PDHonline Course E501 (3 PDH)

Wind Energy Project Analysis

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2020

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1. Wind Energy Background

The kinetic energy in the wind is a promising source of renewable energy with significant potential in many parts of the world. The energy that can be captured by wind turbines is highly dependent on the local average wind speed. Regions that normally present the most attractive potential are located near coasts, inland areas with open terrain or on the edge of bodies of water. Some mountainous areas also have good potential. In spite of these geographical limitations for wind energy project siting, there is ample terrain in most areas of the world to provide a significant portion of the local electricity needs with wind energy projects.

Wind farms that use multiple turbines are being constructed in the multi-megawatt range. Over the last decade, typical individual turbine sizes have increased from around 100 kW to 1 MW or more of electricity generation capacity, with many wind energy projects now being developed offshore. The result of all this progress is that, in some areas of the world, large-scale wind energy projects now generate electricity at costs competitive with conventional power plants (e.g. nuclear, oil and coal).

In addition to these larger scale applications, there are a number of other applications for wind turbines, such as medium scale applications on isolated-grids and off-grid uses for pumping water and providing smaller amounts of electricity for stand-alone battery charging applications.

Wind energy projects are generally more financially viable in “windy” areas. This is due to the fact that the power potential in the wind is related to the cube of the wind speed. However, the power production performance of a practical wind turbine is typically more proportional to the square of the average wind speed. The difference is accounted for by the aerodynamic, mechanical and electrical conversion characteristics and efficiencies of the wind turbines. This means that the energy that may be produced by a wind turbine will increase by about 20% for each 10% increase in wind speed. Wind energy project siting is critical to a financially viable venture. It is important to note that since the human sensory perception of the wind is usually based on short-term observations of climatic extremes such as wind storms and wind chill impressions, either of these “wind speeds” might be wrongly interpreted as representative of a windy site. Proper wind resource assessment is a standard and important component for most wind energy project developments.

2. Description of Wind Turbines

Wind turbine technology has reached a mature status during the past 15 years as a result of international commercial competition, mass production and continuing technical success in research and development. Wind energy project costs have declined and wind turbine technical availability is now consistently above 97%. Wind energy project plant capacity factors have also improved from 15% to over 30% today, for sites with a good wind regime.

Modern wind energy systems operate automatically. The wind turbines depend on the same aerodynamic forces created by the wings of an aeroplane to cause rotation. An anemometer that continuously measures wind speed is part of most wind turbine control systems. When the wind speed is high enough to overcome friction in the wind turbine drivetrain, the controls allow the rotor to rotate, thus producing a very small amount of power. This cut-in wind speed is usually a gentle breeze of about 4 m/s. Power output increases rapidly as the wind speed rises. When output reaches the maximum power the machinery was designed for, the wind turbine controls govern the output to the rated power. The wind speed at which rated power is reached is called the rated wind speed of the turbine, and is usually a strong wind of about 15 m/s. Eventually, if the wind speed increases further, the control system shuts the wind turbine down to prevent damage to the machinery. This cut-out wind speed is usually around 25 m/s. The major components of modern wind energy systems typically consist of the following:

- Rotor, with 2 or 3 blades, which converts the energy in the wind into mechanical energy onto the rotor shaft;
- Gearbox to match the slowly turning rotor shaft to the electric generator;
- Tall tower which supports the rotor high above the ground to capture the higher wind speeds;

- Solid foundation to prevent the wind turbine from blowing over in high winds and/or icing conditions
- Control system to start and stop the wind turbine and to monitor proper operation of the machinery.

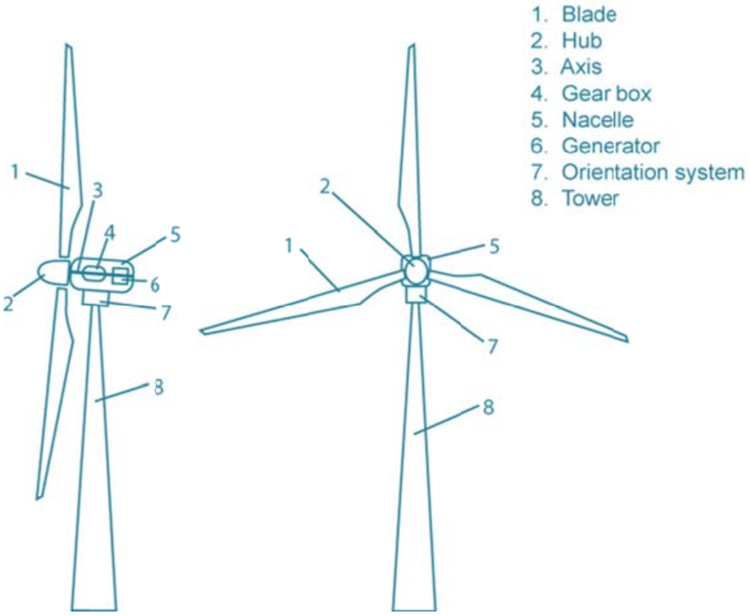

Figure 1. Wind Energy System Schematic illustrates the configuration of a typical "Horizontal Axis Wind Turbine" or HAWT wind energy system

3. Wind Energy Application Markets

Wind energy markets can be classified based on the end-use application of the technology. Wind energy projects are common for off-grid applications. However, the largest market potential for wind energy projects is with on-grid (or grid-connected) applications.

4. Off-grid applications

Historically, wind energy was most competitive in remote sites, far from the electric grid and requiring relatively small amounts of power, typically less than 10 kW. In these off-grid applications, wind energy is typically used in the charging of batteries that store the energy captured by the wind turbines and provides the user with electrical energy on demand. Water pumping, where water, rather than energy, can be stored for future use, is also a key historical application of wind energy. The key competitive area for wind energy in remote off-grid power applications is against electric grid extension, primary (disposable) batteries, diesel, gas and thermoelectric generators. Wind energy is also competitive in water pumping applications.

5. On-grid applications

In on-grid applications the wind energy system feeds electrical energy directly into the electric utility grid. Two on-grid application types can be distinguished.

- Isolated-grid electricity generation, with wind turbine generation capacity typically ranging from approximately 10 kW to 200 kW.
- Central-grid electricity generation, with wind turbine generation capacity typically ranging from approximately 200 kW to 2 MW.

6. Isolated-grids

Isolated-grids are common in remote areas. Electricity generation is often relatively expensive due to the high cost of transporting diesel fuel to these isolated sites. However, if the site has good local winds, a small wind energy project could be installed to help supply a portion of the electricity requirements. These wind energy projects are normally referred to as wind-diesel hybrid systems. The wind energy system's primary role is to help reduce the amount of diesel fuel consumption. A wind-diesel hybrid system is shown in Figure 2.

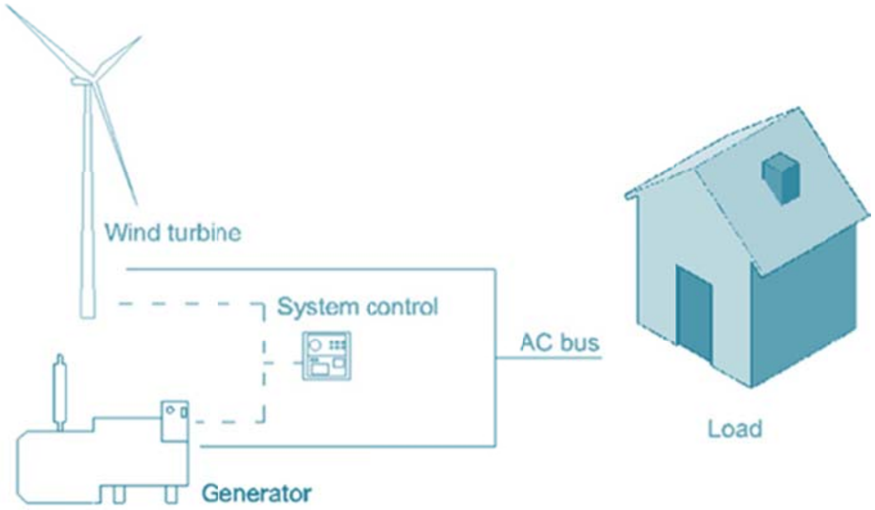

Figure 2. Wind-diesel hybrid system

7. Central-grids

Central-grid applications for wind energy projects are becoming more common. In relatively windy areas, larger scale wind turbines are clustered together to create a wind farm with capacities in the multi-megawatt range. The land within the wind farm is usually used for other purposes, such as agriculture or forestry. Another common approach for wind energy project development includes the installation of one or larger scale wind turbines by individuals, businesses or co-operatives. A wind farm consists of a number of wind turbines (which are often installed in rows perpendicular to the wind direction), access roads, electrical interconnections and a substation, a monitoring and control 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 design and specification of the civil, electrical and mechanical infrastructure, the layout of the wind turbines, the purchasing of the equipment, the construction and the commissioning of the installation. Construction involves preparing the site, grading roads, building turbine foundations, installing the electrical collection lines and transformers, erecting the turbines and construction of the substation and building.

The wind resource assessment and approvals for a wind farm are often the longest activities in the development of the wind energy project. These can take up to 4 years in the case of a large wind farm requiring a comprehensive environmental impact study. The construction itself can normally be completed within one year. The precise determination of the wind resource at a given site is one of the most important aspects in the development of a wind energy project as the available wind resource at the project site can dramatically impact the cost of wind energy production. In the case where a pre-feasibility study indicates that a proposed wind energy project could be financially viable, it is typically recommended that a project developer take at least a full year of wind measurements at the exact location where the wind energy project is going to be installed. For very small-scale projects (e.g. off-grid battery charging and water pumping), the cost of wind monitoring could actually be higher than the cost to purchase and install a small wind turbine. In this case a detailed wind resource assessment would normally not be completed.

8. Wind Energy Project Model

Wind Energy Project Model is used to easily evaluate the energy production, life-cycle costs and greenhouse gas emissions reduction for central-grid, isolated-grid and off-grid wind energy projects, ranging in size from large scale multi-turbine wind farms to small scale single-turbine wind-diesel hybrid systems. This section describes the various algorithms used to calculate, on an annual basis, the energy production of wind energy systems. A flowchart of the algorithms is shown in Figure 3.

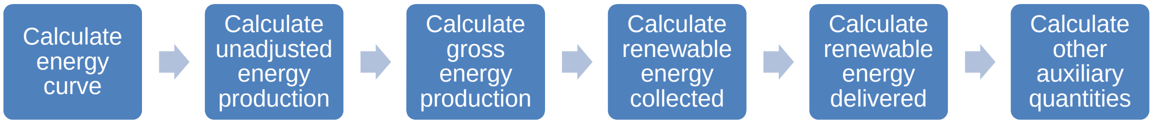

Figure 3. Wind energy model

9. Unadjusted Energy Production

Unadjusted energy production is the energy that one or more wind turbines will produce at standard conditions of temperature and atmospheric pressure. The calculation is based on the energy production curve of the selected wind turbine and on the average wind speed at hub height for the proposed site.

10. Wind speed distribution

Wind speed distribution, when required for modelling is calculated as a Weibull probability density function. This distribution is often used in wind energy engineering, as it conforms well to the observed long-term distribution of mean wind speeds for a range of sites. In some cases the model also uses the Rayleigh wind speed distribution, which is a special case of the Weibull distribution, where the shape 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:

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

This expression is valid for k >1, x ≥ 0, and C > 0. k is the shape factor, specified by the user. The shape factor will typically range from 1 to 3. For a given average wind speed, a lower shape factor indicates a relatively wide distribution of wind speeds around the average while a higher shape factor indicates a relatively narrow distribution of wind speeds around the average. A lower shape factor will normally lead to a higher energy production for a given average wind speed. C is the scale factor, which is calculated from the following equation:

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

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

In some cases, the model will calculate the wind speed distribution from the wind power density at the site rather than from the wind speed. The relations between the wind power density WPD and the average wind speed $\bar{v}$ are:

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

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

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

11.Energy curve

The energy curve data is the total amount of energy a wind turbine produces over a range of annual average wind speeds. Energy curve is specified 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:

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

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 $\bar{v}$.

12.Unadjusted energy production

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

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

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

Where $\bar{V}$ is the average wind speed at hub height H, $\overline{V_0}$ is the wind speed at anemometer height H_0, and α is the wind shear exponent. Values of H, H_0, $\overline{V_0}$ 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 $\bar{V}$.

13.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 determine the renewable energy delivered. Gross energy production E_G is calculated through:

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

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:

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

$$c_T = \frac{T_0}{T} \tag{9}$$

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.

14.Renewable Energy Delivered

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

15.Renewable energy collected

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

$$E_C = E_G c_L \tag{10}$$

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

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

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.

16.Absorption rate and renewable energy delivered

Wind energy project model calculates the wind energy delivered E_D according to:

$$E_D = E_C \mu \tag{12}$$

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 absorbed by the isolated-grid or the off-grid system. For central-grid applications, this rate is always equal to 100% since the grid is assumed to be large enough to always absorb all the energy produced by the wind energy project. For isolated-grid and off-grid applications, the user enters the value of the absorption rate.

For isolated-grid and off-grid applications, the model computes 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 specified by the user. WPC is obtained 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.

17. Excess renewable energy available

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

$$E_x = E_c - E_D \qquad (14)$$

18. Specific yield

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

$$Y = \frac{E_C}{N\,A} \qquad (15)$$

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

19. Wind plant capacity factor

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

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

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.

20.Different measures of cost and data limitations

Cost can be measured in a number of different ways, and each way of accounting for the cost of power generation brings its own insights. The costs that can be examined include equipment costs (e.g. wind turbines, etc.), financing costs, total installed cost, fixed and variable operating and maintenance costs (O&M), fuel costs, and the levelised cost of energy (LCOE).

The analysis of costs can be very detailed, but for comparison purposes and transparency, the approach used here is a simplified version. This allows greater scrutiny of the underlying data and assumptions, improving transparency and the confidence in the analysis, as well as facilitating the comparison of costs in order to identify what are the key drivers in any differences.

The three indicators that have been selected are:

- Equipment cost (factory gate FOB and delivered at site CIF);
- Total installed project cost, including fixed financing costs
- The levelised cost of electricity LCOE.

The analysis in this chapter focuses on estimating the cost of wind energy from the perspective of a private investor, whether they are a state-owned electricity generation utility, an independent power producer, or an individual or community looking to invest in small scale renewables (Figure 4). The analysis is a pure cost analysis, not a financial one, and excludes the impact of government incentives or subsidies, taxation, system balancing costs associated with variable renewables, and any system-wide cost savings from the merit order. Similarly, the analysis doesn't take into account any CO2 pricing, nor the benefits of renewables in reducing other externalities (e.g. reduced local air pollution, contamination of natural environments, etc.).

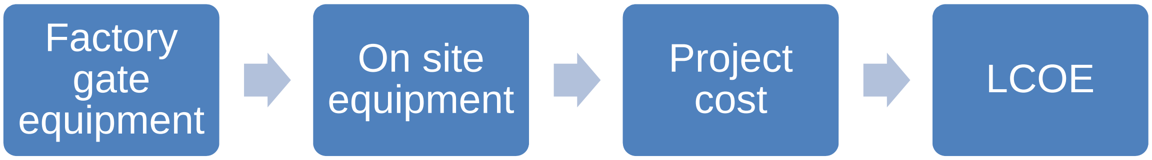

Figure 4. Wind power generation cost indicators and boundaries

21.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 yielder 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 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
It = investment expenditures in the year t
Mt = operations and maintenance expenditures in the year t
Ft = fuel expenditures in the year t
Et = 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.

22.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.

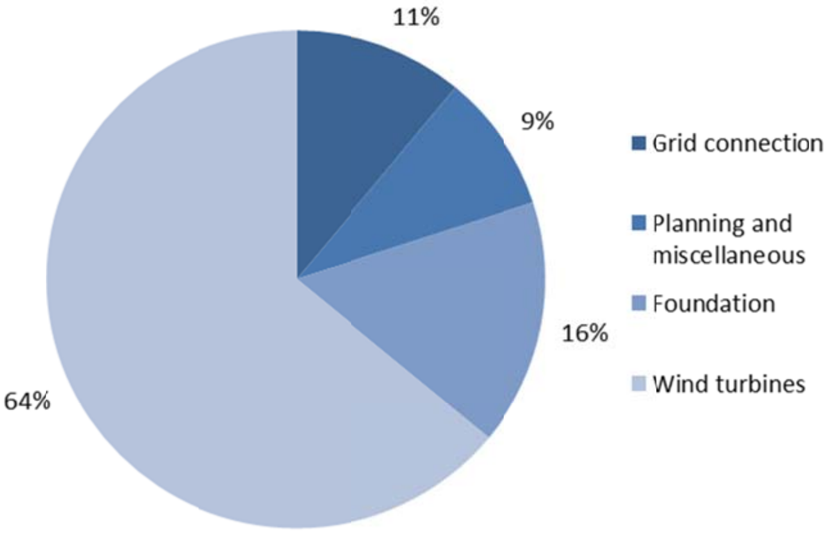

Figure 5. Capital cost breakdown for a typical onshore wind power system and turbine

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 miscellaneous costs associated with the tower, such as the rotor hub, cabling and rotor shaft. Overall, the turbine accounts for between 64% to as much as 84% of the total installed 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, the competitiveness of the local wind industry and the cost structure of the country where the project is being developed.

23.Wind Turbine Costs

The wind turbine is the largest single cost component of the total installed 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.

24.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.

25.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 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, helping to reduce 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. The construction of vessels and cranes specifically designed to install wind turbines therefore offers an opportunity to reduce installation time and costs.

26.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 labour 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.