5. Offshore Wind

Offshore wind technologies are designed to extract energy from the winds which exist above the seas and oceans.

5.1. History and Development

For thousands of years wind has been used to power sailing ships, for milling grain in traditional windmills, and for pumping water. The development of modern wind turbines, used for generating electricity, began at the end of the nineteenth century; however, it is only since the 1980's that the technology reached sufficient maturity to enable a large-scale wind power industry to evolve.

In comparison to onshore wind power projects, the construction of offshore wind turbines requires significant engineering for substructure, installation, electrical connection, and the use of materials which resist the corrosive marine environment. Although offshore wind speeds are generally higher than on land, these factors have prevented wind turbines being used offshore in the past. Offshore, it is more feasible to utilize large-scale wind turbines and, with the increase in size and efficiency of wind turbines and experience in this field, offshore deployment of wind power is gaining momentum.

The first offshore wind project, a wind farm of eleven 450kW wind turbines, was installed in Denmark in 1991.

5.1.1. Level 2

From 1970 to 1990, mainly onshore wind turbines were being installed due to economic factors. The capacity was lower and the costs for offshore wind farms were high compared to onshore. However, with the increase in size and efficiency of the wind turbines, in combination with advantages in offshore wind power, have reduced the costs of contracting and operating an offshore wind farm. One of the first wind farms to be constructed was Irene Vorrink, Netherlands in 1996, with 28 wind turbines of 16.8MW capacity. By 2002, the Horns Reef wind farm on the West Coast of Denmark had a total capacity of 160MW from 80 wind turbines.

Most wind turbine manufacturers are manufacturing wind turbines specially designed for offshore wind farms. In the past, manufacturers were designing wind turbines mainly for onshore deployment. Now most manufacturers design wind turbines purely for use in offshore wind farms.

One of the factors that influenced the development of offshore wind was the development in design which led to the introduction of new materials (e.g. carbon fibre, glass fibre) which enabled engineers to tackle issues such as the corrosive marine environment, or larger, stronger and lighter rotor blades.

Wind turbine manufacturers are testing larger wind turbines with high tip speeds in order to increase efficiency and produce more power. Multi-MW machines may be the future of offshore wind since the main barrier for offshore wind was the capital cost of the wind farm. By producing larger machines it is possible to reduce the capital cost as well as operation and maintenance cost per kWh.

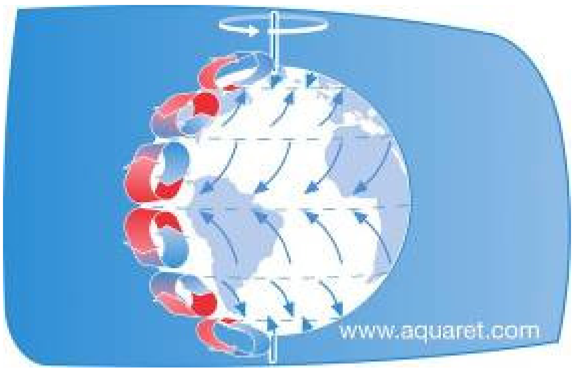
Manufacturers are now developing direct drive generators. This removes the gearbox from the nacelle. This improves the efficiency of the wind turbines and their reliability, due to the absence the gearbox.

Inverters or other means of transforming power are now being used in order to allow the turbines to operate at variable speeds, harnessing more wind power and increasing runtime.

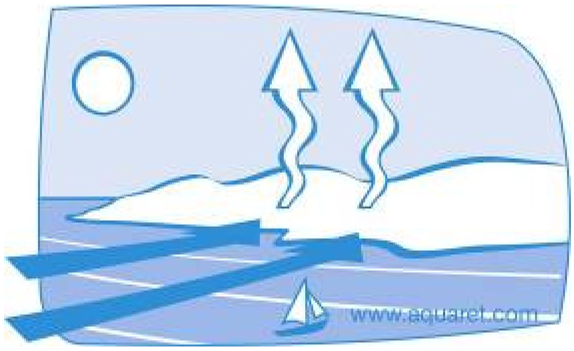
Improvements to foundation structures are subject to research in order to make deployment in deeper waters and difficult seabed conditions feasible. Floating support is the main foundation structure under investigation.

5.2. Energy Source and Location

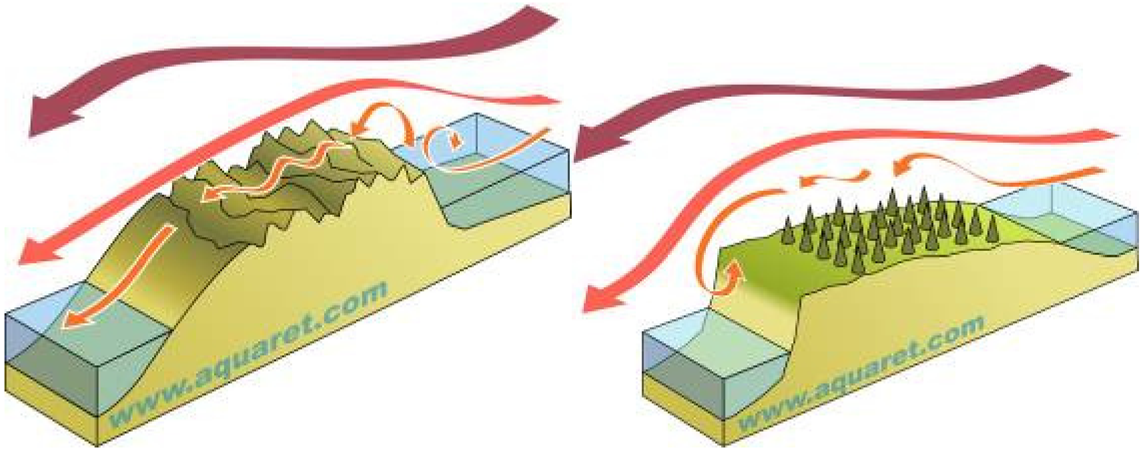
Wind is the movement of air; this carries kinetic energy which can be harnessed by wind turbines. The atmospheric winds that circle the earth are created because the Earth's surface is unevenly heated by the sun, with the poles receiving less solar energy than the equator, and by the rotation of the planet. Warm air is less dense and lighter than cold air. Air in the warmer regions rises, and cooler more dense air flows in to take its place, creating winds.



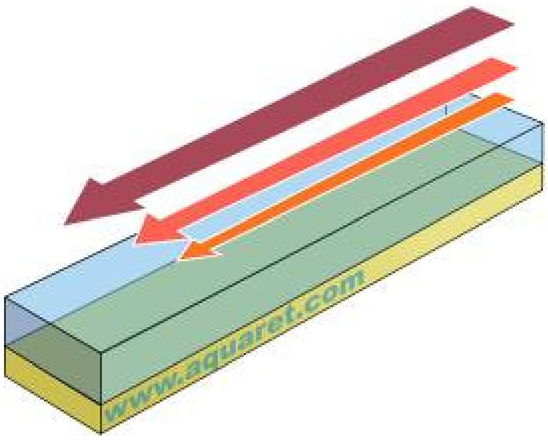
Because land and water absorb the sun's heat at different rates, the air over land heats up and cools down more quickly than air over water. During the day, the air over land expands and rises and is replaced by the cooler sea air, creating sea breezes on coastlines. At night, these winds are reversed.



The greater the wind speed, the greater the energy it contains. Offshore wind speeds are generally higher than on land. As wind blows over the water surface generating waves, it loses some energy due to friction.



The energy in wind is stronger further from the coastline, and increases in strength with increasing height above the water surface.

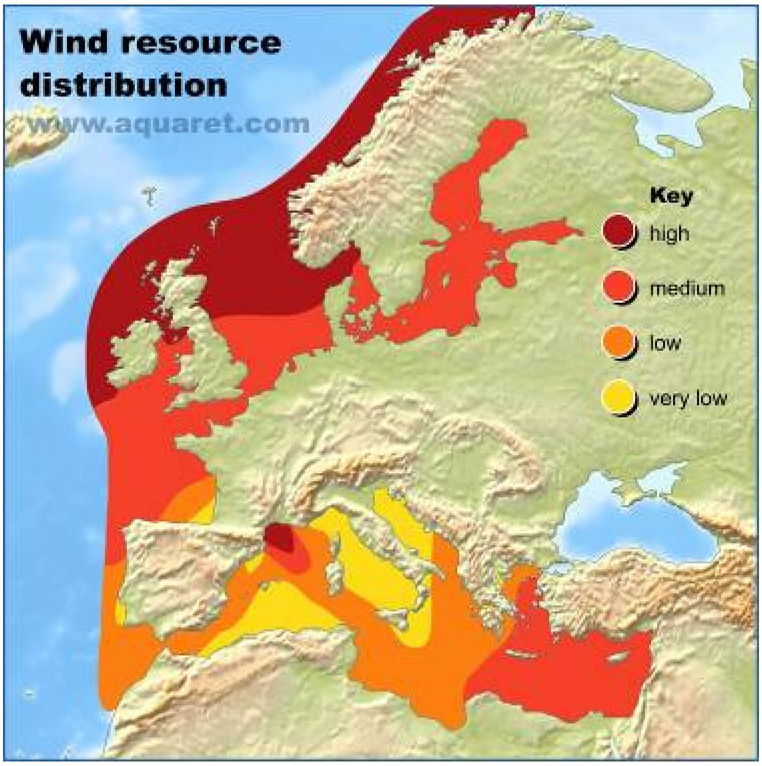


5.2.1. Level 2

- Meteorological conditions and forecasts of the proposed locations must be assessed. An understanding of the wind regime is vital. Offshore wind speeds are usually stronger and smoother than onshore.
- The depth and nature of the sea bed are factors to consider at specific locations. There are a limited number of options for foundation structures, and these will have significant effects on the total cost of the erection of turbines.
- Distance from shore and servicing stations must be considered. This can affect both the speed and cost of both the erection of the wind farm as well as the maintenance operations. It can also lead to the need for constructing onsite maintenance facilities, especially for large wind farms.
- The navigation of vessels, fishing and commercial trade routes must be taken into account. Depending on the size of the wind farm, it is possible that commercial vessel routes may be affected.
- The ecosystem may be affected by the wind farm; therefore fish, marine mammals and birds in the area must be investigated.

5.2.2. European Resource Map

The map below indicates the level of resource across Europe.

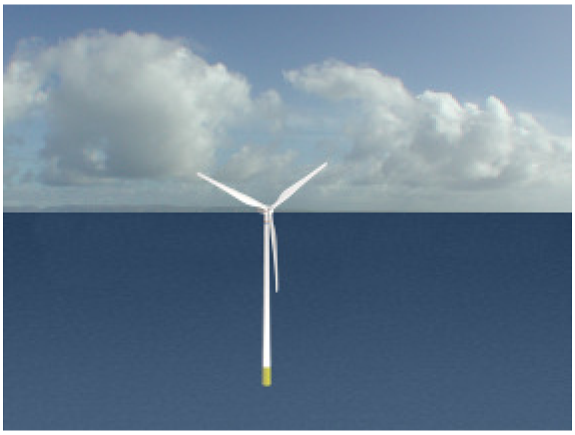


5.3. Technology Types

Wind turbines are designed to extract the kinetic energy in wind. This is achieved by allowing wind to blow past rotor blades, causing them to rotate and drive a shaft.

Modern wind turbines come in two basic types: horizontal axis and vertical axis.

Horizontal axis turbines are the most common form of wind turbine used today. Horizontal axis is the only type of wind turbine being installed offshore mainly due to its higher efficiency.



Wind turbines may be located near shore or in the deeper waters offshore. Installations have been limited to relatively shallow waters, however with increased experience and recent developments, deeper water installations offer a potential opportunity. These will use the stronger winds further out at sea and provide the opportunity for more areas to be developed, minimising the visual impact onshore.

5.3.1. Level 2

Operating Principles

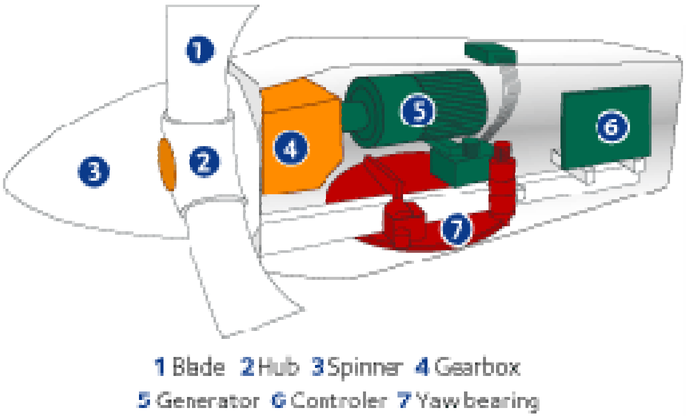
The wind turbine operation principle is straightforward. The wind causes the rotors to start rotating the main shaft which is connected to the rotor hub. Through the gearbox, the rotor shaft motion is transmitted to the generator which produces power.

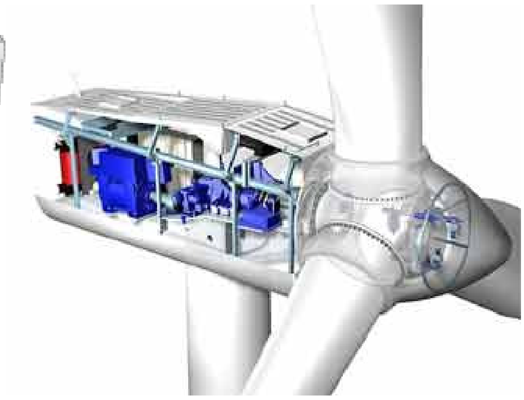
As mentioned in Level 1, there have been designs of both vertical and horizontal axis turbines used in the past (illustrated above). Vertical wind turbines were abandoned in the mid-1990's due to aerodynamic inefficiency since the range of the angle of attack between the wind and the rotor blades is very wide.

Horizontal wind turbines can be classified into several categories since many different concepts may be used related to the operation of the turbine. There are upwind turbines with blades facing the wind. Downwind turbines are the opposite as the wind flows from the rear of the turbine towards the rotors.

Wind turbines may also be classified according to the method by which their power is regulated at high wind speeds. One category is stall-regulated wind turbines. These types of turbines have constant rotor blade pitch angle which, as wind speed increases, the blades become increasingly stalled, thus regulating the rotational speed of the rotor. The second category is the pitch regulated wind turbines which, instead of using a fixed rotor angle, alters the angle in order to regulate the power of the wind turbine.

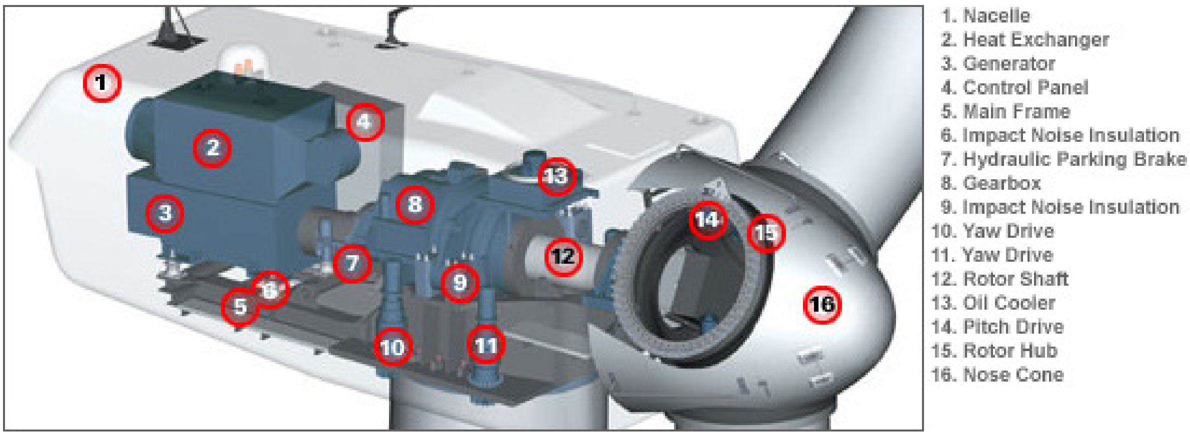
Main components:





Kentish Flats wind farm website

Horns Rev wind farm website



GE wind energy website

5.4. Lifecycle

The key factors and issues that need to be considered at each of the four lifecycle stages for an offshore wind power scheme can be found by following the links below:

- Design & planning
- Construction & installation
- Operation & management
- Decommissioning

5.4.1. Design and Planning

A suitable location must first be identified. Particular attention is required on the following factors;

The meteorology is important in terms of the wind regime which aids the developers in terms of wind turbine selection. The meteorology is also important in terms of moisture levels. Offshore moisture may be rich in contents of unfriendly salt which may cause erosion.

The nature and depth of the sea bed should be considered, as these may affect the foundation selection.

The distance from shore or other service station is considered to minimize the cost of both construction and maintenance. This distance affects the infrastructure costs in terms of the transmission of the produced power as well as the voltage and frequency which are required for grid connection.

The impact on the environment and ecosystem is considered; marine mammals, fish, migratory birds and their flight paths should be investigated.

A supervisory control and data acquisition (SCADA) system is required for the wind farm. This system connects all components (i.e. wind turbine's meteorological stations and substations) of the wind farm to a central computer, which allows the operator to monitor and control the wind farm operation.

5.4.1.1. Level 2

<u>Essential Design Criteria</u>

Wind Speeds

The wind farm developer will first have to identify several locations with the most adequate mean wind speeds. Although modern wind turbines have a kick-in speed of 4-5 m/s, it is recommended to install the wind turbines at a location where the mean wind speed is 7 m/s or higher in order for the wind turbines to operate and produce power for longer time periods throughout its lifecycle. This is essential in order to reduce the overall costs per kWh.

Technology Scale

Modern wind turbines range in size from small machines that produce a few hundred watts to very large turbines producing five megawatts of power or more. In order for offshore projects to be economically feasible, they generally need to use large turbines with capacities of several megawatts. The wind turbines can be installed as single devices or in arrays/farms of multiple devices in order to maximise the area of wind intercepted. Projects may have capacities of a few megawatts, to several gigawatts, in larger offshore wind farms.

Wind Turbine Spacing

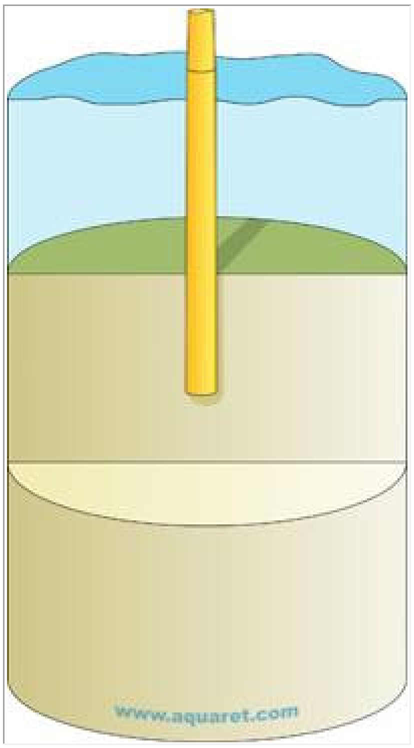
Wind turbine spacing must not deviate from the manufacturer's specifications due to possible wake losses since the appropriate spacing strongly depends on the nature of the terrain and wind rose at a site. Wind turbine spacing may be varied in order to achieve the optimum performance of the wind farm; however, variations must always carry the approval of the wind turbine manufacturer.

5.4.2. Construction and Installation

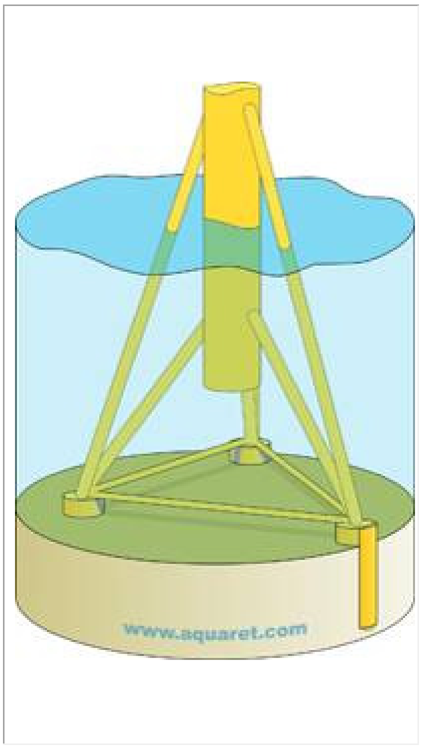
The construction of the most components is carried out onshore. The nacelle is usually fully assembled prior to being transferred to the site. All other components are transferred and then assembled on site, once the foundations are securely constructed. The power cables have to be at the site in order to start turbine assembly.

The assembled nacelle, tower, hub, and rotor blades are transferred to the site and the assembly commences in a similar fashion to onshore wind farms. The tower is erected and secured on the foundation structures; the tower may be in 2 or more pieces. This is followed by the nacelle and the blades.

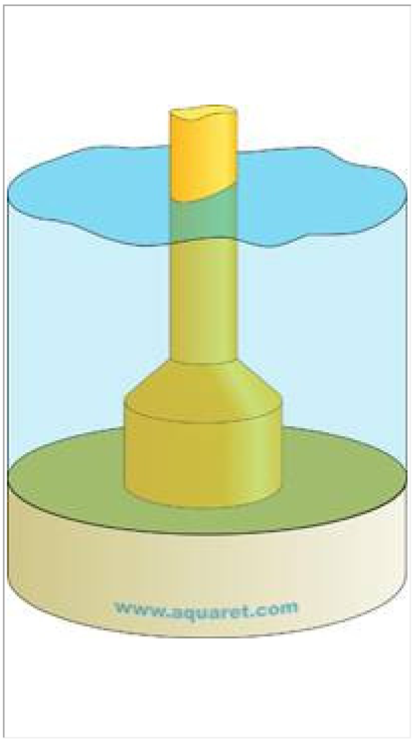
The foundations are the main difference between onshore and offshore wind turbine designs. While onshore wind turbines require large concrete foundation structures, offshore wind turbines require different types of foundation structures depending on the depth and material of the sea bed. Foundation structures for offshore wind turbines include mono-piles, tripods, concrete gravity based and floating support. The choice of the type of foundation is dependent on the depth of the sea bed and the nature of the sea bed. Examples of foundation concepts are shown in the figures below figures.



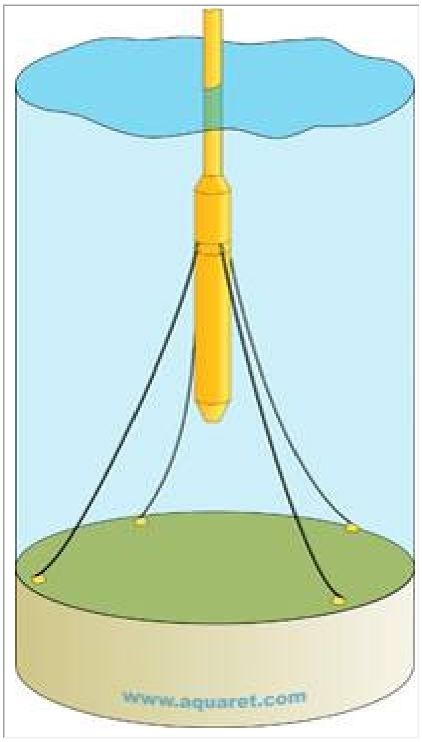
Mono-pile



Multi-pile support structure



Gravity Base Structure



Floating Support Structure

More difficulties arise when the components are transported to the installation site. With the foundations ready to support the tower and other components, specialized vessels, and even barges, must be deployed in order for the transport of components to be possible. More specialized equipment is required in order for the final assembly to be completed. This equipment includes cranes or other lifting equipment.

Mooring structures are only required in the case of floating wind turbines. Mooring structures are required in order to keep the turbine within a restricted area in order to allow vessel navigation within the area while at the same time avoiding accidents.

5.4.2.1. Level 2

Example for installation

An example of a typical offshore wind farm is the Horns Rev wind farm located on the west coast of Denmark. For this wind farm project, the mono-pile foundation was chosen.

The first phase of the construction process for the foundations requires the preparation of the sea bed. In order to minimise the erosion, a gravel mattress was prepared for the foundation. Then the mono-pile was placed at the required position and pile driven through the mattress into the sea bed. The depth of the mono-pile into the sea bed is approximately 25m. Specially designed barges equipped with a heavy duty ram were used. The transition pieces were cast together with the mono-piles featuring the boat landing arrangements, and cathodic protection. The cable ducts for the submarine cables were closed with concrete and the gravel mattress was covered with gravel and stones. For the wind turbine erection phase, specially built jack-up vessels with submersible legs equipped with lifting equipment were used in order to lift all the components of the wind turbines to secure them to place.

5.4.3. Operation and Management

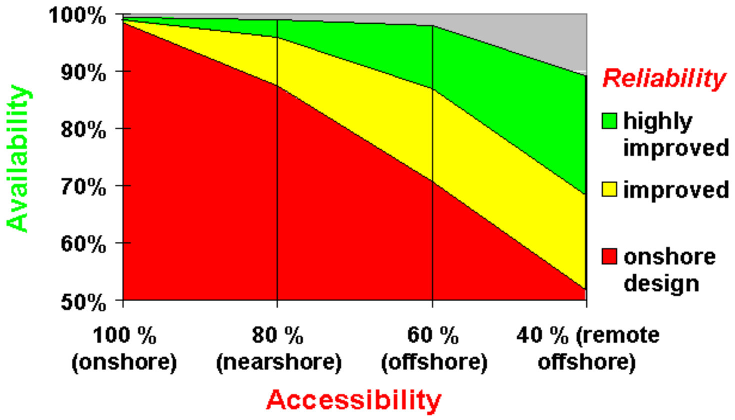
Operation of Wind farm

The daily operation of a wind farm is monitored and controlled using a supervisory control and data acquisition (SCADA) system. This system connects all components (i.e. wind turbines, meteorological stations and substations) of the wind farm to a central computer, which allows the operator to monitor and control the wind farm operation. The system provides and stores information regarding the operation of the wind farm and failures or problems in the operation of specific turbines can be identified.

Maintenance

The maintenance procedure required for offshore wind turbines requires similar technical expertise to that of onshore wind turbines because they share similar components. However, components are usually larger for offshore wind turbines.

The figure below illustrates the importance of reliable wind turbines, especially for remote offshore locations, sometimes based 14-20 km from shore, such as with Horns Rev.



Wind turbines are designed so that routine inspection is required one to three times per year. In the case of the Horns Rev wind farm in Denmark, the wind turbines were designed for two annual service calls. Routine maintenance inspections are naturally different depending on the manufacturer's instructions and the technologies used for a particular turbine. Unplanned maintenance may significantly increase the maintenance cost (i.e. operating and management costs, thus the costs/kWh).

5.4.4. Decommissioning

No projects or wind farms have completed their estimated lifecycle of 25 years. Decommissioning the project will consist of the removal of the devices and foundations from the sea in order to bring the area to the state which it was before the project, which is usually the requirement in most projects. Although the device removal would not be difficult, it will be more complex for the foundation structures. Mono-pile foundations or multi pile foundations, which are generally pile driven into the seabed, will involve a complex procedure to remove. Gravity based structures will also be very expensive due to their immense weight.

It is possible that foundation structures could be reused for the installation of other turbines in the same area provided that they are suitable for the technologies available at the time of decommissioning.

5.5. Economical Factors

As more offshore wind farms are being constructed, investment costs of wind farms are decreasing as the technology advances and the scale of wind farms gets bigger.

The first Danish offshore wind farm had investment costs of 2.200€/kW; this has been reduced to 1.650€/kW for the Horns REV wind farm (equivalent to 4.9c€/kWh). It is anticipated that investment costs will continue to drop as the technology develops. This is because of higher capacity turbines and experience gained from earlier projects; special vessels are also being developed for transport and installation of the turbines.

5.5.1. Level 2

Although accurate figures are not available, OWE suggests that foundations could cost up to 30% more than onshore foundations with other costs roughly 25% higher. Some newer wind farms completed in 2007, such as Arklow Bank (County Wicklow, Ireland), have capital costs of €1.200 - 1.300/kW, which compares more reasonably with onshore wind farms capital costs of €700-1000/kW.

These capital costs per kW (or MW) are expected to become lower in the future due to continuous development of the specialised vessels used for transport and installation of wind turbines. The increasing turbine size (i.e. higher capacity) implies economies of scale. As a result of wind conditions at offshore sites, the overall cost/kWh produced is expected to be lower compared to an inland site.

Technological risks:

Technological trends are towards wind turbines of higher capacity to use offshore (2-2.5 MW or more). There are risks associated with intensive research and development to this end. Although economies of scale exist in the energy production costs, they can increase capital costs and further research and development costs. However, these risks may be overcome with economies of scale and better efficiency of wind turbines due to more stable wind conditions at coastal and offshore sites.

Technological risks are also relevant in the area of component design. In an effort to reduce maintenance costs, there has been research to find replacements for the gearbox, which is a vital and expensive component in a direct-drive system. Such a development would increase the risks due to the yet unproven design of the system.

The financing of projects by investors has been limited due to high capital costs required as a result of the cost of foundations and maintenance cost caused by the remoteness of locations.

5.6. Environmental Interactions

Wind energy produces clean energy. Wind farms use only wind power to produce electrical power. There are no exhaust gases from the combustion of fossil fuels such as petroleum based fuels and gas (e.g. conventional power plants). This benefits the struggle against global warming because of the reduction in CO2 emissions, and also reduces emissions of other polluting gases such as SOx or NOx (i.e. by products of combustion).

Environmental interaction occurs with the marine life at the location of the wind farm. It is possible that the wind farm and its infrastructure may affect the ecosystem in the area. Although direct danger for marine life is not apparent, the routes of the fish and marine mammals may be affected and there is a possibility that the whole ecosystem may be disturbed. Direct danger is only evident with respect to birds and migratory birds that periodically travel though the same routes.

A general matrix of the potential key environmental interactions can be found on the following pages.

Development phase	Activity	Impact mechanism	Interactions with the physical environment	Interactions with the biological environment	Interactions with conservation (ecological designations, natural heritage, anthropogenic heritage etc.)	Interactions with the socio-economic environment
Commissioning, operation and management	Extraction of wind energy and generation of power	Turbine blade movement	No key interactions anticipated	Risk of collision with birds	Protected bird species may be affected	Interference with radar installations, telecommunications and televisions
		Noise generated by turbines	No key interactions anticipated	Localised avoidance by some fish species may be observed	Potential disturbance to marine mammals over significant distances - localised avoidance may be observed	No key interactions anticipated (dependent on distance from shore)
		Reduction of greenhouse gas and exhaust emissions from fossil fuel combustion	Reduction in air pollution and atmospheric anthropogenic greenhouse gasses	Ecological effects resulting from greenhouse gas emissions and air pollution will be reduced	Ecological effects resulting from greenhouse gas emissions and air pollution will be reduced	Clean energy produced helping to meet national/international targets
		Transmission of electricity through subsea cable	No key interactions anticipated	Electrical and magnetic interference with movements of fish species (shark and ray species will be especially sensitive)	Electro-magnetic Fields (EMF) may affect sea mammals passing through the vicinity of the installation	Electric, magnetic interference and heat affects resulting from the operational electricity transmission lines
		Increased vessel activity for maintenance	No key interactions anticipated	No key interactions anticipated	Potential disturbance to marine mammals	Regular additional vessel activity within the local seascape
		Local business and employment opportunities	No key interactions anticipated	No key interactions anticipated	No key interactions anticipated	Potential employment opportunities for local residents and benefits for the local economy
Accidental events	Incident leading to chemical spill	Chemical pollution	Local/widespread changes in water and sediment chemistry	Species and habitats may be harmed and damaged by chemical pollution		Chemical pollution may affect other sea users for example; fish farmers, tourists and mariners etc.
	Incident leading to oil/fuel spill	Oil pollution	Transitory oil slicks on surface waters and risk of long-term seabed and shoreline pollution	Species and habitats may be harmed and damaged by oil pollution		Oil pollution may affect other sea users for example; fish farmers, tourists and mariners etc
	Loss of equipment / structural components	Disruption to the seabed from sinking debris	Changes to the seabed profile and seabed composition	Localised disruption to seabed species and habitats		Additional hazard to navigation, disruption of fishing grounds
		Pollution of surface waters and shorelines from floating debris	No key interactions anticipated	Disruption to shoreline habitats through smothering and harm to species through ingestion/entanglement		Risk of release of oils, fuels and other pollutants Risk of release of substances (e.g. hydraulic fluids)
Decommissioning	Total removal of installation	Reversion to baseline conditions	Dispersal of any accumulated sediments around the installation Loss of and 'wind shadow areas' around the installation Loss of any calming effects around the installation (current movement and wave action)	Potential disruption to ecosystems established and adapted to post-installation hydrographic conditions Impacts of EMF on fish species will be eradicated	Protected species foraging and migrating within the water column may be disrupted Impacts of noise generation on marine mammals will be eradicated Protected bird species no longer affected by the presence of moving turbine parts	Removal of navigational risks 'Exclusion zones' removed
	Replacement of turbines	Increased vessel activity	No key interactions anticipated	No key interactions anticipated	Potential temporary disturbance to marine mammals	No key interactions anticipated
		Local business and employment opportunities	No key interactions anticipated	No key interactions anticipated		Potential economic benefits from utilisation of local resources, support companies and services

Potential key interactions between offshore wind installations and the receiving environment

Development phase	Activity	Impact mechanism	Interactions with the physical environment	Interactions with the biological environment	Interactions with conservation (ecological designations, natural heritage, anthropogenic heritage etc.)	Interactions with the socio-economic environment
Preparatory works	Surveying	Disturbance of seabed through sampling	Minor impacts may result from baseline environmental surveys. For example, localised loss of substrates, plants and animals on the seabed through coring, boring and grab sampling, disruption to mammals from seismic and other vessel-based surveys.			Local contractors and scientific experts can be employed to conduct and support baseline surveys for example, vessel operators, consultants and divers etc.
		Noise disturbance through increased vessel activity and sonar / seismic surveying	No key interactions anticipated	Potential harm to fish species	Disruption of marine mammal behaviour	No key interactions anticipated
		Disruption of seabed and water column during and after dredging	Areas of the seabed may be dredged affecting seabed morphology and increasing water turbidity	Plants and animals may be removed and directly impacted by any dredging prior to construction	Protected migratory fish species and protected predatory bird species may be affected.	Temporary disruption to other sea users and navigation resulting from vessel activity and marine works.
Construction and Installation	Foundation and infrastructure installation	Physical presence of vessels and associated equipment/structures	No key interactions anticipated	No key interactions anticipated	Potential disturbance to marine mammals	Increased potential navigational risk to other sea users Creation of exclusion zones to other sea users including fishermen
		Disturbance to seabed and generation of noise through piling	Localised impact on morphology – cuttings will become established on the seabed. These may subsequently be distributed over a wider area.	Direct localised impact on seabed species and habitats	Underwater noise may impact marine mammal species over significant distances	Unfamiliar vessels and superstructures associated with onsite fabricating and installation will be visible within the local seascape for extended periods of time
		Disturbance to seabed and water column through installation of foundations	Alteration of hydrological and sedimentation patterns Alteration of wave height Changes in tidal current behaviour and character downstream of installation	Installations may act as artificial reefs and fish aggregation devices Interference with migration patterns	Potential disturbance to marine mammals	Increased potential navigational risk to other sea users
		Disturbance to the seabed and other sea users through the installation of subsea cables	Resuspension of sediments and particulate matter into the water column	Direct localised impact on seabed species and habitats	Potential disturbance to marine mammals	Increased potential navigational risk to other sea users Creation of exclusion zones to other sea users including fishermen
	Turbine installation	Physical presence of supersurface structures	Creation of 'wind shadow' downwind of installed structures	Collision between birds and turbines (both migratory and resident)	Protected bird species may be affected	Changes to landscape and seascape character Visual intrusion Interference with recreational sailing access Increased potential navigational risk to other sea users Creation of exclusion zones to other sea users including fishermen

5.7. Future Potential

Alternative energy sources are favoured in response to the global energy landscape. The rates at which oil prices increase are expected to have significant impacts on the economy worldwide as there are many oil dependent national economies.

Wind energy, compared to other renewable energy resources such as wave, is at an advantage due to the fact that it is already operational and the industry has gained valuable experiences from the operation of wind farms and design over the past 30 years. The industry is expanding and developments in technology increase the potential output of wind farms, and decrease the costs.

The diagram above shows that offshore wind potential for Europe is high, perhaps enough to fulfil the needs of Europe for electricity exclusively through wind power.

5.7.1. Level 2

The European Wind Energy Association (EWEA) set targets in 2003 for both onshore and offshore wind energy in terms of MW of installed capacity. In 2003, EWEA set targets of 65GW onshore and 10GW offshore by 2010, and 110GW onshore and 70GW offshore by 2020. For offshore wind in particular, the target for installed capacity is 7 times the target for 2010. The EWEA in 2004 further increased the set industry targets for 16% of all wind power, i.e. 70GW within 16 years (by 2020).

In general, offshore wind power potential, and feasibility in terms costs, are becoming more attractive as the technology continues to advance and more wind turbine manufacturers begin to produce turbines for offshore use. The increase of the size of the wind turbines and the distance from shore (i.e. reducing noise) implies that more efficient wind turbines will be installed, thus reducing costs of offshore wind power.

Social issues may arise depending on the culture and economy of the locality. With careful planning and investigation, environmental disturbance, visual impact, and conflicts with other industries can be avoided.

5.8. Case Studies

Several Case studies are presented on the following pages.

Case Study - Horns Reef Wind Farm

Project Name	Horns Reef Wind Farm
Location	Horns Reef, Denmark
Installed capacity	160 MW
Technology Type	Vestas V80 – 80m rotor diameter, 70m hub height, upwind wind turbines,
Project Type/Phase	Demonstration project / operational wind farm
Year	Construction, March 2002 – December 2002; wind farm fully operational since December 2002

Project Description

The devices used at this wind farm are the Vestas V80 2MW. By making use of 80 turbines, a total capacity of 160 MW has been installed. The wind turbines are three-bladed upwind, pitch regulated turbines, with a rotor diameter of 80 meters and at a hub height of 70m. This model's tower has been designed for a height of approximately 60-100m.

Despite being 14-20 km from the shore, the water depth of only 6-12m and sea bed conditions enabled the manufacturers to use the mono-pile foundation type which is one of the easiest to install.

With the mean wind speed in the area of 9.7 m/s the wind farm may produce 600GWh per annum.

Project Partners

1. DONG Energy; Elsam (Danish power supplier) was responsible for the project; Elsam has now merged with DONG Energy.

2. In 2006 Vettenfall obtained a 60% ownership of the wind farm of Horns Rev.

Cost and Financing

The capital cost of the project is €270.000.000. Elsam was guaranteed a selling price of approximately €0.045 per kWh.

Further Information

http://www.hornsrev.dk – the wind farm's official website
http://www.vattenfall.dk/ - an owner
http://www.dongenergy.com/EN/index.htm/ - owner's website
http://www.offshorewindenergy.org/ - Offshore Wind Energy Europe

Case Study - London Array

Project Name	London Array
Location	20km (12 miles) from the Kent and Essex coasts in the outer Thames Estuary, UK.
Installed capacity	up to 1000MW
Technology Type	Wind turbines
Project Type/Phase	Considered as one of the largest projects in offshore wind farms
Year	Construction in late 2008; expected to be completed in 2012.

Project Description

A range of different models of wind turbines will be used for this project. It is estimated that on completion there will be 271 wind turbines installed of capacity of 3-7MW. The cutting edge technology enables the wind turbines to provide energy generation at speeds of as little as 3m/s, increasing the overall performance of the wind farm. It is expected that on completion the wind farm should produce electricity for 75,000 homes which is equivalent to roughly 3,525 GWh / year.

Project Partners

London Array Ltd – a consortium of Shell WindEnergy Ltd, E.on UK Renewables and DONG Energy.

In May 2008 Shell withdrew from the project. The other partners bought Shell's share. Masdar Initiative then joined as a joint venture party.

Cost and Financing

- Estimated at £2 Billion

Further Information

http://www.londonarray.com

Case Study - Nysted Offshore Wind Farm

Project Name	Nysted Offshore Wind Farm
Location	Denmark. 10 km south of Nysted
Installed capacity	165,6 MW
Technology Type	72 wind turbines
Project Type/Phase	Nysted Wind Farm is one of two demonstration projects approved by the Danish Government in 1998.
Year	Constructed in May 2003 – January 2004; operational since then.

Project Description

Wind turbines used for this project were the BONUS Energy A/S 2.3 MW wind turbines of hub height of 69m and rotor diameter of 82m. The wind turbines are supported by mono-pile foundations which are most commonly used for offshore wind farms.

In the area there is an estimated mean wind speed of 9.1 m/s at a height of 69m which may produce 595 GWh of energy per year.

Project Partners

At the time the project was built, the project was the responsibility of Elsam and was part of the action plan from the Danish Government to construct two offshore wind farms (Horns Rev and Nysted).

Nysted Offshore Wind Farm at Rødsand is owned by a joint venture, in which DONG Energy owns 80% and E.ON Sweden 20%.

Cost and Financing

- 270 million Euro
- Further information on the Nysted project is not available in terms of costs of running the wind farm. It is estimated that 595 GWh of energy are produced per year, sufficient to self-finance the wind farm and provide a profit for the developer during the wind turbines' useful lifecycle. Based on an income of 5c€ per KWh the income from energy production could be €29-30 million per year.

Further Information

http://uk.nystedhavmoellepark.dk/frames.asp

Case Study - Scroby Sands

Project Name	Scroby Sands
Location	United Kingdom, East Anglian Coast, 3km east of Great Yarmouth
Installed capacity	60MW
Technology Type	Wind turbines
Project Type/Phase	One of the first commercial offshore wind farms.
Year	Commissioned March 2004

Project Description

Wind turbines used for this project were the Vestas 2MW offshore wind Turbines. These are 68m hub height and 80m rotor diameter wind turbines which are located roughly 2.3km from shore. The water depth in the location varies between 4-8m and mono-pile foundation was used. The energy generated, according to the wind farm develop/owner E.on UK, is enough to power 30,000 – 35,000 (141 - 164.5GWh / year).

Project Partners

E.on UK

Cost and Financing

Capital costs of €110 Million.

Further Information

http://www.eon-uk.com/

5.9. Test Your Knowledge

Learning Outcomes - Offshore Wind

Level	Offshore Wind
Basic [1]	On successful completion of this module you will be able to: • Understand the basic physical processes that result in wind formation on land and sea • Understand that wind energy is a renewable resource. • Recognise that wind energy resources are widely but not evenly distributed across Europe and that local topography affects wind speeds • Recognise that modern wind turbines fall into two basic categories (horizontal and vertical axis) though only horizontal axis turbines have been used offshore to date • Identify the different project phases such as Design and Planning, Construction and Installation, Operation and Management, and Decommissioning • Understand the importance of taking into consideration of all these project phases when evaluating the impacts and feasibility of a particular development • Explain how energy extraction leads to a number of possible interactions (both negative and positive) with the surrounding environment • Understand that the surrounding environment includes physical processes, wildlife and habitats, conservation interests, communities and social features, as well as commerce and economic activities • Outline how negative impacts can be minimised • Name specific examples where offshore wind energy is being extracted
Intermediate	On successful completion of this module you will be able to: • Describe key developments in the use of offshore wind energy • Describe how winds are formed by the uneven heating of the Earth's surface by the sun • Describe how sea breezes are formed by the uneven absorption of the sun's heat by the land and the sea • Describe some of the factors which are important at each phase of the project • Describe the various impacts and opportunities associated with the technology • Outline the key types of environmental interactions associated with aquatic renewable technologies • Explain how these may change through a project lifecycle, in different locations and at different times • Outline some of the factors which influence the overall cost of the project for the different technologies • Describe specific examples where offshore wind energy is being extracted

[1] **Basic –** Equivalent to EQF (European Qualification Framework) Level1 and Bloom's Taxonomy "Knowledge" category. This level requires the student to have basic general knowledge of the subject, be able to recall important information.

Intermediate – Equivalent to EQF level 2 and Bloom's Taxonomy "Comprehension" category**.** This level requires the student to be able to explain basic factual knowledge.

5.9.1. Quiz

Answers are given in the footnote[2]

Q1 Offshore wind as an energy source for land based activities:

a) Has been used for thousands of years

b) Is currently being developed as an source of electrical energy

c) Has been used over the past decade and is now a fully commercial scale business sector

d) Has not yet been tested

Q2 The first offshore wind project; a wind farm of eleven 450kW wind turbines, was installed in Denmark in:

a) 1911

b) 1972

c) 1991

d) 2007

Q3 The source of offshore wind energy is:

a) Kinetic energy in the wind caused by the uneven heating of the earth's surface by the sun

b) Potential energy in the wind caused by the uneven heating of the earth's surface by the sun

c) Water flowing in and out of tidal areas caused by the gravitational pull of the moon and the sun on the seas

d) The hydrological cycle

Q4 Choose the combination of words which best complete this sentence:

_____ air is less dense and lighter than _____ air, therefore air in warmer regions ____ and ______ more dense air flows in to take its place, creating winds.

a) Warm, cold, rises, cooler

b) Cold, warm, rises, cooler

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[2] 1c, 2c, 3a, 4a, 5a, 6a, 7d, 8d,

c) Warm, cold, sinks, cooler

d) Cold, warm, sinks, cooler

Q5 Offshore wind speeds are generally higher

a) Further away from the coastline and increase with height

b) Close to the coastline and increase with height

c) Further away from the coastline and decrease with height

d) Close to the coastline and decrease with height

Q6 The only type of wind turbine which has been used to date for offshore wind energy projects are:

a) Horizontal axis turbines

b) Vertical axis turbines

c) Darrieus turbines

d) Savonius wind turbines

Q7 The following is an example of where offshore wind energy is being extracted:

a) Yell Sound, Shetland Islands, Scotland device using a 150kW reciprocating hydroplane device

b) Aguçadoura, Northern Portugal device using 3 x 750kW floating articulated attenuators

c) La Rance, Estuary, France using 24 x 10MW low-head bulb type turbines

d) Scroby Sands, England using 30 x 2MW horizontal axis turbines

Q8 The following is an impact associated with extraction of wind energy:

a) Reduced tidal range leading to potential decrease in number of intertidal species

b) Reduced wave action leading to potential changes in intertidal and sunlittoral habitats

c) Reduction on tidal current energy leading to potential increase in sediment settlement downstream of the device

d) Risk of bird collisions with moving turbine blades

5.10. Further Information

Publications:

Wind Energy – The Facts, EWEA

An extensive publication issued by the European Wind Energy Association which offers extensive information on wind energy mainly for onshore applications. Extensive information regarding offshore wind may not be available.

Sea Wind Europe, by Greenpeace Europe

Prospects of Offshore Wind Energy, BWEA

Websites:

The European Wind Energy Association http://www.ewea.org

Useful information regarding the technology, economics, market development and other issues associated with wind energy in general.

Offshore Wind Energy Europe http://www.offshorewindenergy.org

Valuable source of information on offshore wind energy. Many reports and search engines to source reports on offshore wind energy.

British Wind Energy Association (BWEA) http://www.bwea.org

Horns Rev Wind Farm http://www.hornsrev.dk/Engelsk/default_ie.htm

Blyth Offshore Wind farm http://www.amec.com/wind/2ndlevel.asp?pageid=8035

Kentish Flats Wind farm http://www.kentishflats.co.uk/index.dsp?area=1374