Environmental, Health, and Safety Guidelines for Wind Energy

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[1]. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them.

The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons.

When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

Applicability

The EHS Guidelines for wind energy include information relevant to environmental, health, and safety aspects of onshore and offshore wind energy facilities. Annex A contains a full description of industry activities for this sector. EHS issues associated with the operation of transmission lines are addressed in the EHS Guidelines for Electric Transmission and Distribution. This document is organized according to the following sections:

[1] Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with wind energy facilities, along with recommendations for their management.

1.1 Environment

Construction activities for wind energy projects typically include land clearing for site preparation and access routes; excavation, blasting, and filling; transportation of supply materials and fuels; construction of foundations involving excavations and placement of concrete; operating cranes for unloading and installation of equipment; and commissioning of new equipment. Decommissioning activities may include removal of project infrastructure and site rehabilitation.

Environmental issues associated with these construction and decommissioning activities may include, among others, noise and vibration, soil erosion, and threats to biodiversity, including habitat alteration and impacts to wildlife. Due to the typically remote location of wind energy conversion facilities, the transport of equipment and materials during construction and decommissioning may present logistical challenges. Recommendations for the management of these EHS issues are provided in the environmental construction and decommissioning section of the **General EHS Guidelines**.

Environmental issues specific to the operation of wind energy projects and facilities include the following:

- Visual impacts
- Noise
- Species mortality or injury and disturbance
- Light and illumination issues
- Habitat alteration
- Water quality

Visual Impacts

Depending on the location and local public perception, a wind farm may have an impact on visual resources. Visual impacts associated with wind energy projects typically concern the turbines themselves (e.g. color, height, and number of turbines) and impacts relating to their interaction with the character of the surrounding landscape.

Prevention and control measures to address visual impacts include[2]:

- Consult the community on the location of the wind farm to incorporate community values into design;
- Consider the landscape character during turbine siting;
- Consider the visual impacts of the turbines from all relevant viewing angles when considering locations;
- Minimize presence of ancillary structures on the site by avoiding fencing, minimizing roads, burying intraproject power lines, and removing inoperative turbines;
- Avoid steep slopes, implement erosion measures, and promptly revegetate cleared land with native species only;
- Maintain uniform size and design of turbines (e.g. direction of rotation, type of turbine and tower, and height);
- Paint the turbines a uniform color, typically matching the sky (light gray or pale blue), while observing marine and air navigational marking regulations;
- Avoid including lettering, company insignia, advertising, or graphics on the turbines.

Noise

Wind turbines produce noise when operating. The noise is generated primarily from mechanical and aerodynamic sources. Mechanical noise may be generated by machinery in the nacelle. Aerodynamic noise emanates from the movement of air around the turbine blades and tower. The types of aerodynamic

[2] Gipe (1995).

noise may include low frequency, impulsive low frequency, tonal, and continuous broadband. In addition, the amount of noise may rise with increasing rotation speed of the turbine blades, therefore turbine designs which allow lower rotational speeds in higher winds will limit the amount of noise generated.

Measures to prevent and control noise are mainly related to engineering design standards. For example, broadband noise is generated by air turbulence behind the blades and increases with increasing blade rotational speed. This noise may be controlled through the use of variable speed turbines or pitched blades to lower the rotational speed.

Additional recommended noise management measures include:

- Proper siting of wind farms to avoid locations in close proximity to sensitive noise receptors (e.g. residences, hospitals, and schools);
- Adherence to national or international acoustic design standards for wind turbines (e.g. International Energy Agency, International Electrotechnical Commission [IEC], and the American National Standards Institute).

Species Mortality or Injury and Disturbance

Onshore

The operation of onshore wind turbines may result in collisions of birds and bats with wind turbine rotor blades and / or towers, potentially causing bird and bat mortality or injury. Potential indirect impacts to birds may include changes in quantity and type of prey species resulting from habitat modification at the wind farm project site, and changes in the type and number of perching and nesting sites due to either natural habitat modification or the use of wind turbines by birds.[3]

The impact to birds and bats depends on the scale of the project and other factors including technology considerations (e.g. tower dimension and turbine design), lighting of the wind turbine, and layout of the wind farm. In addition, site characteristics may influence this impact, including physical and landscape features of the wind farm site (e.g. proximity to habitat that may concentrate birds, bats, or their prey), the numbers of birds and bats moving through the wind farm site, the risk behaviors of birds (e.g. soaring height) and bats (e.g. migration routes), and meteorological considerations.

Prevention and control measures to address these impacts include the following:

- Conduct site selection to account for known migration pathways or areas where birds and bats are highly concentrated. Examples of high-concentration areas include wetlands, designated wildlife refuges, staging areas, rookeries, bat hibernation areas, roosts, ridges, river valleys, and riparian areas;
- Configure turbine arrays to avoid potential avian mortality (e.g. group turbines rather than spread them widely or orient rows of turbines parallel to known bird movements);
- Implement appropriate stormwater management measures to avoid creating attractions such as small ponds which can attract birds and bats for feeding or nesting near the wind farm.

Offshore

Noise generated during the *operation* of the offshore wind farms is not likely to displace marine fish and mammals away from the project site. Activities associated with the installation or removal of offshore wind turbines and subsurface cables may result in temporary displacement of fish, marine mammals, sea turtles, and birds. This displacement may result from direct auditory, visual, or vibratory disturbance impacts or indirectly from increased sediment levels in the water column due to disturbance of the seabed.

[3] NWCC (1999).

Measures to address these impacts depend on the characteristics of the local habitat and may include:

- Employ a 'soft start' procedure for pile-driving activities to help prevent exposure of fish, marine mammals, and sea turtles to damaging sound levels and provide them with an opportunity to leave the area;
- Use of hydraulic jet plowing technology for the installation of cables, which is considered the least environmentally damaging alternative when compared to traditional technologies;
- Use of a monopole turbine foundation, which results in the least amount of seabed disturbance compared to other foundation types.[4]

Similar to onshore wind farms, there is a risk of bird mortality and injury due to collisions with offshore wind turbines. Prevention and control measures to minimize seabird collision risks include:

- Proper siting to avoid high-density bird use areas, including migratory pathways;
- Maintain turbine tower heights below typical elevations of migratory bird pathways;
- Maintain rotor blades a suitable distance from the ocean surface to avoid strikes with seabird activity close to the ocean surface;
- Employ slower-turning rotor blades to make them more visible.[5]

Shadow Flicker and Blade Glint

Shadow flicker occurs when the sun passes behind the wind turbine and casts a shadow. As the rotor blades rotate, shadows pass over the same point causing an effect termed shadow flicker. Shadow flicker may become a problem when residences are located near, or have a specific orientation to, the wind farm.

Similar to shadow flicker, blade or tower glint occurs when the sun strikes a rotor blade or the tower at a particular orientation. This can impact a community, as the reflection of sunlight off the rotor blade may be angled toward nearby residences. Blade glint is a temporary phenomenon for new turbines only, and typically disappears when blades have been soiled after a few months of operation.

Prevention and control measures to address these impacts include the following:

- Site and orient wind turbines so as to avoid residences located within the narrow bands, generally southwest and southeast of the turbines, where shadow flicker has a high frequency. Commercially available modeling software can be used to identify a 'zone' of flicker and the wind farm can then be sited appropriately;
- Paint the wind turbine tower with non-reflective coating to avoid reflections from towers.

Habitat Alteration

Onshore

The potential for alteration of terrestrial habitat associated with the construction and operation of onshore wind turbines is limited given the relatively small individual footprints of these facilities. Avoidance and minimization of these impacts is described in the **General EHS Guidelines** as noted above. The construction of access roads for siting of wind facilities in remote locations may, however, result in additional risks for the alteration of terrestrial habitats. The **EHS Guidelines for Roads** provides additional guidance on prevention and control of impacts associated with construction and operation of road infrastructure.

[4] CWA (2004).
[5] CWA (2004).

Offshore

The installation of offshore wind turbine foundations may result in the loss of existing marine habitat due to the excavation of the sea bottom. Depending on wind turbine location, this may result in the loss of key life cycle (e.g. spawning, rearing), recreational, or commercial fishery habitats, although the potential for negative impacts is low considering the limited individual footprint of these installations.[6] The physical presence of the submarine portion of the wind turbine tower and the foundation may provide a new substrate (artificial habitat), resulting in the colonization of certain marine species on the new substrate. The turbine foundation may also create a new refuge habitat for marine fish and other biota.[7]

The potential negative impacts can be avoided or minimized by proper siting of the turbines outside of environmentally sensitive areas.

Water Quality

Onshore

The installation of turbine foundations, underground cables, and access roads may result in increased erosion and sedimentation of surface waters. Measures to prevent and control erosion and sedimentation are discussed in the **General EHS Guidelines** and in the **EHS Guidelines for Roads**.

Offshore

The installation of the turbine foundations and subsurface cables may disturb the marine seabed and may temporarily increase suspended sediments in the water column, thereby decreasing water quality and potentially adversely affecting marine species and commercial or recreational fisheries.

Prevention and control measures to address the impacts include the following:

- Conduct a site selection process which considers the potential for interference of structural components of the project with commercial or recreational fisheries and marine species habitats;
- Plan the installation of structural components taking into account sensitive life-cycle periods;
- Use silt curtains, where feasible, to contain turbidity from underwater construction.

1.2 Occupational Health and Safety

Occupational health and safety hazards during the construction, operation, and decommissioning of onshore and offshore wind energy conversion projects are generally similar to those of most large industrial facilities and infrastructure projects. They may include physical hazards such as working at heights, working in confined spaces, working with rotating machinery, and falling objects. Prevention and control of these and other physical, chemical, biological, and radiological hazards are discussed in the **General EHS Guidelines**.

Occupational health and safety hazards specific to wind energy facilities and activities primarily include the following:[8]

- Working at heights
- Working over water

Working at Heights

Working at heights may be required during construction activities, including the assembly of wind tower components and general maintenance activities during operations. Prevention and control of hazards associated with working at heights include:

[6] CWA (2004).

[7] Studies have shown that artificial submarine structures may reduce the mortality rate of fish species, increase food availability, and provide shelter (Bombace 1997).

[8] A comprehensive set of guidelines for safe working procedures during construction and operation and maintenance of offshore wind turbines is available from BWEA (2005).

- Prior to undertaking work, test structure for integrity;
- Implementation of a fall protection program that includes training in climbing techniques and use of fall protection measures; inspection, maintenance, and replacement of fall protection equipment; and rescue of fall-arrested workers;
- Establishment of criteria for use of 100 percent fall protection (typically when working over 2 m above the working surface but sometimes extended to 7 m, depending on the activity). The fall-protection system should be appropriate for the tower structure and movements to be undertaken including ascent, descent, and moving from point to point;
- Install fixtures on tower components to facilitate the use of fall protection systems;
- Provide workers with an adequate work-positioning device system. Connectors on positioning systems must be compatible with the tower components to which they are attached;
- Ensure that hoisting equipment is properly rated and maintained and that hoist operators are properly trained;
- Safety belts should be of not less than 15.8 mm (5/8 inch) two in one nylon or material of equivalent strength. Rope safety belts should be replaced before signs of aging or fraying of fibres become evident;
- When operating power tools at height, workers should use a second (backup) safety strap;
- Signs and other obstructions should be removed from poles or structures prior to undertaking work;
- An approved tool bag should be used for raising or lowering tools or materials to workers on elevated structures.
- Avoid conducting tower installation or maintenance work during poor weather conditions and especially where there is a risk lightning strikes;

Working over Water

Prevention and control measures associated with working over open water include the basic principles described for working at heights, as above, in addition to the following:

- Completion of a risk assessment and management plan for water, wind, and weather conditions before conducting work;
- Use of approved buoyancy equipment (e.g. life jackets, vests, floating lines, ring buoys) when workers are over, or adjacent to, water where there is a drowning hazard;
- Orientation of worker to avoid salt spray and contact with waves;
- Provision of appropriate marine vessels and qualified boat operators and emergency personnel.

1.3 Community Health and Safety

Community health and safety hazards during the construction, operation, and decommissioning of onshore and offshore wind energy projects are similar to those of most large industrial facilities and infrastructure projects. They may include structural safety of project infrastructure, life and fire safety, public accessibility, and emergency situations, and their management is discussed in the **General EHS Guidelines**.

Community health and safety hazards specific to wind energy facilities primarily include the following:

- Aircraft and marine navigation safety
- Blade and ice throw
- Electromagnetic interference and radiation
- Public access

Aircraft and Marine Navigation Safety[9]

Wind turbine blade tips, at their highest point, may reach more than 100 meters in height. If located near airports or known flight paths, a wind farm may impact aircraft safety directly through potential collision or alteration of flight paths. Similarly, if located near ports, harbors, or known shipping lanes, an offshore wind turbine may impact shipping safety through collision or alteration of vessel traffic.

Prevention and control measures to address these impacts include the following:

- Consult with air and marine regulatory traffic authorities before installation, in accordance with air and marine traffic safety regulations;
- When feasible, avoid siting wind farms close to airports or ports and within known flight path envelopes or shipping lanes;
- Use anticollision lighting and marking systems on towers and blades.

Blade / Ice Throw

A failure in the rotor blade or ice accretion can result in the 'throwing' of a rotor blade or ice from the wind turbine,[10] which may affect public safety, although the risk of ice throw is only relevant to cold climates and the overall risk of blade throw is extremely low.[11]

Blade throw management strategies include the following:

- Establish safety setbacks, and design / site wind farms such that no buildings or populated areas lie within the possible trajectory range of the blade. This safety setback range is unlikely to exceed 300 meters, although the range can vary with the size, shape, weight, and speed of the rotor, and with the height of the turbine;[12,13]
- Equip wind turbines with vibration sensors that can react to any imbalance in the rotor blades and shut down the turbine if necessary;
- Regularly maintain the wind turbine;
- Use warning signs to alert the public of risk.

Ice throw management strategies include:[14]

- Curtail wind turbine operations during periods of ice accretion;
- Post signs at least 150 meters from the wind turbine in all directions;
- Equip turbines with heaters and ice sensors;
- Use cold-resistant steel for the turbine tower;
- Use synthetic lubricants rated for cold temperature;
- Use black fluoroethane-coated blades;
- Provide full-surface blade heating, if available, or otherwise use leading-edge heaters at least 0.3 m wide.

Electromagnetic Interference

Wind turbines could potentially cause electromagnetic interference with aviation radar and telecommunication systems (e.g. microwave, television, and radio). This interference could be caused by three main mechanisms, namely near-field effects, diffraction, and reflection or scattering.[15,16] The nature of the potential impacts depends primarily on the location of the wind turbine relative to the transmitter and receiver,

[9] International marine navigational safety marking guidelines are available from IALA (2004). An example of aircraft navigational safety markings can be found in CASA (2004).
[10] The risk of being hit by turbine parts or ice fragments within a distance of 210 m is 1:10,000,000. (Taylor and Rand, 1991)
[11] Data indicate that most ice fragments found on the ground are estimated to be 0.1 to 1 kilogram mass and are between 15 and 100 meters from the wind turbine. (Morganet al. 1998)
[12] For more information on safety setback considerations, see Larwood (2005).
[13] Taylor and Rand (1991).
[14] Laakso et al. (2003).
[15] Bacon (2002).
[16] Near field refers to the potential of a wind turbine to cause interference due to electromagnetic fields emitted by the turbine generator and switching components. Diffraction occurs when the wind turbine not only reflects but also absorbs a telecommunications signal. Reflection and scattering occur when a wind turbine either obstructs or reflects a signal between a transmitter and receiver.

characteristics of the rotor blades, signal frequency receiver, characteristics, and radio wave propagation characteristics in the local atmosphere.[17]

Aviation Radar

Wind farms located near an airport may impact the operation of aviation radar by causing signal distortion, which may cause loss of signal and / or erroneous signals on the radar screen. These effects are caused by tower and rotor component reflection and radar chopping.[18]

Prevention and control measures to address these impacts include the following:

- Consider wind energy equipment component designs that minimize radar interference, including the shape of the turbine tower, the shape and materials of the nacelle, and use of radar-absorbent surface treatments (e.g. rotor blades made of glass-reinforced epoxy or polyester) which should not create electrical disturbance;
- Consider wind farm design options, including geometric layout and location of turbines and changes to air traffic routes;
- Consider radar design alterations including relocation of the affected radar, radar blanking of the affected area, or use of alternative radar systems to cover the affected area.[19]

Telecommunication Systems

Prevention and control measures to address impacts to telecommunications systems include the following:

- Modify placement of wind turbines to avoid direct physical interference of point-to-point communication systems;
- Install a directional antenna;[20]
- Modify the existing aerial;
- Install an amplifier to boost the signal.[21]

Television

Prevention and control measures to address impacts to television broadcast include the following:

- Site the turbine away from the line-of-sight of the broadcaster transmitter;
- Use non-metallic turbine blades;
- If interference is detected during operation:
  - Install higher quality or directional antenna;
  - Direct the antenna toward an alternative broadcast transmitter;
  - Install an amplifier;
  - Relocate the antenna;
  - If a wide area is affected, consider the construction of a new repeater station.[22]

Public Access

Safety issues may arise with public access to wind turbines (e.g. unauthorized climbing of the turbine) or to the wind farm substation.

Prevention and control measures to manage public access issues include:

[17] Sengupta and Senior (1983).

[18] Tower reflection: Metal turbine towers can reflect a high proportion of the transmitted signal back to the radar and therefore reduce the detection of aircraft in the vicinity of the turbine tower. Rotor component reflection: Rotating blades can cause "blade flash," which is a term used to describe a strong radar-reflected signal from the rotor blade. The risk of this occurring is very low and, when it occurs, is short-lived. Rotating components within the nacelle (e.g. shafts and generators) can interfere with the radar. Radar chopping: The rotation of the blades can cause modulation or "chopping" of the radar signal behind the blade, which occurs because the rotor blades intermittently obscure the radar returns of objects behind them (AWEA, 2004a).

[19] AWEA (2004a).

[20] AWEA (2004b).

[21] URS (2004).

[22] AWEA (2004b).

- Use gates on access roads;
- Fence the wind farm site, or individual turbines, to prohibit public access close to the turbine;
- Prevent access to turbine tower ladders;
- Post information boards about public safety hazards and emergency contact information.

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Wind energy facilities do not normally generate process emissions and effluents during their operation. Guideline values for process emissions and effluents in this sector are indicative of good international industry practice as reflected in relevant standards of countries with recognized regulatory frameworks Air emissions, wastewater discharges, and solid wastes related to construction and decommissioning activities are discussed in the **General EHS Guidelines**. .

Noise Guidelines

Noise impacts should not exceed the levels presented in the **General EHS Guidelines**, nor result in a maximum increase in background levels of 3 dB at the nearest receptor location.

However, noise generated from wind farms tends to increase with the speed of the wind, as does overall background noise due to the friction of air over existing landscape features. Increased wind speeds may also mask the noise emitted by the wind farm itself, and wind speed and direction may affect the direction and extent of noise propagation. The application of noise guideline values, and the assessment of background levels, should therefore take these factors into consideration.

Additional consideration may be required to address the nuisance factor associated with impulsive or tonal characteristics of noise (sound of a specific frequency, similar to musical notes) emitted from some wind farm configurations.[23]

Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

For monitoring of bird and bat injury and mortality, dead bird searches – involving entire carcasses, partial remains, and feathers – is the most common way to monitor for collisions with wind farms.[24]

In addition, the marine environment of offshore wind farms should be monitored both temporally and spatially for parameters including benthic organisms, mammals, and fish. Parameters may include infauna (sediment and infaunal communities); hard substrate habitat; fish; sandeel (indicator species of changes to sediment characteristics); birds; and marine mammals (seals and harbor porpoises).

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with

[23] Some jurisdictions apply a "penalty" of 5 dB(A) that is added to the predicted levels.

[24] See Brett Lane & Assoc. (2005) for further information on bird and bat collision monitoring. Additional information is also available from Environment Canada (2005).

the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

2.2 Occupational Health and Safety

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[25] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[26] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[27] Indicative Occupational Exposure Limit Values published by European Union member states,[28] or other similar sources.

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive)[29].

Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals[30] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines.**

[25] Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/
[26] Available at: http://www.cdc.gov/niosh/npg/
[27] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992
[28] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/
[29] Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm

[30] Accredited professionals may include certified industrial hygienists, registered occupational hygienists, or certified safety professionals or their equivalent.

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Annex A: General Description of Industry Activities

Wind energy conversion projects are based on harnessing natural wind and converting it into electrical energy. These types of energy projects have been increasing in number over the past 20 years and are becoming a more important source of renewable energy. The projects can be located at onshore or offshore locations. The primary factor in determining a site for a proposed wind farm is the presence of a good wind resource. A wind resource use assessment is conducted to assess wind characteristics prior to siting, designing and constructing a wind farm. Other factors include financial cost of construction, access to transmission lines, environmental conditions, land use and community support.

As with other industry sectors, the life cycle of a wind energy conversion project consists of wind resource use assessment, construction, operation, maintenance, and decommissioning phases. Activities typically associated with the construction phase include access road construction or upgrade, site preparation, transport of wind turbine components and installation of wind energy project components (e.g. anemometers, wind turbines, transformers, substations). Decommissioning activities depend on the proposed subsequent use of the site, but they typically consist of removal of infrastructure (e.g. turbines, substations, roads) and reclamation of the project site, which may include revegetation for projects located onshore. The following section provides a description of the facilities and activities common to the construction and operation of onshore and offshore wind energy conversion projects. Unique characteristics of offshore wind energy projects are described in a separate subsection below.

Facilities and Activities Common to Onshore and Offshore Wind Farms

Wind turbines typically face the wind with the nacelle and tower behind and are arranged so that one turbine does not interfere with the capture of wind by another turbine. For larger wind energy projects, the turbines are typically arranged in bands or lines perpendicular to the prevailing wind direction or they follow the contours of ridges to obtain higher wind speeds. The primary factor in the separation of individual turbines within a wind farm is wind speed and turbulence. The general rule of thumb of downwind separation of turbines is 5 to 7 times the rotor diameter. The area required for a wind turbine project will vary with the number of turbines proposed, however, the actual area of disturbance of a wind energy project (e.g. the area required for the turbines and access roads) is much less than the total project area. For example, a typical wind farm of 20 turbines might extend over an area of 1 square kilometer, but only 1 percent of the land area would likely be used.[31]

Structural elements of a wind energy project include wind turbines, transformers, underground collector transmission cables between the wind turbines, substations, and aboveground transmission lines to connect to an existing power grid and access roads (figure A-2). Wind turbines are spaced to maximize wind energy potential while minimizing space use. The primary factors to determine the spacing of the individual turbines are wind speed and turbulence. Generally, wind turbines are separated by 3 to 5 rotor diameters across the prevailing wind energy direction and by between 5 and 7 rotor diameters in line with the prevailing wind energy direction.[32]In some jurisdictions, the minimum recommended distance between wind turbines is 200 meters to avoid inhibiting bird movement between the turbines.[33] If turbines are within 5 rotor diameter spacing in a frequent wind direction, it is likely that high wake losses will result.[34]

[31] AWEA 2004c.
[32] AWEA 2004c.
[33] EC 2005.
[34] Gardner et al. 2003.

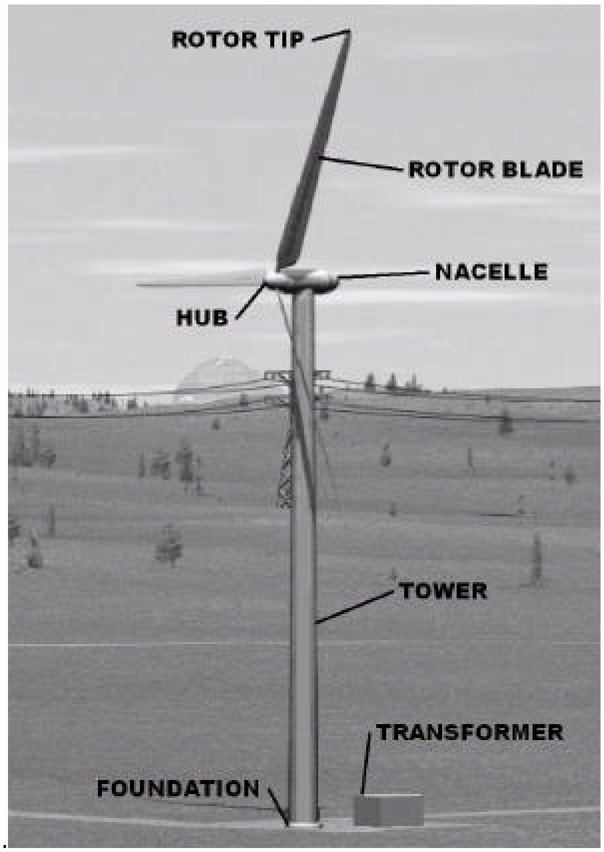
The wind turbine generator is the fundamental component of a wind energy project and is responsible for harnessing the wind and turning it into electricity. The dominant wind turbine design has historically been the upwind, three-bladed, passive stall-controlled, constant-speed machine. The next most common design is similar, but it is pitch or active stall controlled. The rated nameplate capacity (e.g. size) of wind turbines has increased steadily from 50 kilowatts in 1980 to 5 megawatts in 2003, with the average size of an onshore wind turbine in 2005 being 2 megawatts.[35] The increase in generating capacity of wind turbines has led to an increase in rotor diameter and tower height.

The turbine consists of a foundation, tower, nacelle, rotor blades, rotor hub, and lights (figure A-1). The tower is bolted to the foundation, which onshore is typically a thick slab of reinforced concrete measuring 12 to 15 meters in each plan dimension and 2 to 3 meters deep.[36]

To capture wind, the rotor blades are elevated from the ground using towers. The turbine towers are primarily a tapered cylinder in shape and usually made of steel, and can range from 25 meters to more than 100 meters in height. They are usually painted light gray, but they can have different painted markings for air traffic and marine safety (offshore), depending on country-specific requirements.

The majority of rotor blades are made of glass polyester resin, thermoplastics or epoxy resin (epoxy-based resin is now predominating). Carbon fiber is increasingly used as part of the composite structure. These materials have high strength, light weight, and flexibility. Rotor diameter has increased over the last 40 years from 24 meters in 1960 to 114 meters in 2003.[37] Virtually all modern wind turbine rotors conventionally blades turn clockwise when facing the turbine with the hub in front.[38] The typical onshore rotor diameter is between 60 and 80 m.

Figure A-1. Typical Structural Components of a Wind Turbine.



[35] Gardner et al. 2003.
[36] AWEA 2004d.
[37] Gardner et al. 2003.
[38] AWEA 2004d.

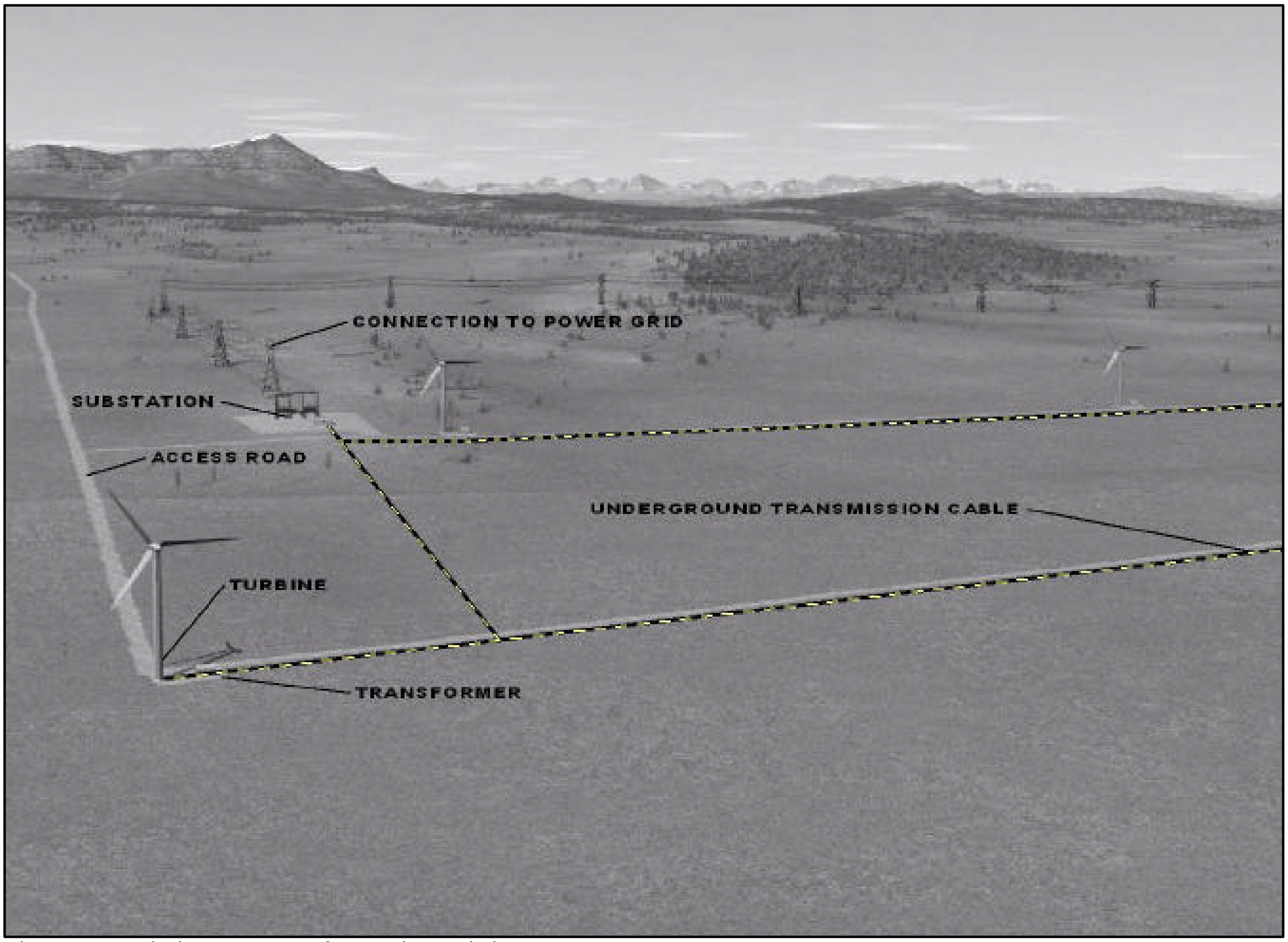


Figure A-2. Typical Components of an Onshore Wind Farm

Typical erection procedures for an onshore wind turbine include preparation of the foundation; tower assembly; hub, rotor, and nacelle lift; and rotor assembly.[39]

As the wind speed increases, the rotor blades begin to rotate. This rotation turns the generator inside the nacelle, thereby converting some of the wind's energy to electricity. Most wind turbines start generating electricity at approximate wind speeds of 3–4 m/sec (10.8–14.4 km/hr), generate maximum power at wind speeds around 15 m/sec (54 km/hr), and shut down to prevent damage at around 25 m/sec (90 km/hr).[40] The maximum blade tip speed can be approximately 89m/s or 320 km/hr.[41] At high wind speeds, there are three principal means of limiting rotor power: stall control, variable pitch control and active stall control. In stall control, the aerodynamic design of the rotor blade regulates the power of the rotor. At high wind speeds, a stall controlled blade will begin to go into stall above a pre-determined power limit determined by the aerodynamic design of the rotor blade. In pitch control, the pitch of the rotor blades can be altered up to 90^{o} to maximize wind capture. Once the power limit is reached, the pitch is changed to begin spilling energy from the rotor. Active stall control is a combination of stall and pitch control whereby the blades are similarly designed

39 Gardner et al. 2003.

40 BWEA 2005b.

41 NZWEA 2005.

to stall control blades, but can still be turned to adjust the pitch. Until the 1990s, passive stall regulation was the preferred strategy, however, pitch regulation and active stall regulation are now the favored means of limiting rotor power for large turbines.[42]

A turbine will typically generate electricity 70 to 85 percent of the time.[43] The amount of energy in the wind is proportional to the cube of the wind speed. In other words, doubling the wind speed results in eight times the energy in the wind. The turbine's wind energy production does not change in the same proportion, however, but roughly with the square of the wind speed. The power generated by a wind turbine is generally at 700 volts, which is not suitable for power transmission.[44] Therefore, each turbine will use a transformer to 'step up' the voltage to meet a specific utility voltage distribution level. This energy is transmitted to a nearby substation that collects the energy from all the turbines of a wind farm. The connection between a turbine transformer and the substation and the substation and the electrical grid can be made using underground or aboveground transmission cables. Depending on the project layout, the turbine transformers can be connected independently to the substation, or the turbines can be interconnected to each other and then connected to a substation.

The design lifetime of a wind turbine is approximately 20 years, but in practice turbines may last longer at sites with low turbulence. Rotor blades are designed to such exacting standards, that they are rarely replaced even beyond their design lifetime, whereas gearboxes, according to recent experience, may need replacement before the rated design lifetime. The operation of a wind energy project does not typically require an onsite staff.

Routine maintenance will be conducted throughout the lifetime of the wind turbine, generally amounting to approximately 40 hours a year.[45] Maintenance activities may include turbine and rotor maintenance, lubrication of parts, full generator overhaul, and maintenance of electrical components as necessary.

The operation and maintenance of wind farms does not typically involve air emissions or effluent discharges. Fluids and other waste materials associated with typical maintenance activities are not normally stored onsite and are disposed of according to appropriate regional or national regulations and / or best management practices.

Facilities Unique to Offshore Wind Farms

The structural elements and operation of an offshore wind farm are similar to an onshore wind farm. The main differences between offshore and onshore turbines are the size of the turbines, the height of the turbine towers, and the diameter of the rotor blades. A typical offshore wind turbine has a height to tip between 100 and 120 meters, a tower height of approximately 60 to 80 meters, and a rotor blade length between 30 and 40 meters.[46] Another difference is that offshore wind farms typically use subsurface (marine and terrestrial) cables to transmit electricity from the turbines to the transformer and from the transformer to a substation located on land (Figure A-3)

The structural component materials (e.g. towers) will be similar to their onshore counterparts, however, some different methods are used to adapt the structure to the marine environment, including coating the metal parts to protect them from corrosion; using sealed nacelles; designing different foundations / towers to cope with wind, wave, current, tide, and seabed interactions (see Figure A-2); and providing special access platforms for maintenance.

[42] AWEA 2004d.
[43] BWEA 2005d.
[44] BWEA 2005b.
[45] Gardner et.al. 2003.
[46] BWEA 2005c.

Offshore wind farms are generally constructed in relatively shallow water that is less than 30 meters deep. The distance from shore will vary by project, depending on siting requirements (e.g. wind characteristics) and constraints (e.g., environmental issues such as visual amenity).

Typical activities for the construction of offshore wind turbines include establishment of the turbine foundation; marine transport of the turbine components; tower assembly; lifting of the nacelle and rotors onto the wind tower; and rotor/ nacelle assembly.

The types of foundations and associated applications that can be used for offshore wind turbines include:

- Monopile - Most conditions, preferably shallow water and not deep soft material;
- Tripod: Most conditions, preferably not deep soft material and suits water depths greater than 30 m;
- Concrete gravity base: Virtually all sediment conditions;
- Steel gravity base: Virtually all sediment conditions, and deeper water than concrete;
- Monosuction caisson: Sands, soft clay conditions;
- Multiple suction caisson: Sands, soft clay conditions; deeper water than monosuction; and
- Floating – Deep waters to 100 meters.

Figure A-3 Typical Components of an Offshore Wind farm