscheduled repair of significant damage or the replacement of principal components).

O&M costs appear to be the lowest in the United States at around USD 0.01/kWh (USD 10/MWh), perhaps due to the scale of the market and the long experience with wind power. European countries tend to have higher cost structures for O&M for onshore wind projects.

O&M costs for offshore wind farms are significantly higher than for onshore wind farms due to the higher costs involved in accessing and conducting maintenance on the wind turbines, cabling and towers. Maintenance costs are also higher as a result of the harsh marine environment and the higher expected failure rate for some components. Overall, O&M costs are expected to be in the range of USD 0.027 to USD 0.054/kWh (USD 27 to USD 54/MWh).

Given that offshore wind farms are at the beginning of their deployment phase, O&M costs remain highly project-specific, and it will take time for learning to reduce costs and for a clear trend to emerge. However, it is clear that reducing O&M costs for offshore wind farms remains a key challenge and one that will help improve the economics of offshore wind.

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