Guide to an Offshore Wind Farm

Update 2025

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September 2025

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ORE Catapult was established in 2013 by the UK Government and is one of a network of Catapults set up by Innovate UK in high growth industries. It is the UK's leading technology innovation and research centre for offshore renewable energy.

Independent and trusted, with a unique combination of world-leading test and demonstration facilities and engineering and research expertise, ORE Catapult convenes the sector and delivers applied research, accelerating technology development, reducing risk and cost and enhancing UK-wide economic growth.

Active throughout the UK, ORE Catapult has operations in Glasgow, Blyth, Levenmouth, Aberdeen, Hull, the South West and Wales.

www.ore.catapult.org.uk

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The Crown Estate (TCE) has a diverse £16bn portfolio that includes urban centres and development opportunities; one of the largest rural holdings in the country; Regent Street and St James's in London's West End; and Windsor Great Park. TCE also manage the seabed and much of the coastline around England, Wales and Northern Ireland, playing a major role in the UK's world leading offshore wind sector.

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CES delivered the ScotWind and INTOG seabed leasing rounds, and works to enable a sustainable offshore wind sector in Scotland.

For more information visit: www.crownestatescotland.com.

Offshore Wind Growth Partnership

The Offshore Wind Growth Partnership is the UK's flagship supply chain growth funding and business support organisation dedicated to offshore wind.

Its mission is to accelerate development of the UK's offshore wind supply chain.

OWGP has been set up as an independent, not-for-profit organisation to support development of the offshore wind supply chain, helping to generate know-how, economic value, highly skilled jobs, and export income for UK businesses.

In December 2024, it was announced that OWGP is expanding its activities to take on the role of the Offshore Wind Industrial Growth Plan Delivery Body ("IGP Delivery Body").

The IGP Delivery Body's role and objectives are described in the Industrial Growth Plan (published in April 2024), available on the Offshore Wind Industry Council (OWIC) website.

For more information, visit: https://owgp.org.uk/

Scottish Enterprise

Scottish Enterprise (SE) is Scotland's national economic development agency and provides a range of services to businesses, entrepreneurs, and organizations looking to grow, innovate, or invest in Scotland.

For more information visit: https://www.scottish-enterprise.com/

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Highlands and Islands Enterprise (HIE) is the economic and community development agency for the Highlands and Islands covering over half of Scotland. HIE works with communities, enterprises, stakeholders and investors to unlock the region's potential for growth and progress, while driving fair work and net zero practices. HIE's flexible support includes specialist advice across topics including innovation, R&D and improving productivity, as well as access to property, and funding.

For more information visit: http://www.hie.co.uk.

South of Scotland Enterprise

South of Scotland Enterprise (SOSE) is the economic and community development agency for the South of Scotland. SOSE help businesses and enterprising communities throughout Dumfries and Galloway and the Scottish Borders to thrive, grow, and fulfil their best potential.

For more information, visit: https://www.southofscotlandenterprise.com.

BVG Associates

BVG Associates provides strategy consulting in renewable energy. We help our clients to do new things, think in new ways and solve tough problems. Our practical thinking integrates the business, economics and technology of renewable energy generation systems. We combine deep wind industry knowledge with skills gained in the world of business consulting. Our purpose is to help our clients succeed in a sustainable global electricity generation mix founded on renewables.

For more information visit: www.bvgassociates.com

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Introduction

This Guide

The aim of this guide is to help companies and individuals develop a greater understanding of the components and processes involved in the development of offshore wind farms that will be built up to 2035, and in doing so help them realise the opportunities that will arise.

This guide details the process and technologies involved in fixed offshore wind projects. It is accompanied by The Guide to Floating Offshore Wind, which focusses on floating technologies.

There is no single way to build and operate an offshore wind farm and much depends on the specific conditions at the site. The pace of innovation in the wind industry has been rapid over the past decade; however, up to 2035, we can be reasonably confident of the technologies that will be deployed. An important uncertainty is turbine size because although manufacturers are working on designs that will ultimately stretch capacities to greater than 15 MW, the timing of their introduction is a complex commercial decision.

Projects vary considerably in their size and their distance from shore. For the purposes of this document, we have assumed a 1 GW project of 67 15 MW turbines located 80 km from shore in 50 m water depth and commencing operation in 2030. Installed turbine ratings have grown rapidly over recent years. There are competing opinions on whether this rate of growth will be sustained as the industry continues to develop, with some turbine manufacturers encouraging the industry to standardise on existing rating and some pushing for ever higher ratings. We have selected to use 15 MW turbines throughout this report as we believe this is the most likely turbine to be used on projects commencing operation in 2030, this reflects current industry trends, however sizes are like to increase beyond this for later projects.

We have endeavoured to ensure that the information is as accurate and informative as possible. However, the industry is developing quickly and we at BVG Associates continue to learn. We would value feedback on the content of this document via info@bvgassociates.com.

Where relevant, for each element in the wind farm we cover:

- **Function.** What the component or service does.
- **What it costs.** We provide typical prices for a project with parameters described above. We recognise that there can be quite a range in prices of any element, due to specific timing or local issues, exchange rates, competition and contracting conditions. Prices for large components include delivery to nearest port to supplier and warranty costs. Developer costs (including internal project- and construction management, insurance, typically spent contingency and overheads) are included in the highest-level boxes but are not itemised. The sum of costs in lower-level boxes therefore is often lower than in the highest-level box. Costs, when combined with project life of 25-30 years, capacity factor of just over 50% and weighted average cost of capital equate to the bid prices seen in recent UK Government Contract for Difference auctions.
- **Who supplies them (examples only).** The list of suppliers is indicative rather than exhaustive. We have focused on suppliers with proven capability and generally have not listed suppliers with likely future capability or located distant from the UK (for example in US or China). Nevertheless, any omission does not reflect any judgement of a company’s capabilities.
  - For the latest details on the offshore wind supply chain, ORE Catapult’s UK Offshore Wind Directory is constantly updated with information from suppliers and other sources. See: https://www.uowd.co.uk/uowd/
- **Key facts.** Description including dimensions / materials where relevant or what is involved in delivering the service / how it relates to other elements and other relevant information.

- **What's in it.** We list the sub-components / services described elsewhere in the guide, or standard components / materials / processes used across a range of industries.

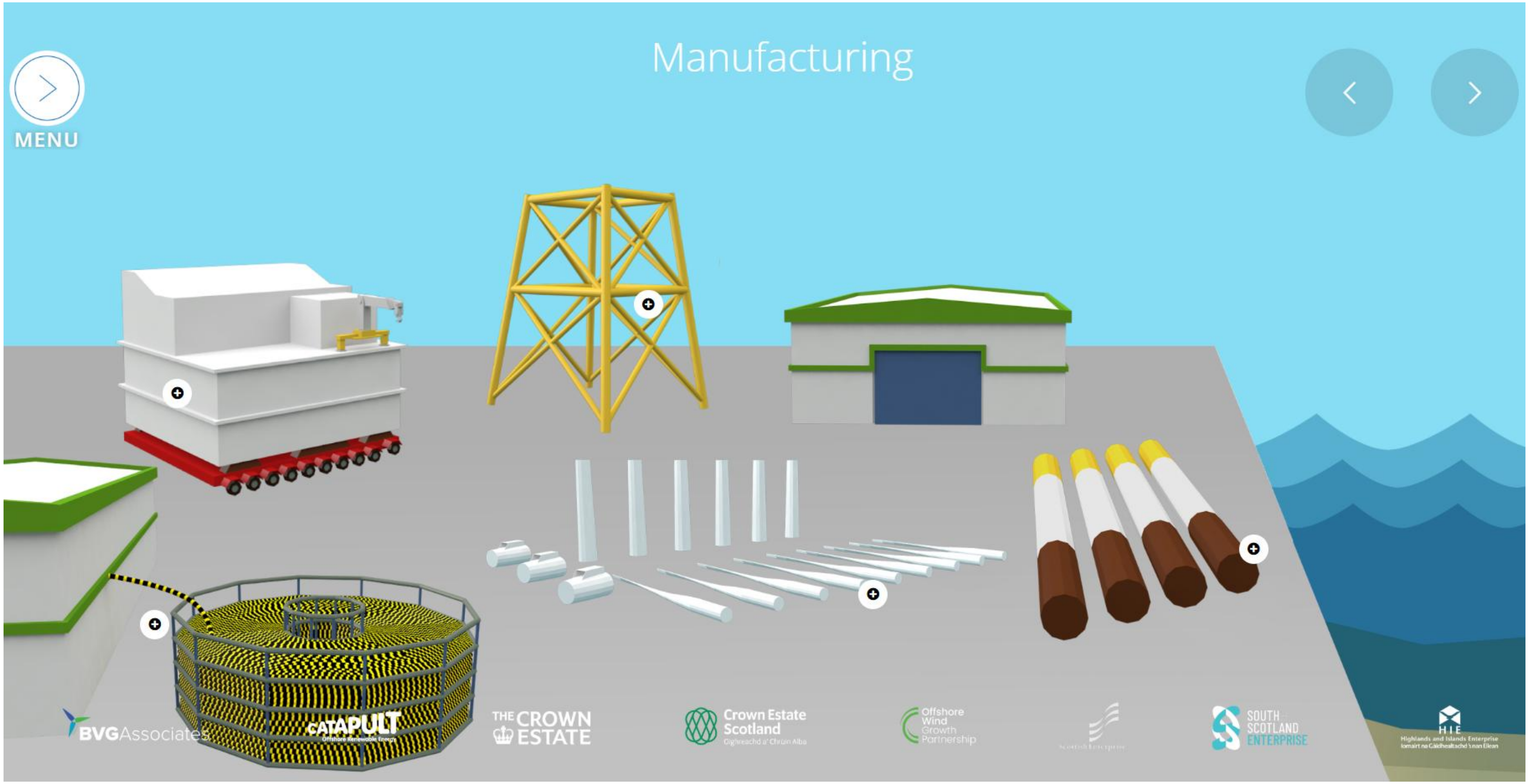
A glossary is provided, recognising that there are many industry-specific or technical terms and abbreviations used in the descriptions.

Images

Processes in the development, installation and operation of an offshore wind farm

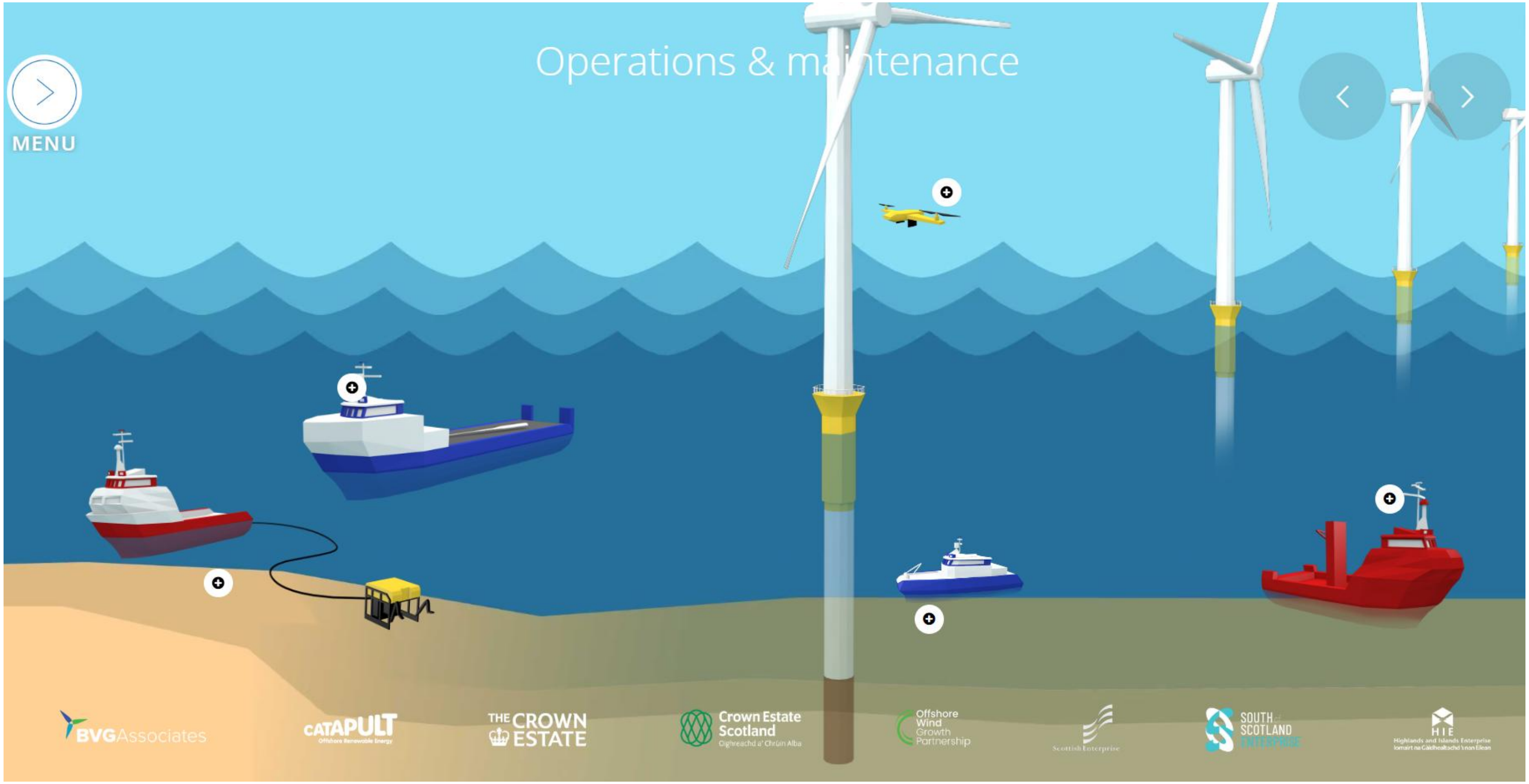
Development and project management

Manufacturing



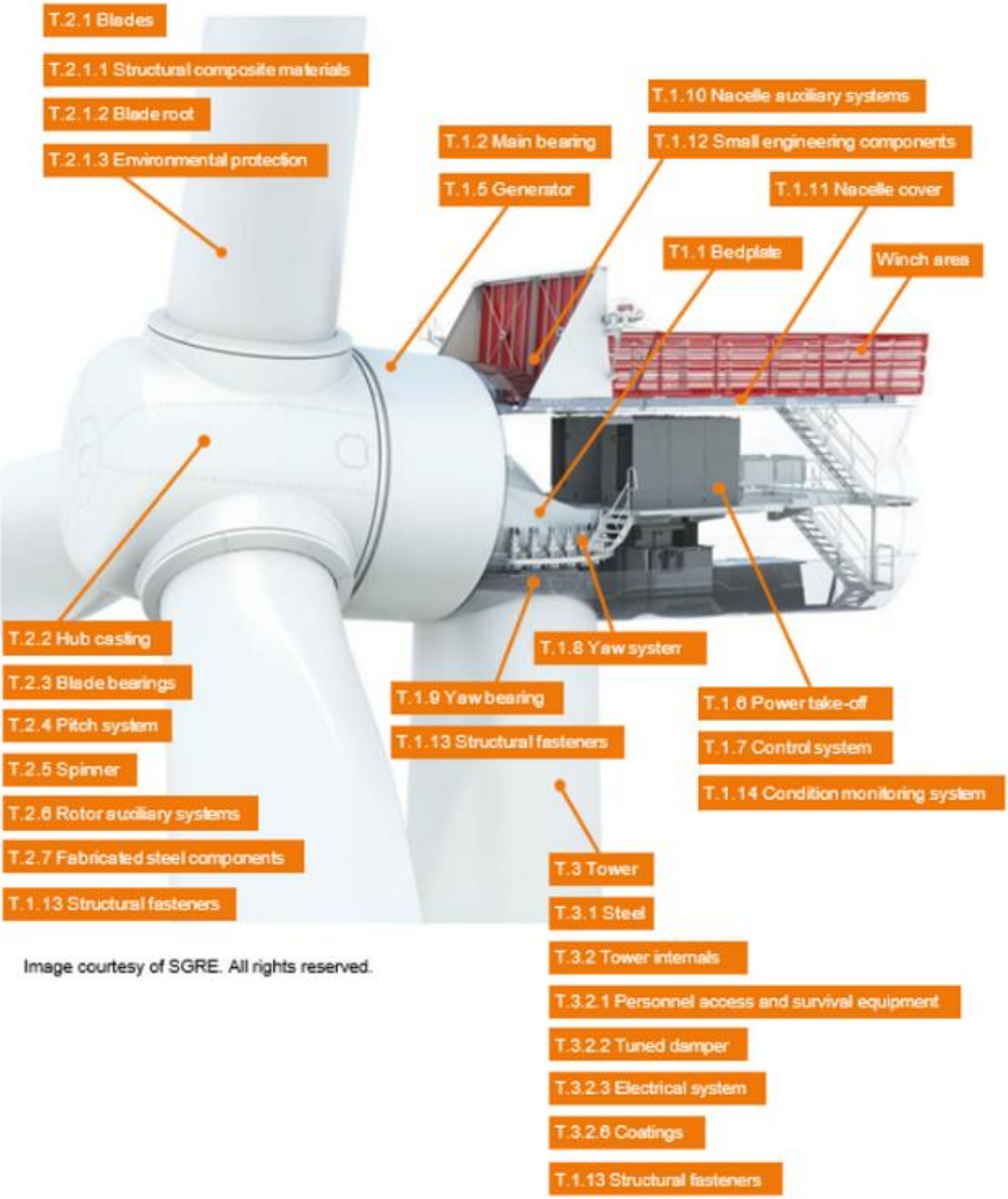
Installation

Operations and maintenance

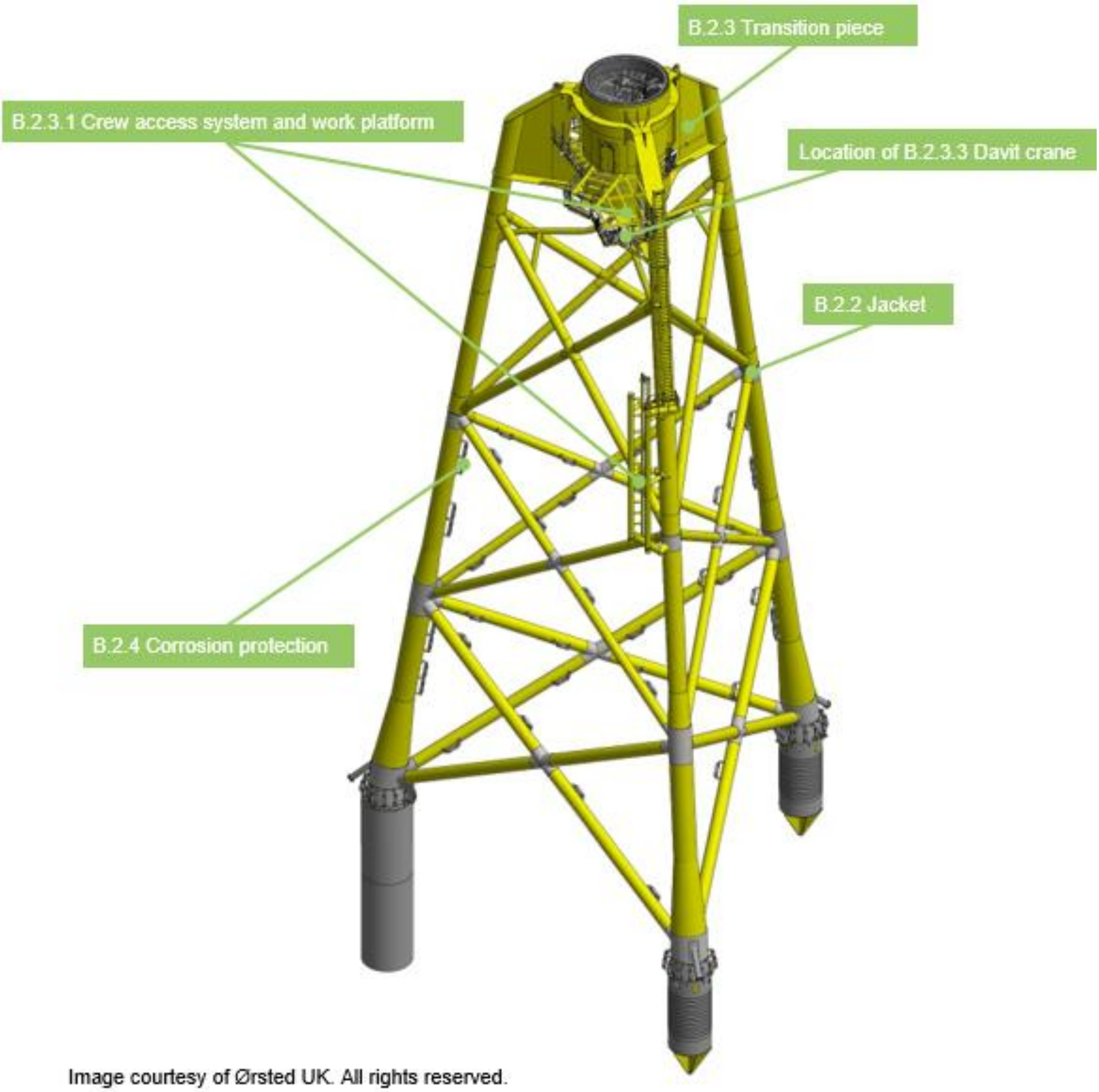


Decommissioning and repowering

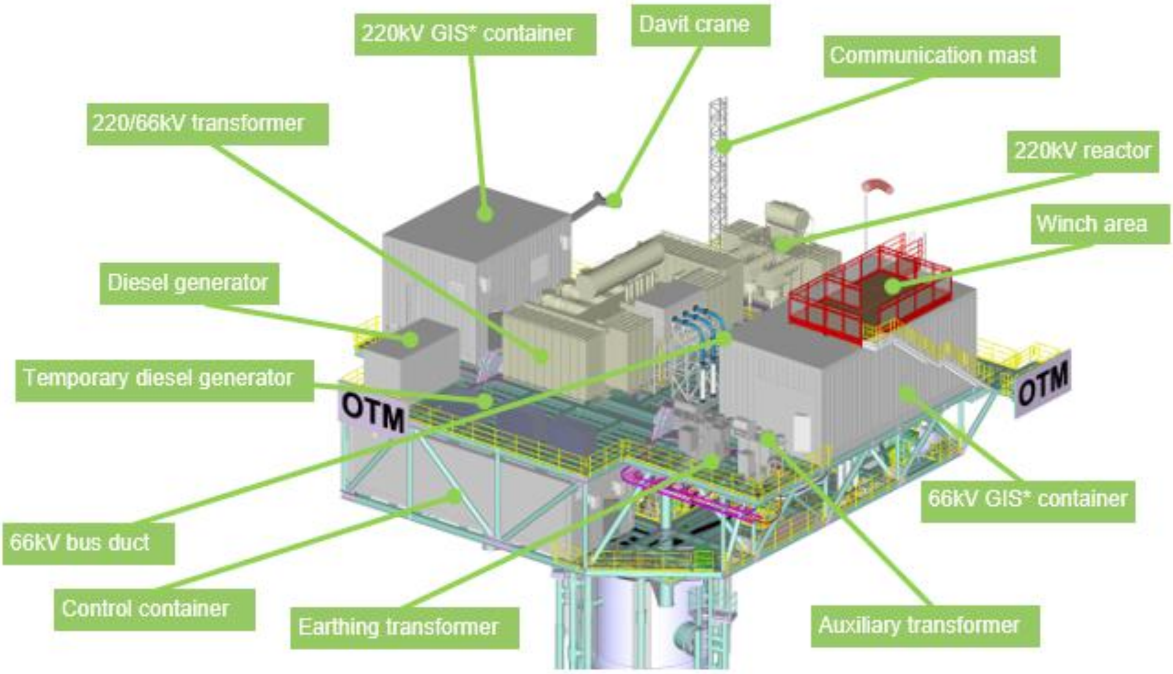
An offshore wind turbine



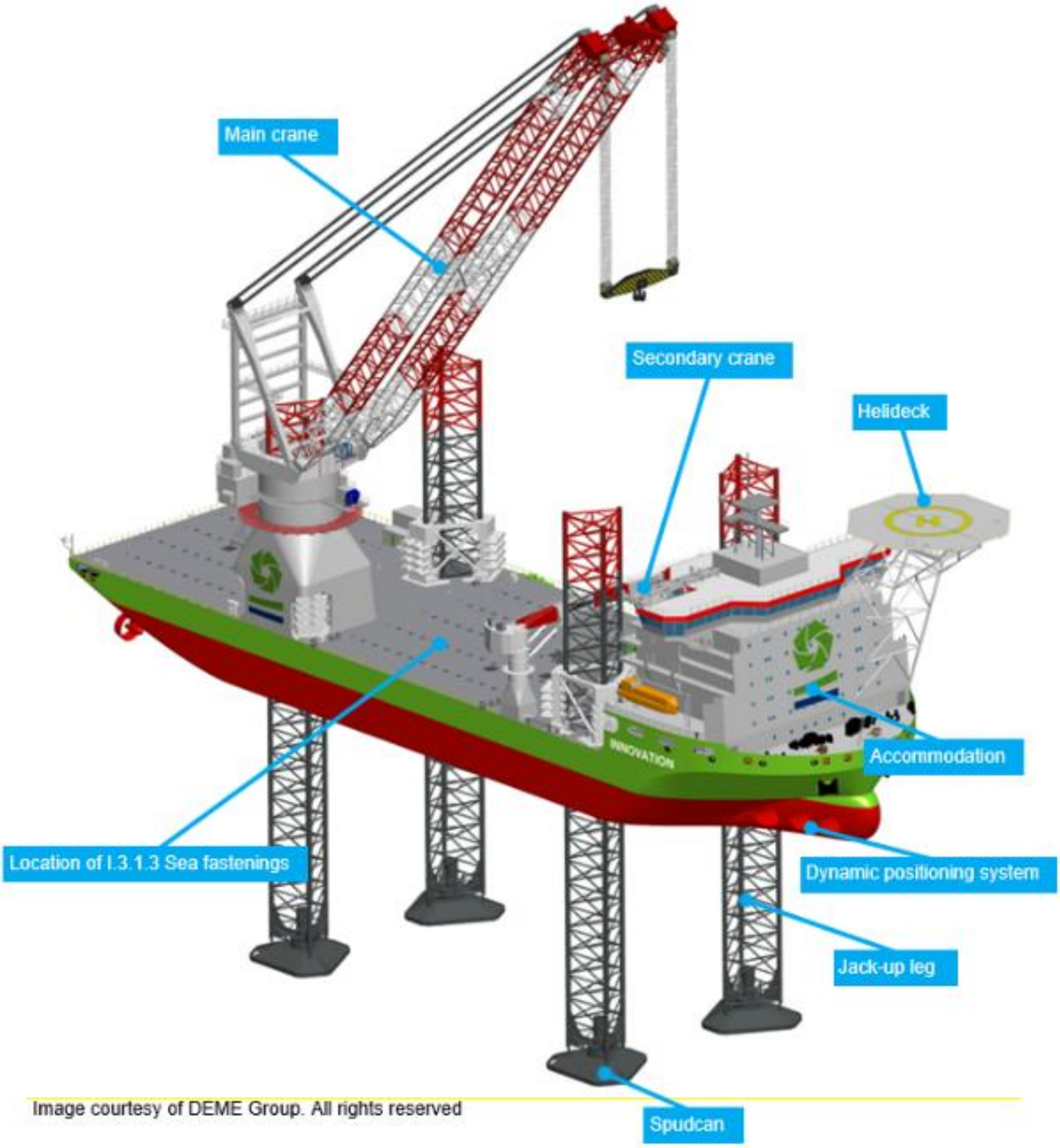
An offshore wind turbine jacket foundation



An offshore substation



An offshore wind turbine installation vessel



P Development and project management

Function

Development and project management covers the activities up to the point of financial close or placing firm orders to proceed with wind farm construction. This includes activities required to secure planning consents such as the environmental impact assessment, and activities required to define the design and engineering aspects.

What it costs

About £155 million for a 1 GW wind farm. This includes development and consenting services, environmental surveys, resource and metocean assessment, geological and geotechnical surveys, engineering and consultancy. It also includes development expenditure incurred by lost projects (not itemised in sections below).

A substantial portion of the cost is attributed to project management, which accounts for £48.4 million, while development and other consenting services excluding environmental impact assessments represents an additional £61.6 million.

Who supplies this

The development and consenting stage is managed by the wind farm developer. The main UK developers are: EDF Renewables, EDP Renewables, E.ON, Equinor, RWE, Ørsted, Red Rock Power, ScottishPower Renewables, SSE, Vattenfall and Flotation Energy.

Key facts

Sea bed leasing for existing offshore wind farms has been managed by The Crown Estate or Crown Estate Scotland through several leasing rounds that began in 2000.

Crown Estate Scotland was formed to manage the sea bed in Scottish Waters on behalf of Scottish Ministers. The Crown Estate retains responsibility for the sea bed in England, Northern Ireland and Wales.

Before the consenting process can begin, the developer must secure a sea bed lease from The Crown Estate or Crown Estate Scotland. These are granted through periodic leasing rounds.

Offshore wind projects of more than 100 MW installed capacity in England and Wales are defined as nationally significant infrastructure projects (NSIP) and are examined by the Planning Inspectorate.

The Secretary of State for the Department for Energy Security and Net Zero (DESNZ) grants or refuses consent based on a recommendation made by the Planning Inspectorate.

In England, a Development Consent Order is granted under the Planning Act 2008 (as amended) which incorporates a number of consents, including a marine licence and onshore consents. In Wales the marine licence is determined by Natural Resources Wales.

In Scotland, the Scottish Government's Marine Directorate examines applications for the offshore works and Scottish Ministers grant or refuse consent under the Marine (Scotland) Act of 2010 (up to 12 nm from shore) and the Marine and Coastal Access Act 2009 for projects 12-200 nm from shore. A streamlined process incorporates consent under Section 36 of the Electricity Act 1989 in parallel.

In Northern Ireland, the Marine Strategy and Licensing team within the Department of Agriculture, Environment and Rural Affairs (DAERA) manages the consent application and decision making process for offshore wind projects.

Other important aspects of the development process include securing land permissions for onshore substations and cable routes and engaging with the supply chain.

Onshore consent, including the transmission cable landfall, is awarded by the relevant local planning authority (LPA), except where a project is handled under an NSIP in England and Wales, in which case the onshore consents are considered within the NSIP process.

Developers typically build internal teams of about up to 50 staff during the development phase, which contract specialist packages of work to environmental and engineering consultancies and data acquisition and analysis companies.

The development process from first consideration of a site to FID typically takes between four and seven years in the UK. The offshore wind industry, and in particular some of the organisations which regulate it in Europe, are looking at how it can be accelerated.

What's in it

P.1 Development and consenting services

Function

Development and consenting covers the work needed to secure consent and manage the development process through to financial investment decision (FID).

What it costs

About £73 million for a 1 GW wind farm. This includes environmental impact assessments plus staff costs and other subcontractor work.

Who supplies this

Development services are typically led by the developer's special purpose vehicle (SPV), which manages the development process and subcontracts work to a range of specialist consultancies. The SPV is a legal entity, which invests in and owns the offshore wind farm project.

Suppliers include ABL Group, APEM, Arup, BVG Associates, DORIS, ERM, Entrust Professional, Kinewell Energy, Lloyd's Register, Mott MacDonald, OEG Renewables, RPS, Turner & Townsend, Wood Thilsted and Xodus.

Key facts

Developers typically set up an SPV for a wind farm. Should the project advance to construction, the SPV will continue to operate for the duration of the wind farm's life.

If the SPV is a joint venture between two or more developers, it is likely that the development team will be based in stand-alone offices to manage confidentiality.

The SPV provides a structure to enable external investment, although this investment is most likely to take place at FID or post construction.

In the UK, the SPV manages the design of the wind farm and secures consent for the wind farm and transmission assets.

An early formal step in the consenting process is the production of a scoping report, the purpose of which is to scope the level of impact on various receptors in order to properly define the required assessment process and methodologies, and to ensure the Environmental impact assessments (EIA) focuses on those impacts that may lead to substantial effects, It also provides an early opinion from the planning authorities to help shape and focus the development activity.

Developers aim to secure planning consent while retaining as much design flexibility as they can. A particular risk for developers is specifying a specific foundation solution or a maximum turbine size, which may prove to be restrictive at the point of procurement and require the developer to request variations to the consent order.

With too much design flexibility, the environmental impacts become less certain and more complex to analyse, which may be deemed undesirable by the consenting authorities. The range of options included in the proposed design is known as the design envelope, which includes a clear upper and lower bound on the scale of the project for example in terms of tip height.

Developers need to undertake an EIA, which describes the potential impacts with regards to a wide range of environmental factors.

The environmental statement is based on a number of detailed analyses. Most offshore wind developers have a predominantly in-house development management capability, with specialist work being outsourced. Specialist suppliers will often second employees into the developer's team for the duration of the development phase.

Throughout the development process, developers are obliged to seek the views of a number of statutory consultees. These include a wide range of government appointed consultees and authorities, affected local authorities and those that have an interest in the land affected. Non-statutory consultees with specific interests in the development are also likely to be consulted (such as RSPB).

Developers will also seek the views of local communities as part of this process and hold a series of public information and consultation events.

Supporting the work will be a range of specialist consultants, covering engineering design, legal issues, land use, environmental and stakeholder relations.

What's in it

- Environmental impact assessments [P.1.1]

P.1.1 Environmental impact assessments

Function

An EIA assesses the potential impact of the proposed development on the physical, biological and human environment during the construction, operation and decommissioning of the wind farm.

What it costs

About £11 million for a 1 GW wind farm.

Who supplies this

EIA suppliers include AECOM, Arcus, Arup, Cura Terrae Land & Nature, ERM, GoBe, Intertek, Land Use Consultants, Natural Power (Fred. Olsen), Royal Haskoning, RPS ,SLR and Sealand Projects.

Key facts

The most recent EIA regulations specify that the assessment must consider impacts on human health, climate change and biodiversity. To determine the impacts, a full suite of environmental surveys is undertaken.

After assessing the potential impacts, mitigation measures are defined and applied in order to determine the residual effects associated with the development. A core part of the EIA is the Cumulative Impact Assessment (CIA) where the development's impacts combined with those impacts from other foreseeable projects are assessed. The EIA is used to inform the Environmental Statement (ES), or EIA Report, which forms the core documentary evidence that is submitted to support a consent application.

Consultation with statutory consultees, special interest groups and the local community is performed throughout the EIA process and allows the consenting authority as well as other stakeholders and the public to voice their opinion and concerns.

The EIA process can take up to three years to complete, with the main driver being the length of time it takes to complete the required environmental survey work.

Under the Habitats Directive and the Conservation of Habitats and Species Regulations 2010 (as amended), developers should consider the potential effects on protected habitats. If the development is likely to affect a designated European site, the developer must provide a report with the application showing the designated European site that may be affected together with sufficient information to enable the decision maker to make an appropriate assessment, if required. A Habitat Regulations Appraisal (HRA) is performed as an integral part of an EIA to ensure that a project conforms to The Conservation of Habitats and Species Regulations (2010). More recently, HRAs are done at a plan level, including all wind farms in a leasing round.

What's in it

- Scoping
- Assessment
- Site-specific impacts
- Mitigation
- Residual impacts
- Environmental Statement
- Habitat regulations assessment

P.2 Environmental surveys

Function

A full suite of environmental surveys of the wind farm location and its surroundings is undertaken to determine the environmental impacts. These surveys establish the baseline for the assessment and allow impact modelling to be undertaken.

What it costs

About £9 million for a 1 GW wind farm.

Who supplies this

Suppliers include APEM, Applied Genomics, Arup, BMT, Briggs Marine, Carcinus, DORIS, ERM, Fugro, Fred. Olsen, Gardline Marine Services, Global Maritime, Mott MacDonald, Natural Power, Ocean Ecology, Ocean Infinity, RPS, RSK Environment, SLR, Sulmara, Venterra, Wood Thilsted and Xodus.

Key facts

Environmental surveys are one of the first tasks to be undertaken at a potential wind farm site and it can take two years or more before sufficient data is collected in order to apply for consent.

The surveys include bird, fish, marine mammal and habitat surveys as well as marine navigation studies, socio-economic surveys, commercial fishing, archaeology, noise analysis, landscape and visual assessment and aviation impact assessments.

Companies and developers recognise more detailed surveying can reduce costly consenting delays and post construction environmental monitoring requirements.

Some surveys need to establish regional behaviours of wildlife, for example bird feeding and breeding patterns and in these cases data may need to be collected for several years. For highly mobile wildlife populations such as birds or sea mammals, it may be difficult to establish whether the predicted impacts during construction will be enduring.

Surveys look at the distribution, density, diversity and number of different species. Increasingly these surveys are being aided by new technologies such as drones and artificial intelligence species recognition.

A challenge in the assessments is trying to understand the cumulative impacts of several wind farms, particularly when these are the subject of separate EIA and consenting processes.

Some environmental surveys are undertaken by companies that also offer geological or hydrological surveys, in which case the work can be done from the same vessels or aircraft in parallel. There are also opportunities to engage the fishing community to support relevant surveys.

Environmental surveys are typically undertaken by companies from the home market, partly because there is sufficient local resource and partly because some of the wildlife impacts are site specific and require detailed local knowledge and expertise.

Under the Offshore Wind Evidence and Change programme, The Crown Estate along with Natural England, Scottish Government and the Royal Society for the Protection of Birds regularly launches projects to protect and enhance marine biodiversity while encouraging offshore wind deployment.

What's in it

- Benthic environmental surveys [P.2.1]
- Fish and shellfish surveys [P.2.2]
- Ornithological environmental surveys [P.2.3]
- Marine mammal environmental surveys [P.2.4]
- Onshore environmental surveys [P.2.5]
- Human impact studies [P.2.6]

P.2.1 Benthic environmental surveys

Function

Benthic studies survey species that live on the sea bed and in sediment. The survey data and analysis is used to define areas of similar environmental conditions on the sea bed and to inform habitat and species impact studies.

Figure 1 Deployment of Van Veen grab sampler during benthic environmental survey campaign, courtesy of Fugro.

What it costs

About £1.2 million for a 1 GW wind farm.

Who supplies this

Suppliers include ABPmer, APEM, Fugro, Gardline, Natural Power (Fred. Olsen) and Ocean Ecology.

Key facts

Sampling sites are chosen so as to produce the most effective broad-scale categorisation of the overall region, as well as attempting to investigate smaller scale features such as reefs.

Specific attention is given to the presence of particular ecosystems, such as certain reef species, where their presence is of crucial significance to the EIA.

Methods include grab and sampling, epibenthic beam trawling and drop down video (DDV). Generally, surveys are designed to ground proof on geophysical data (bathymetry and sidescan), acquired for site characterisation of ground conditions, which has been interpreted to provide predictive habitat mapping.

What's in it

- Species identification and counting
- Laboratory analyses
- Impact models and reports

P.2.2 Fish and shellfish surveys

Function

Fish and shellfish surveys establish what species are present in the water column within the proposed wind farm site and surrounding areas. The resulting data is used to inform environmental impact analysis and reporting.

Figure 2 Beam trawling operations during fish and shellfish survey campaign, courtesy of Fugro.

What it costs

About £1 million for a 1 GW wind farm.

Who supplies this

Suppliers include ABPmer, APEM, Fugro, Gardline, Natural Power (Fred. Olsen) and Precision Marine.

Key facts

Beam trawls or otter trawls (dragging a net along the sea bed) are used to sample the species present in the area. In addition, other fishing methods such as lobster pots or gill nets can also be used on area where trawling cannot take place. Plankton nets can also be used for fish egg/larval studies (these are required).

Surveys are undertaken to characterise the species present in the area of the wind farm, but also to address specific questions such as whether fish are spawning in the area, should this be an issue for EIA.

Surveys can often be done using locally based fishing vessels, providing they reach safety standards. This approach offers the potential for good engagement with the local fishing community.

What's in it

- Species identification and counting
- Laboratory analyses
- Impact models and reports

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P.2.3 Ornithological environmental surveys

Function

Ornithological surveys establish the presence and behaviour of birds within the wind farm boundary and surrounding areas. The data from these bird surveys is used to establish the risks to birds that a wind farm may pose.

Figure 3 Seabird surveyors during survey campaign, © ESS Ecology.

What it costs

About £2.6 million for a 1 GW wind farm.

Who supplies this

Suppliers include APEM, ECON, ESS Ecology, FLI Services, Fred. Olsen, HiDef Aerial Surveying and RPS.

Key facts

Offshore ornithological surveying is normally one of the first tasks to be undertaken at a potential wind farm site because at least two years of data are needed to establish baseline conditions given the high level of spatial and temporal variation in bird abundance and distribution throughout the annual cycle. Furthermore, offshore ornithological constraints can have an important influence on wind farm design.

Seabirds, inshore wintering waterfowl, and terrestrial birds on migration are all surveyed to determine how they make use of the proposed area and therefore the different effects that a wind farm may have, including potential collision with turbines, disturbance and displacement, and both direct and indirect habitat loss (for example through effects on prey species).

A variety of methods are available for these purposes, each with their own advantages and disadvantages. Boat-based and digital aerial surveys are typically used to establish site-based population estimates and to gather behavioural data including species' flight heights (a key variable used to assess potential collision). Other methods such as GPS tracking, radar and coastal vantage point (VP) surveys can also be used to answer site-specific questions for example to establish connectivity between a specific breeding colony of seabirds and the proposed wind farm. Increasingly, these methods are being aided by new technologies, such as artificial intelligence image recognition and unmanned aerial drones.

What's in it

- Species identification and counting
- Impact models and reports

P.2.4 Marine mammal environmental surveys

Function

Marine mammal surveys establish the diversity, abundance, distribution and behaviour of cetaceans (including porpoises, dolphins and whales) and seals within the wind farm boundary and surrounding areas.

Figure 4 Deployment of passive acoustic monitoring equipment during marine mammal environmental surveys, courtesy of Fugro.

What it costs

About £2.6 million for a 1 GW wind farm.

Who supplies this

Suppliers include ABPmer, APEM, Cork Ecology, ECON, ESS Ecology, Fugro, Gardline, HiDef Aerial Surveying, Jon Ford Environmental, Natural Power (Fred. Olsen), Ocean Information Services, RPS and Seiche.

Key facts

Marine mammals are surveyed to determine how they make use of the proposed area and therefore the different effects that a wind farm may have, including potential disturbance and displacement, physical and auditory injury during pile driving, and both direct and indirect habitat loss (for example through effects on prey species).

A variety of methods are available for these purposes, each with their own advantages and disadvantages. The methods used will be dependent on the species and site in question. Traditional visual surveys using boat and aerial platforms are being supplemented or replaced by new, more accurate technologies such as static and towed acoustic monitoring, tagging of individuals with satellite transmitters and remotely controlled video monitoring supported by artificial intelligence image recognition.

Surveys are typically undertaken monthly for at least two years to establish how these variables change across seasons and between years. The data from these surveys is used to establish the potential impacts to marine mammals that a wind farm may pose.

What's in it

- Offshore ornithological and mammal surveying vessels and craft [P.2.4.1]
- Species identification and counting
- Impact models and reports

P.2.4.1 Offshore ornithological and mammal surveying vessels and craft

Function

Bird and marine mammal survey vessels and aircraft provide a platform for surveying to take place.

Figure 5 Specialist survey aircraft carrying out offshore wildlife surveys, courtesy of APEM.

Who supplies this

Vessels: Enviro-serve, Fugro, Gardline and Ocean Information Services.

Aircraft (including, but not limited to): APEM, Green Rebel, and HiDef Surveying.

Key facts

Traditional visual methods for surveying marine mammals are often undertaken concurrently with offshore ornithology surveys, offering a cost saving. Unfavourable weather and sea conditions have to be considered in the planning of surveys to ensure that the data collected is robust.

Multiple crews are used, including experienced and qualified surveyors, who rotate in shifts in order to avoid fatigue and maintain visual acuity. Traditional visual boat-based surveys can be supplemented with a towed hydrophone to undertake passive acoustic monitoring for marine mammals.

Whilst traditional visual aerial surveys can be used to record marine mammals, these are not suitable to record marine birds as the aircraft fly at relatively low altitudes and can cause disturbance (and therefore the data collected is not representative of baseline conditions). Instead, digital aerial survey aircraft can be used which fly at much higher altitudes, recording both birds and marine mammals.

These survey aircraft have a range of remote sensing instruments on board such as high-resolution digital cameras, lidar, video imaging and imaging spectrometers. Twin-engine planes, with long-range fuel tanks and autopilot capabilities allow for extensive surveying offshore without the need for on-board surveyors.

There is potential for the increased use of autonomous vessels and aircraft with remote sensing instruments and artificial intelligence to analyse data, to reduce cost and carry out more extensive offshore surveys.

What's in it

- Vessels and aircraft
- Provision of suitably experienced and qualified crew

P.2.5 Onshore environmental surveys

Function

Onshore environmental surveys consider the potential ecological impact that cable-laying and onshore substations and new port facilities may have on the onshore environment.

Figure 6 Onshore environmental surveys, courtesy of Rampion Offshore Wind.

What it costs

About £1.2 million for a typical 1 GW wind farm.

Who supplies this

Suppliers include Andrew McCarthy Associates, APEM, BCM Environs, ESS Ecology, Fred. Olsen, Natural Power, RSK and Thomson Ecology.

Key facts

Wildlife surveys are often undertaken by ecological companies who have specialised capabilities for particular species.

Studies tend to look at the distribution, density and number of different species.

Wildlife ranging from badgers to small reptiles are considered, depending on the nature of the proposed site.

Fragile coastal ecosystems are a prime area of focus.

What's in it

- Surveying
- Data analysis
- Reporting

P.2.6 Human impact studies

Function

Human impact studies assess the impact that a proposed wind farm may have on the community living in and around the coastal area near the wind farm including assessing visual and socio-economic impacts.

What it costs

About £770,000 for a 1 GW offshore wind farm.

Who supplies this

Suppliers include BizGive, ERM, Hayes Mackenzie, Hoare Lea, LUC, Royal HaskoningDHV, RPS and SLR.

Key facts

Visual assessments comprise of photomontages from specific viewpoints of what the proposed wind farm will look like. Noise assessments assess that potential noise impacts and determine whether the impact of the proposed wind farm is within the guidance of relevant noise standards. Other areas studies include fisheries and archaeology.

The socio-economic study assesses the impacts of a wind farm or coastal infrastructure, for example a port, such as changes in employment, transportation or recreation, or changes in the aesthetic value of a landscape. It estimates the impacts on the local society, not only of these socio-economic changes, but also of the composite of biological, geological, and physical effects caused by the proposed change on the local area.

Socio-economic studies include a mix of objective and subjective data. Objective data can include statistics on age, income distribution, ethnicity, mortality, housing type and occupancy, and education. Subjective data can be derived from surveys and observations. These are used to provide systematic estimates of the ways in which various groups perceive their socio-economic environment and thus the impact of the proposed change. Studies consider the onshore cable route and substation.

What's in it

- Surveys
- Consultation

P.3 Resource and metocean assessment

Function

Resource and metocean assessments provide atmospheric and oceanographic datasets to inform the engineering design of a wind farm, the potential future energy production, and to fully describe the likely operating conditions at the proposed wind farm location.

Figure 7 Example of a floating lidar used to capture atmospheric data. Image courtesy of EOLOS. All rights reserved.

What it costs

Costs for resource and metocean assessment are about £7 million for a 1 GW offshore wind farm

Example costs for elements of this include:

- Structure: £3.5 million
- Sensors: £2.9 million
- Maintenance: £660,000

Who supplies this

Floating lidars: AXYS Technologies, EOLOS, EOLFI, Fraunhofer IWES, Fugro, IDS Monitoring, RPS and ZX Lidars.

Lidar units: Leosphere and ZX Lidars.

Metocean campaigns and buoys: AXYS Technologies, Fugro, Partrac and Sonardyne.

Reference data provision: The Met Office, StormGeo and Vortex.

Resource campaign management and design: Arup, AXYS Technologies, BMT, Briggs Marine, DNV, DORIS, Fugro, Global Maritime, HR Wallingford, K2 Management, Mott MacDonald, Natural Power, Oldbaum, RPS, Venterra, Wood, Wood Thilsted, Xodus and ZX Measurement.

Key facts

Measurement systems are installed at the project location to collect wind and other relevant meteorological data. Meteorological sensors measure wind speed (with instruments at a number of heights or measuring over a range of heights with one sensor), wind direction, temperature, pressure, humidity, solar radiation and visibility. Measuring wind speeds at different heights provides critical information about the wind speed profile at the site, aiding decisions about the turbine and floating substructure design. Wind speed data is required to at least the proposed hub-height of the wind turbines, which is 130 m or more above sea level for a 15 MW turbine. Metocean buoys are installed in and around the floating offshore wind farm site to collect metocean data. Metocean sensors include wave, sea level and current sensors (for example acoustic Doppler current profiler) which are sometimes sea bed positioned. These record the full wave data spectrum including velocity, direction, and period. Multiple sensors are used to provide spatial coverage and redundancy. This information is crucial in establishing whole system dynamics including substructure design types, turbine ratings, vessel types and operations and maintenance (O&M) strategies.

Long-term reference datasets are required to describe the climatology of the proposed site over a longer period typically more than 15 years. Data is usually collected for a period of at least one year to reflect seasonal variation in wind resource and metocean conditions.

These combined data sets are used in the offshore wind farm system design process, the turbine selection process and to predict the annual energy production (AEP) of the offshore wind farm. Metocean data is also used to inform the vessel selection and operational strategies for the site and is made available to vessel operators and marine planners during the construction and operational phases.

A key interface exists in determining the long-term site conditions between wind resource and metocean disciplines. The output from this interface is the extreme wind and wave climate for the proposed site.

Traditionally assessment was done using hub-height wind masts which are fixed to the sea bed and require a subsea structure, but the trend is towards the use of floating lidars as they are cheaper and easier to install.

Lidars are a type of remote sensing anemometry device which uses lasers to measure wind speed and direction at up to 300 m above sea level. Floating lidars are moored buoys on which lidars are mounted. This allows the lidars to be deployed and change location as per demand.

When using lidar as the primary measurement instrument, supplementary modelling may be used to inform site conditions such as turbulence and horizontal wind gradients.

Wind and metocean measurement systems require power supply to run sensors, data storage and telemetry. For low power systems this is often achieved with solar PV panels, small wind turbines and battery storage. Larger systems use diesel generators or hydrogen fuel cells.

Current state of the art campaigns integrate measurement and modelling techniques across both oceanographic and wind resource disciplines. The study can be further broadened to look at further issues such as turbulence, atmospheric stability conditions and the influence of neighbouring offshore wind farms on the proposed site wind conditions.

Resource and metocean systems require maintenance, including inspection, cleaning, and refuelling (where diesel generators or hydrogen fuel cells or similar are used). Maintenance visits are typically carried out two to four times per year. Systems are designed to operate autonomously, with onboard power, data and communications systems.

Sensors provide data on meteorological and oceanographic conditions at the site of interest. Data loggers provide data storage, processing, and remote communications capability.

What's in it

- Anemometers
- Buoys
- Data loggers
- Lidar systems
- Maintenance
- Meteorological sensors
- Metocean sensors
- Wave measurement sensors

P.4 Geological and hydrographical surveys

Function

Sea bed surveys analyse the sub sea bed environment of the proposed wind farm site and export cable route to assess its geological condition and engineering characteristics. The data collected is utilised in a wide range of engineering and environmental studies through the design and development phase.

What it costs

About £9.4 million for a 1 GW wind farm.

Who supplies this

Suppliers include ABL Group, Acteon Group, Arup, Briggs Marine, Cathie, CMS Geoscience, DORIS, EGS, Enshore Subsea, Fugro, G-tec, Gardline, Horizon, James Fisher Marine Services, MMT, Mott MacDonald, Ocean Infinity, Oceaneering, OEG Renewables, RPS, Sulmara, Tekmar Group, Venterra, Wood Thilsted and Ultrabeam.

Key facts

Sea bed surveys consist of two main parts; geophysical surveys of sea bed features and bathymetry; geotechnical surveys of the sea bed characteristics.

Sea bed surveys are an important component of the development process and aid a number of processes, such as optimising the foundation design and wind farm layout, as well as minimising risk during installation activities.

Environmental and sea bed (geotechnical and geophysical) surveys and data collection start up five years or more before the planned operation of the wind farm.

Offshore wind development typically requires more data collection over larger areas but the technical approaches are similar to other sectors, such as oil and gas.

The move to auction based systems such as Contract for Differences (CfD) in the UK has placed a greater emphasis on geological and hydrographical surveys as developers require greater design and cost certainty earlier in the development process.

What's in it

- Geophysical surveys [P.4.1]
- Geotechnical surveys [P.4.2]
- Hydrographic surveys [P.4.3]

P.4.1 Geophysical surveys

Function

Geophysical surveys establish sea floor bathymetry, sea bed features, water depth and soil stratigraphy, as well as identifying hazardous areas on the seafloor and manmade risks such as unexploded ordnance (UXO).

What it costs

About £2.5 million for a 1 GW wind farm.

Who supplies this

Suppliers include AAE Technologies, Acteon, Argeo, Fugro, Gardline, G-tec, Horizon Geosciences, Inosys, Kraken, MMT, Oceaneering, Sulmara, Ternan Energy and TGS.

Key facts

Geophysical surveys are non-intrusive and include remote sensing techniques such as seismic methods, echo sounding and magnetometry.

The techniques used consist of bathymetry (water depth) mapping with conventional single or multibeam echo soundings or swathe bathymetry, sea floor mapping with side scan sonar, magnetometer for UXO, acoustic seismic profiling methods and high resolution digital surveys.

Surveys run along transects across zones within the proposed wind farm site and cable routes.

Information from geophysical surveys is used to aid the design and implementation of the benthic and geotechnical surveys, so they are often undertaken near the beginning of the development process.

Data from geophysical surveys are used to produce charts and maps for GIS systems, which are then used for site layout design.

Geophysical surveys can be used to identify UXO on or below the sea bed.

Geophysical surveys may also consider marine archaeology that may be present in the wind farm site. This is typically dealt with by specialist archaeological survey companies, and is offered as a service in conjunction with the geophysical surveys.

What's in it

- Geophysical survey vessels [P.4.1.1]

P.4.1.1 Geophysical survey vessels

Function

Specialist vessels are used to carry out geophysical surveys of the sea bed.

Who supplies this

Suppliers include Fugro, Gardline, Hydrosurv, Horizon Geosciences, Kraken Robotics, MMT, Sulmara and XOCEAN.

Key facts

Geophysical vessels are typically about 30-70 m in length, however smaller autonomous vessels are increasingly being considered. The vessels must provide a stable platform even in unfavourable sea and weather conditions.

On manned vessels, multiple crews, including highly specialised equipment operators, are utilised and the vessel has sleeping berths and living quarters to allow the vessel to have an operational endurance of up to a month.

Crew work 12 hour shifts with rotations month by month enable a constant flow of data observation, processing and interpreting.

Figure 8 A specialist geophysical survey vessel. Image courtesy of Fugro. All rights reserved.

What's in it

- Specialist crew
- Survey and analysis equipment

P.4.2 Geotechnical surveys

Function

Geotechnical site investigations are conducted following the geophysical survey to use the information obtained to target soil and rock strata boundaries, engineering properties and specific sea floor features.

Figure 9 Technician carrying out geotechnical survey in laboratory, courtesy of Igeotest.

What it costs

About £5 million for a 1 GW wind farm.

Who supplies this

Suppliers include Fugro, G-tec, Gardline, Geoquip Marine, Horizon. OWC, Rydar Geotechnical and Sulmara.

Key facts

Geotechnical studies are predominantly intrusive and include such methods as boreholes with soil/rock sampling, and cone penetration testing (CPT).

Geotechnical investigation is generally the most expensive part of wind farm survey work, making it a substantial at-risk investment for developers. Typically the geotechnical surveys are performed in phases to add value to the project risk mitigation process.

Geotechnical surveys require specialised equipment and skilled personnel. The scope of the investigation depends on the type of foundation being considered and the variability in the sea bed characteristics.

Boreholes and CPTs to depths in the order of 50-70 m are carried out to investigate the physical characteristics of the sea bed. Surface push CPTs are also used as a rapid method to gather sea bed soil stratigraphy. Cable routes are typically investigated using vibrocores and CPTs to a depth of 5 m.

Offshore laboratories are used to obtain basic soil parameters and the samples taken are then returned to an offshore laboratory for detailed testing. Often soil dynamics tests are performed to monitor the soil behaviour under the constant dynamic loading on the foundation by the wind, waves and current.

Resultant data from the geotechnical surveys are combined with results of the geophysical survey, to improve the geological model prior to the design and installation of foundations. Geotechnical data is also used at a later date in combination with heavy lift jack-up vessel information to determine the risks and feasibility of conducting heavy lift construction activities.

Fixed offshore wind farms require geotechnical data to depths of 50 to 70 m to inform the design of monopile or jacket foundations.

What's in it

P.4.2.1 Geotechnical survey vessels

Function

Specialist vessels carry out geotechnical surveys of the sea bed.

Figure 10 Geotechnical survey and drilling vessels Fugro Synergy (front) and Fugro Bucentaur (back), courtesy of Fugro.

Who supplies this

Suppliers include Fugro, G-tec, Gardline, Horizon and Sulmara.

Key facts

The vessels are typically 60 -100 m length and typically operate their drilling systems through a central moon pool. Some sea bed systems are deployed over the side or stern via A-frames or heavy lift cranes. The vessels are able to operate independently in remote locations.

Jack-up vessels can also be used (albeit smaller than those used for foundation and turbine installation) where water depth and sea bed conditions are suitable. The vessels must be able to position themselves at specific locations for borehole sampling using dynamic positioning or anchors and must be able to withstand unfavourable sea and weather conditions.

The vessels provide a stable platform for the acquisition of samples and in-situ testing. Due to the expense of hiring these vessels, multiple crews, including highly specialised equipment operators, are utilised and the vessels have sleeping berths and living quarters to allow the vessel to have an operational endurance of over a month.

Offshore laboratories also allow for data acquisition and processing onboard. Crew rotations month by month enable a constant flow of data collection, processing and interpreting.

What's in it

- Specialist crew
- Survey and analysis equipment

P.4.3 Hydrographic surveys

Function

Hydrographic surveys examine the impact of the wind farm development on local sedimentation and coastal processes such as erosion. This is often part of the geophysical survey. These surveys are also part of the post construction monitoring during the operations phase.

What it costs

About £1.9 million for a 1 GW wind farm.

Who supplies this

Specialist hydrographic survey companies such as Fugro, Gardline and MMT perform the surveys and consultants such as ABPmer and HR Wallingford undertake the impact modelling.

Key facts

Understanding the sedimentation environment of the proposed site is of particular importance as it will inform the scour characteristics of the site and subsequent protection measures required.

What's in it

- Vessels
- Crews
- Survey equipment

P.5 Autonomous survey vessels

Function

Various development and project management surveys are increasingly being carried out by autonomous vessels. These include Maritime Autonomous Surface Ships (MASS) and MiniMASS, are designed to perform various offshore wind farm operations such as surveys, inspections, and maintenance. These vessels operate with varying degrees of autonomy, enhancing operational efficiency, safety, and reducing the need for onboard personnel.

What it costs

The day rate for an autonomous survey vessel varies significantly with the type of equipment needed on board.

Who supplies this

Suppliers include XOCEAN, Ocean Infinity, Fugro, Kongsberg Maritime, L3Harris, Saab Seaeye. Saildrone, Sea-Kit, Subsea7 and Sulmara.

Key facts

Autonomous vessels are classified based on size and degree of autonomy:

- MiniMASS (Maritime Autonomous Surface Ships less than 2.5 meters): These vessels are under 2.5 meters in length and are typically used for nearshore surveys and environmental monitoring. They are exempt from certain certifications due to their size, as outlined by the Maritime and Coastguard Agency (MCA).
- MASS (Maritime Autonomous Surface Ships over 2.5 meters): Vessels exceeding 2.5 meters in length, used for a broader range of offshore tasks, including geophysical and hydrographic surveys.

The International Maritime Organization (IMO) defines four degrees of autonomy for MASS:

- Degree One: Ships with automated processes and decision support, with seafarers onboard ready to take control as needed.
- Degree Two: Remotely controlled ships with seafarers onboard; the vessel is operated from another location, but crew members can take control if necessary.
- Degree Three: Remotely controlled ships without seafarers onboard; the vessel is entirely operated from a remote location.
- Degree Four: Fully autonomous ships capable of making decisions and determining actions by themselves.

Autonomous vessel adoption is accelerating in the UK offshore wind sector due to improved operational safety by reducing offshore personnel exposure, lowering overall operational costs, reducing environmental impact, and increasing survey efficiency. These vessels expand operational windows and support better data acquisition, allowing developers to manage project risks more effectively.

What's in it

- Autonomous or remotely operated vessel platform (surface or subsurface)
- Shore-based remote operation centres with satellite communications
- Advanced sensor and instrumentation suites (sonar, cameras, environmental monitoring sensors)
- Automated navigation, positioning, and control systems
- Onboard data acquisition, processing, and transmission systems
- Energy-efficient power sources, such as batteries or hybrid systems.

P.6 Engineering and consultancy

Function

Provides technical expertise, planning, and advisory services to design, optimise, and outline technical specification for offshore wind farm development.

What it costs

About £9.5 million for a 1 GW offshore wind farm.

Who supplies this

Suppliers include:

ABL Group, Acteon Group, APEM, Apollo, Arup, BMT, BVG Associates, CASC, Cathie, Chartwell Marine, Correll Group, DORIS, Enshore Subsea, Entrust Professional, Environment Ltd (Atlantic58), ERM, First Marine Solutions, First Subsea, Global Maritime, Heavy Lift Projects, HR Wallingford, JDR Cable Systems, Kent, Kinewell Energy, Maritime Developments, Mott MacDonald, Motive Offshore Group, Ocean Infinity, Oceaneering, OEG Renewables, Offshore Solutions Group, ONYX Insight, Pharos Offshore, RPS, SeaRoc, Seaway 7, SMD, Sulmara, Tekmar Group, Turner & Townsend, Venterra, Verlume, W3G Marine, Western Isles Marine, Wood, Wood Thilsted and Xodus.

Key facts

Front-end engineering and design (FEED) studies address areas of wind farm system design and develop the concept of the wind farm in advance of procurement, contracting and construction.

Earlier on in the process, pre-FEED studies are used to develop an outline concept of the project for the purposes for defining the consent envelope and to inform environmental impact studies.

The FEED study is refined through the development process in to “detailed design” post-FID. Designs are ultimately used to frame and process substantial engineering and procurement decisions.

Key parameters such as turbine size, foundation type, wind farm layout, substation design, electrical system and grid connection method are considered in order to minimise the project’s levelised cost of energy (LCOE).

FEED studies also include planning of onshore and offshore operations, port and vessel strategies, determining contracting methodologies and the development of key risk management and health and safety procedures.

The FEED study seeks to understand the total wind farm system in an integrated way and to consider the impact of engineering decisions on the LCOE, and to ensure that engineering decisions take full cognisance of environmental and consenting risks and impacts.

The FEED study is a multi-disciplinary process that requires extensive communication and coordination, often across multiple teams and organisations.

Engineers normally use industry-specific standards to guide the design process for components including the substructure. The most complete standards for floating offshore wind are IEC 61400-3-1 and DNV-ST-0126.

The output of FEED studies is used by construction management teams in order to procure and construct the wind farm.

The move to auction based systems such as CfD in the UK has placed a greater emphasis on FEED studies as developers require greater cost certainty earlier in the development process.

Project certification is an independent process used to give confidence to parties such as the developer’s senior management, lenders or insurers, that the design, manufacture and installation of the whole project has been carried out to appropriate standards. It is not a regulatory requirement in the UK but is normally used for offshore wind projects.

What's in it

- Layout design and optimisation
- Turbine selection
- Foundation type selection
- Electrical design strategy
- Interface management
- Health and safety planning
- Installation methods
- Operational strategy

T Wind turbine

Function

The turbine converts kinetic energy from the wind into three-phase AC electrical energy.

Figure 11 Wind turbine, courtesy of GE Vernova.

What it costs

The cost for a 15 MW wind turbine is about £18.2 million. This includes components as well as assembly and wind turbine supplier aspects of installation and commissioning, plus warranty provision. Installation and commissioning costs relate mainly to logistics and staff costs at its head office, the construction port, on the installation vessel and on the turbine relating to mechanical and electrical completion, testing and pre-handover checks and trouble shooting. These costs typically exceed £1 million per turbine.

Who supplies this

Suppliers include CSSC Haizhuang, Doosan, Dongfang Electric Corporation, Envision, GE Vernova, Goldwind, MingYang, Shanghai Electric, Siemens Gamesa Renewable Energy (SGRE), Vestas and Unison.

Key facts

Most designs have upwind, pitch controlled, variable speed rotors with three blades. Compared to onshore wind turbines, turbines are much larger and there is an increased focus on reliability and maintainability and a decreased impact of noise, visual and transport constraints.

Wind turbine suppliers are systems integrators, buying bespoke or standard components from a wide range of suppliers. Blades are typically manufactured in-house, along with a few other components in some cases, depending on the industrial strength and breadth of the supplier.

There are fewer offshore turbine suppliers than onshore. The high investment costs, large project sizes but relatively low overall sales volumes make it difficult for new suppliers to enter the market.

Typically, after a new turbine platform is developed, turbine variants are offered with higher rating and/or larger diameter rotor. These variants become possible once the loads and factors of safety are better understood through early operation of first turbines in a new platform. This extends sales lifetime of a given platform while minimising development costs.

Wind turbine suppliers prefer to operate a small number of nacelle assembly facilities and blade manufacturing facilities, to gain economies of scale, reduce quality risks and avoid adding complication and cost to their supply chains. The choice of site depends on the size of the local market, the locations of key suppliers, skills availability, and support for local job creation. The typical design life of an offshore turbine is 25 years. A trend for longer design life is due to the maturing of the industry, as asset owners now expect to operate wind farms for at least this long without the technology becoming obsolete or unsupported by suppliers. The design driver for many components is fatigue loading when generating. Extreme loads due to storms, abnormal events and faults during operation can also be critical. Typically, an offshore turbine will be turning for up to 90% of the time.

Turbines are type certificated by third party authorities. This confirms that the wind turbine type is designed, documented and key features of performance verified in conformity with specific standards and other technical requirements. This certification also covers the suppliers of the key components.

Health and safety requirements are focused on safety by design where the need for people to be put in hazardous environments is minimised or avoided at the design stage.

What's in it

- Nacelle [T.1]
- Rotor [T.2]
- Tower [T.3]

T.1 Nacelle

Function

The nacelle supports the rotor [T.2] and converts the rotational energy from the rotor into three-phase AC electrical energy.

Figure 12 GE's Haliade X 12 MW nacelle. Image courtesy of GE VernovaRenewable Energy. All rights reserved.

What it costs

The nacelle cost for a 15 MW wind turbine is £11.7 million.

Who supplies this

Nacelles are assembled by the wind turbine supplier, using components generally sourced from a range of external suppliers.

Fasteners: Cooper & Turner

Polymer solutions: Nylacast

Key facts

Typical dimensions for a nacelle for a 15 MW turbine are 21 to 25 m long, 9 to 12 m wide and 10 to 12 m high for transport, with masses of 600 to 800 t including the hub. Key nacelle components include the main bearing, gearbox (where used), generator, yaw bearing and yaw system.

The main bearing supports the rotor and transfers the rotor loading to the nacelle bedplate. Several nacelle layouts exist for offshore wind turbines including a single bearing supporting the generator and rotor. Another approach is to support the main shaft with a bearing at each end.

Where used, a gearbox converts rotor torque at a speed of 4 to 8 rpm to a speed of up to about 600 rpm for a medium-speed gearbox. The gearbox is a critical item in the wind turbine drive train, with particular attention given to long-term reliability.

There has been a move away from gearboxes with conventional high-speed generators for offshore turbines. For example, GE Vernova and SGRE have opted for direct drive turbines without a gearbox. Instead, they use a larger and more complex low-speed generator. Vestas has opted for turbines with a gearbox and medium-speed generator.

The generator converts mechanical energy to electrical energy. Most generators use permanent magnets that need no excitation power. This keeps efficiency high, mass low and dimensions small, lowering transport and installation costs but does rely on the supply of rare-earth alloys.

The yaw bearing connects the nacelle and tower, enabling the yaw system to turn the nacelle to any direction during operation. The yaw system orients the rotor and nacelle to the wind direction during operation.

Other nacelle components include the:

- Bedplate which supports the drive train and the rest of the nacelle components and transfers loads from the rotor to the tower
- Main shaft (if used) which transfers torque from the rotor to the gearbox or, for direct drive designs, the generator
- Control system which provides supervisory control (including health monitoring) and power and load control in order to optimise wind turbine life and revenue generation, while meeting externally imposed requirements
- Condition monitoring system which provides additional health checking and failure prediction capability
- Electrical power take-off system, and
- Other auxiliary systems providing heating, cooling, safety and other operational or personnel-support functions.

Nacelle mass is kept as low as reasonably possible to help with overall system dynamics and minimise logistics costs. To keep nacelle mass down, turbine designs may have the transformer and much of the power electronics in the tower base. Mid-grade steels and cast spheroidal graphite (SG) iron are used rather than lower- or higher-grade materials as they offer the lowest cost per unit fatigue strength at acceptable mass.

Before dispatch, the nacelle undergoes a functional test before being prepared for transport and storage. It is also typically tested with its power take-off hardware.

New designs of offshore turbines place a high emphasis on maintainability. This is being achieved through modular designs for large components so more subcomponents can be replaced using the nacelle crane.

The nacelle incorporates high levels of remote monitoring, health checking and control.

What's in it

- Bedplate [T1.1]
- Main bearing [T1.2]
- Main shaft [T1.3]
- Gearbox [T1.4]
- Generator [T1.5]
- Power take-off [T1.6]
- Control system [T1.7]
- Yaw system [T1.8]
- Yaw bearing [T1.9]
- Nacelle auxiliary systems [T1.10]
- Nacelle cover [T1.11]
- Small engineering components [T1.12]
- Structural fasteners [T1.13]
- Condition monitoring system [T.1.14]

T1.1 Bedplate

Function

The bedplate supports the drive train and the rest of the nacelle components and transfers loads from the rotor to the tower.

What it costs

The bedplate cost varies significantly for different nacelle layouts.

Who supplies this

Bedplates are normally cast SG iron, with a steel fabricated rear section.

Casting: Fonderia Vigevanese, MeuselWitz Guss, Sakana, Siempelkamp and Silbitz. Only some can manufacture the largest bedplates for offshore turbines today.

Fabrications: A reasonable range of steel fabricators exist capable of bedplate manufacture.

Key facts

Frequently, bedplates are manufactured in two parts. In a conventional nacelle layout, the heavier section supports the gearbox [T.1.4] and the yaw system [T.1.8], transfers loads from the rotor [T.2] to the tower [T.3] and is frequently cast. A lighter rear section supports the generator [T.1.5] and other components at the rear of the nacelle and is normally fabricated. For a direct-drive turbine, the generator takes the place of the gearbox. Some nacelles have a more integrated layout with less requirement for a rear bedplate.

Bedplates are designed by the wind turbine supplier and generally manufactured by external suppliers. Design considerations include fatigue and extreme loads, stiffness and assembly, and maintainability features such as access ways to critical components.

Once manufactured, the items are machined, shot blasted, metal sprayed and epoxy painted before delivery to the wind turbine supplier. Material is typically EN-GJS-400-18U-LT grade SG iron or a standard 355-grade steel.

What's in it

- Large cast SG iron or fabricated steel structure
- Machining and painting

T1.2 Main bearing

Function

The main bearing supports the rotor and transfers some or all of the rotor loading to the Bedplate.

What it costs

The main bearing cost varies significantly for different nacelle layouts.

Who supplies this

Liebherr, James Walker (Lip seals only), Schaeffler, SKF, Waukesha Bearings and thyssenkrupp.

Key facts

Different nacelle layouts exist for offshore wind turbines, from a bearing at each of the main shaft [T.1.3] to a single bearing supporting the rotor from the generator [T1.5].

Such arrangements may use a combination of spherical roller bearings (to provide axial location) and self-aligning roller bearings, tapered roller bearings, such as the two-row double-outer race (TDO) and tapered double inner (TDI) variants. These are used to manage the combination of radial, thrust and overturning loads. Bearings are often heated prior to mounting on the main shaft in order to provide a robust, stress-concentration free connection.

Cast-iron bearing housings may be used to provide stiff supports for bearings and connection to the nacelle bedplate.

What's in it

- Forged rolled ring, machined and hardened
- Rolling elements (spherical, crowned cylindrical / tapered)
- Rolling element support (cage)

- Lubricants and seals
- SG iron bearing housing

T1.3 Main shaft

Function

The main shaft, if present, transfers torque from the rotor to the gearbox or, for some direct drive designs, the generator. Depending on the layout, It may be supported at the rotor end by the main shaft bearing and at the other end either by the gearbox / generator or separately mounted bearing.

Figure 13 Wind turbine main shaft, © MHI Vestas Offshore Wind.

What it costs

The main shaft cost varies significantly for different nacelle layouts.

Who supplies this

Brück and thyssenkrupp.

Key facts

Conventionally, the rotor is flange-connected to the main shaft using a single or double row of Structural fasteners [T1.13]. The main shaft normally also has a ring of holes for use in positively locking the rotor in fixed position for maintenance activities.

It normally has a central bore which facilitates provision of control signals and electrical or hydraulic power to the hub for operation of the blade pitch system.

For a large 15 MW turbine, the main shaft may have a mass of over 70 t and be forged and machined from high-grade steel such as 42CrMo4 or cast hollow from EN-GJS-400-18U-LT. Different turbine concepts require quite different main shaft designs.

Fatigue loading is critical as the rotating shaft is supporting the mass of the rotor as well as resisting the aerodynamic torque and thrust loads. It is critical to minimise stress concentrations.

What's in it

- Forged / cast shaft
- Machining, NDT and painting

T1.4 Gearbox

Function

Where used, a gearbox converts rotor torque at a speed of 4-8 rpm to a speed of up to about 600 rpm for a medium speed gearbox for conversion to electrical energy by the generator.

Figure 14 Gearbox, courtesy of Bosch Rexroth.

What it costs

The gearbox cost varies significantly for different nacelle layouts.

Who supplies this

Lamond and Murray, Moventas, Renk and ZF Wind Power.

Key facts

The gearbox is a critical item in the wind turbine drive train, with much attention given to the long-term reliable operation given a history of variable quality and reliability, with costly consequences.

Typically, designs incorporate a planetary first stage followed by a higher-speed parallel (helical) stage. Normally, a brake disk is mounted at the rear (higher-speed) end.

Design drivers include peak torques coming from a range of load cases; also loads in storms and during braking or other abnormal events, and avoiding high speeds in the gearbox itself.

Careful consideration is given to the variation in bearing and gear contact points due to a wide variation in operating power levels during turbine life, including periods of standstill and operation under minimal loading, introducing the possibility of skidding within bearings.

Design methodologies combine empirical rules of thumb, detailed dynamic analysis and highly accelerated lifetime testing (HALT) using specialist wind turbine drive train test rigs.

Automatic heating is frequently applied before restart in cold conditions and cooling is designed typically to keep operating temperatures below about 70˚C. Cooling systems may be combined with that of the generator.

Lubricants specific to wind turbine gearboxes have been developed, with reduced end of life environmental impact.

Typically, the gearbox has a bore in the central shaft (along the axis of the main shaft) to facilitate provision of control signals and electrical or hydraulic power to the hub for operation of the blade pitch system.

What's in it

- SG iron castings (including higher grade (say EN-CJS-700-2U) for items such as planet carrier) and steel forgings
- Cylindrical, taper and spherical roller bearings; plain bearings
- Gears
- Lubricants
- Sensors

T1.5 Generator

Function

The generator converts mechanical energy to electrical energy.

Figure 15 Permanent magnet generator, courtesy of Indar.

What it costs

The generator cost varies significantly for different nacelle layouts.

Who supplies this

Suppliers include ABB, Elin, GE, GreenSpur, Ingeteam, Leroy Somer, P.P.I Engineering and VEM.

Key facts

Most generators use permanent magnets that need no excitation power. This keeps mass low and dimensions small, lowering transport and installation costs, but does rely on the use of alloys of rare-earth elements.

All operate at variable speed, with grid connection via a AC-DC-AC converter. This enables the smoothing of drive train loading and the optimisation of aerodynamic performance without the need for a variable ratio gearbox.

Efficiency is critical, especially at part load, as a wind turbine spends many hours generating 20% to 80% of rated power in low-to-medium wind speeds.

Water-cooling is common in order to maximise efficiency and compactness whilst limiting noise levels.

Generator bearings are designed to avoid passage of electrical current and with special emphasis on lubrication. Typically, these are specialist deep-groove bearings, sometimes with ceramic rolling elements.

Related, but not part of the scope of supply of the generator, is the coupling that connects the generator to the gearbox. As both components are flexibly mounted and the wind turbine structure is relatively flexible compared to the loading applied, such couplings generally are able to cope with substantial misalignment.

What's in it

- Castings
- Windings
- Bearings
- Sensors
- High-speed shaft coupling

T1.6 Power take-off

Function

The power take-off receives electrical energy from the generator and adjusts voltage and frequency for onward transfer to the wind farm distribution system.

Figure 16 Medium voltage power converter, courtesy of Ingeteam.

What it costs

The power take-off costs vary significantly for different nacelle layouts.

Who supplies this

Power converters: ABB, AVK SEG, GE Power Conversion, Ingeteam and The Switch.

Transformers: ABB, CG (Pauwels), GE Power Conversion, Schneider Group, SGB and Siemens Power Transmission and Distribution.

Switchgear: CG (Pauwels), GE Grid Solutions, S&C and Siemens Power Transmission and Distribution.

Cabling: Draka (Prysmian), Nexans and Prysmian.

Key facts

Most wind turbines have variable speed generators connected to the grid via AC-DC-AC power converters. There is a range of different generator/converter architectures used. With high power density, today's insulated-gate bipolar transistor (IGBT)-based power converters frequently are water-cooled.

Critical to consider in the design of power converters are requirements imposed by grid operators for wind turbines to support and stabilise the grid during grid faults and to provide or consume reactive power on demand. Some convertors may be split between nacelle and lower tower section to reduce tower head mass.

Where the turbine voltage rating does not match that of the wind farm array, transformers are often placed in the nacelle [T.1], or sometimes at the base of the tower [T.3]. Typically, they transform from low-kV (0.69kV to 3.3 kV) to 33kV, 66kV or 132kV for distribution around the wind farm array and are of dry (cast resin) design, meeting detailed corrosion, environmental and combustion requirements. Typically, they are forced-air cooled.

Switchgear is designed specifically for wind turbine applications, for example gas-insulated for compactness and safety at up to wind farm distribution voltage.

Down-tower cabling is routed to enable the cables to twist, allowing the nacelle two complete revolutions of movement by the yaw system [T.1.8] before an untwisting operation is required.

What's in it

- Power converter
- Transformer
- Switchgear
- Cables

T1.7 Control system

Function

The control system provides supervisory control (including health monitoring) and active power and load control in order to optimise wind turbine life and revenue generation, while meeting externally imposed requirements.

Figure 17 Turbine control panel, courtesy of Mita Technik.

What it costs

The control system costs vary significantly for different nacelle layouts.

Who supplies this

Bachmann, DEIF, KK-Electronic and Mita Teknik.

Key facts

The control system carries out regular health checking using hundreds of sensors monitoring key components and sub systems. In response to unexpected data, it takes decisions to curtail operation and provides regular reporting to the Supervisory Control and Data Acquisition (SCADA) system.

The control system also takes control input from the SCADA system, for example to derate wind turbines in response to utility customer requests. Increasing turbines have a power boost capability where they will generate at higher powers in benign conditions when parameters such as temperature and wind shear are in acceptable ranges.

Key control parameters for active power and load control are rotor speed, output power and the pitch angle of each blade.

Control intelligence may be distributed around the turbine, including in the hub. Control panels contain in-in-house designed and standard panel hardware to interface with sensors and auxiliary systems and combined may weigh up to 750 kg.

In parallel to the control system, a safety system protects the turbine from control system or operator error. Key sensors for this overriding safety system include speed and vibration sensors. An emergency system with physical press-button and/or chord inputs is provided to bring the rotor to a halt in the event of risk to maintenance personnel.

Each wind turbine can operate independently from external intervention, starting and stopping in response to changing wind conditions. Control at a wind farm level is used to optimise energy production and minimise loading, for example by avoiding turbines sitting in the wake of turbines immediately upwind.

What's in it

- Control panels, control system hardware and software
- Sensors: Accelerometers, load cells, power meters, strain gauges, thermocouples, and tachometers
- Safety and emergency systems

T1.8 Yaw system

Function

The yaw system orients the nacelle to the wind direction during operation.

Figure 18 Yaw system, © MHI Vestas Offshore Wind.

What it costs

The yaw system cost varies significantly for different nacelle layouts.

Who supplies this

ABB, Bonfiglioli, Bosch Rexroth and VEM.

Key facts

The yaw system typically consists of about 10 geared electric motors mounted on the nacelle bedplate [T.1.1], with gear mounted on their shaft acting on the toothed inner ring of the yaw bearing [T.1.9]. Each drive has mass up to 1 t and typically has ratio 200-300:1.

To avoid constant varying loading on the drives, a series of about 10 calliper brakes are hydraulically applied to hold the yaw bearing in position, except when movement is required. Even during movement (which may be the order of a few degrees every few minutes in order to align the nacelle to the wind direction), the yaw brakes act to damp movement.

Sensors measure the position of the nacelle and limit switches prevent over-twisting of the cables down the tower.

What's in it

- Yaw motors and associated gearboxes
- Yaw brakes, sensors

T1.9 Yaw bearing

Function

The yaw bearing connects the nacelle and tower, enabling the yaw system to orient the nacelle to any wind direction during operation.

What it costs

The yaw bearing cost varies significantly for different nacelle layouts.

Who supplies this

IMO, Liebherr, R&M Bearings International and thyssenkrupp.

Key facts

Bearings are typically single-row 4-point contact ball bearings made from forged rings, typically of a 42CrMo4 steel, quenched and tempered. Balls are typically material 100Cr6. Total bearing mass may be up to 15 t. Raceways are hard-turned or ground after induction hardening.

Bearings see a complex load pattern and operate with long periods of no or only occasional movement over a small proportion of a revolution. Critical to long-term performance is the provision of flat mounting surfaces (so the tower flange will be machined after welding).

Bearings incorporate gear teeth to mesh with the yaw drives.

What's in it

- Forged rings, machined, hardened and surface finished
- Balls
- Cages / spacers
- Seals
- Grease
- Metal sprayed and/or painted finish

T1.10 Nacelle auxiliary systems

Function

A number of auxiliary systems facilitate ongoing unattended operation of the wind turbine for the vast majority of the time, and support planned maintenance, which typically should be only on an annual basis.

What it costs

The nacelle auxiliary systems cost varies significantly for different nacelle layouts.

Who supplies this

Brake: Siegerland, Stromag and Svendborg.
Cooling: Hydac and Windsyn.
Air conditioning: Cotes.
Anemometry: FT Technologies, Gill Instruments, Kipp & Zonen, NRG Systems, Orga, Thies, Vaisala and Vector Instruments.
Fire protection: Danfoss, Firetrace and Minimax.
Uninterruptible power supply (UPS): AKI Power Systems.
Internal service crane: Effer, Hiab, Liftra and Palfinger Marine.

Key facts

Typically, a mechanical brake is mounted at the rear of the gearbox [T.1.4]. Primary braking of the wind turbine in the event of an emergency is achieved by pitching the blades. In some cases also electrodynamic braking is used but a mechanical brake is also present, frequently with a hydraulically applied calliper acting on a disk.

A rotor lock enables locking of the rotor in a fixed position for maintenance activities. Typically, for large turbines it consists of a peg-and-hole arrangement with manual or automatic hydraulic actuation engaging one or more pegs with holes on the front flange of the main shaft [T.1.3].

A large offshore turbine is about 92-94% efficient in converting kinetic energy in the rotor to electrical energy, requiring at times up to 1 MW of heat to be dissipated from gearbox, generator and electrical system.

To protect all nacelle components from corrosion, the nacelle is well sealed and the whole area is served by a local air conditioning system.

Mounted on the roof of the nacelle is typically a sonic anemometer measuring wind speed and direction.

Frequently, fire protection systems are provided in order to sense and suppress fire in different areas of the turbine. Within electrical panels, nitrogen is used. In open spaces such as the nacelle, spray systems are employed. The fire protection systems have separate control and condition monitoring from the turbine controllers.

To facilitate orderly shutdown of the turbine under grid loss conditions, UPS systems are used to power the control, safety and emergency systems and provide emergency lighting in the tower to facilitate safe exit of personnel. In some cases, UPS power is required in order to ensure requirements for rotor warning lights on the tips of blades continue to operate for an agreed period.

The internal service crane for a large turbine is designed to lift key turbine components during maintenance activities, typically up to 10 t. The crane is controlled wirelessly and operates through cut-outs in the nacelle cover to lower components to the access platform.

What's in it

- Brake
- Rotor lock
- Cooling
- Anemometry
- Fire protection
- UPS
- Internal service crane

T1.11 Nacelle cover

Function

The nacelle cover provides weatherproof protection to the nacelle components plus support and access to external components such as coolers, wind measurement equipment and lighting protection devices.

Figure 19 Nacelle cover, © MHI Vestas Offshore Wind.

What it costs

The nacelle cover cost varies significantly for different nacelle layouts.

Who supplies this

Bach Composites Industry, Eikboom and Sigmatex.

Key facts

As well as providing environmental protection, frequently it supports lighting and other auxiliary supplies and acts as a faraday cage to protect nacelle components from lightning damage.

It is fitted during assembly of the nacelle, either before or after final test, and plays a valuable role in protecting nacelle components during transport to the wind farm site, as well as during operation.

It is designed to withstand wind loading and provide access to lifting points on the nacelle bedplate [T.1.1] for transport and installation.

Careful design also facilitates exchange of nacelle components through hatches or hinged openings in the roof, side or floor.

The nacelle cover is typically manufactured in a number of sections from glass fibre and may have mass up to 25 t.

What's in it

- Fibreglass or steel construction
- Built-in or post-assembled auxiliary systems (for example lighting)
- Maintenance support features

BVGAssociates

T1.12 Small engineering components

Function

A range of frequently standard engineering components makes up the rest of the nacelle assembly.

What it costs

The small engineering component cost varies significantly for different nacelle layouts.

Who supplies this

Many items are off-the-shelf or can be manufactured by a range of metalworking companies.

Key facts

Guards and flooring and maintenance aids are normally fabricated to drawing from steel or aluminium.

A range of cable / hose handing systems, air ducts and similar are needed, depending on nacelle layout.

Anti-vibration mounts support the generator [T.1.5] and sometimes other critical components.

Standard industrial lighting systems are used to facilitate maintenance work.

Fasteners typically vary from M6 upwards and may be grade A4 stainless or galvanised.

What's in it

- Guards, flooring, drip trays, cable and hose handing systems and other fixed maintenance aids
- Anti-vibration mounts
- Lightning conductors
- Small fasteners and other accessories and consumables used during nacelle assembly

T1.13 Structural fasteners

Function

Fasteners (either bolts or studs) are used in a range of critical bolted joints, for example connecting rotor to main shaft, main bearing housings to nacelle bedplate and yaw bearing to the underside of nacelle bedplate.

Figure 20 Structural fasteners, courtesy of Cooper & Turner.

What it costs

The structural fasteners cost for a 15 MW wind turbine nacelle is about £70,000 (similar for rotor and included in total rotor cost).

Who supplies this

August Friedberg, Clyde Cooper & Turner, Fuchs & Sanders, Gexpro Services and Multifix.

Key facts

Fasteners for critical structural joints within large turbines are typically of size up to M72 and grade 10.9.

Often, the fasteners are specified to have threads rolled after heat treatment to improve fatigue properties.

Coatings provide corrosion protection.

All critical structural fasteners are preloaded either using hydraulic torque tooling or (in the case of studs) hydraulic tensioning. Increasingly, preload indicators or other visual checks on tightness are used.

What's in it

- Bolts
- Studs
- Nuts

T1.14 Condition monitoring system

Function

Condition monitoring systems provide additional health checking and failure prediction capability.

Figure 21 Turbine condition monitoring system, courtesy of SKF.

Who supplies this

Brüel & Kjær Vibro, Gram & Juhl, SecondWind and SKF.

Key facts

Condition monitoring systems frequently make decisions about individual components (such as the gearbox) via sensors measuring parameters for that component. They also use a range of sensor and controller outputs and make holistic decisions about all drive train components.

Condition monitoring systems on the Rotor [T.2] are able to assess control behaviour as well as blade health.

Turbine and condition monitoring systems send data to cloud-based databases to facilitate analysis over a wind farm and a larger number of turbines. Results of the analysis can lead to changes in control reducing loads on a failing component. Better understanding of the condition of the turbine drive train can lead to increased power output under some conditions where the fatigue life of the turbine allows.

What's in it

- Sensors
- Condition monitoring hardware and software

T.2 Rotor

Function

The rotor extracts kinetic energy from the air and converts this into rotational energy in the drive train.

Figure 22 Wind turbine rotor, courtesy of Equinor, © Jan Arne Wold.

What it costs

The rotor cost for a 15 MW wind turbine is about £5.1 million.

Who supplies this

Wind turbine rotors are usually designed and supplied by the wind turbine supplier as part of the complete wind turbine. Independent blade manufacturers are used by some wind turbine suppliers.

Blade assemblies: GE, Siemens, and Vestas

Blade moulds: DFS Composites

Fasteners: Cooper & Turner

Polymer solutions: Nylacast

Bearings: R&M Bearings International

Key facts

A rotor for a 15 MW turbine has a mass of about 230 t and a diameter of about 230 m.

The rotor consists of three blades, a hub casting, blade system, bearings, and pitch system.

Blades are typically made from glass fibre, carbon fibre and epoxy or polyester resin. New resin systems are being introduced which enable the recovery and reuse of blade materials at the end of life.

Higher tip speeds typically lead to more efficient energy capture, and tip speeds offshore are higher than those used onshore, but these are limited by design to avoid blade leading edge erosion. This is where repeated impact by raindrops, particulate matter, hail, ice, and salt erodes the blades, causing surface roughness and change in aerodynamic shape to the outer part of the blade's leading edge. This reduces the performance of the blade and increases its sound emissions. If left unrepaired, the damage will continue until it affects the structural integrity of the blade.

Reducing the risk of leading edge erosion is an important focus for innovation. One approach is developing better coatings. Another is to incorporate leading edge protection plates similar to those used in helicopter blades that are flexible enough to cope with the deflections seen in wind turbine blades.

Each blade is bolted to a blade bearing that is bolted to a central hub on the main shaft. The blade bearing enables the pitch mechanism to adjust the blade pitch angle to control power output from the turbine, minimise loads and start or stop turbine as required.

Each blade has its own independent pitch system. Pitch systems are either hydraulically or electrically operated, with little external difference in functionality.

There is potential for larger offshore wind rotors, though for the same design, mass increases faster than the additional energy generated. This is because energy capture is proportional to the two-dimensional swept area (square of blade length), but the blades increase in size and mass in three dimensions (so cube of blade length). Substantial improvements in blade technology have kept the actual increase in mass nearer the square than the cube of blade length as wind turbines have increased in size.

Capacity factors are over 50% for 15 MW offshore turbines on good offshore sites. This compares with capacity factors of about 40% for good onshore sites.

As turbine rotor diameter increases, with the same limit on tip speed, the rotational speed decreases. Lower rotational speeds make it more difficult to design a support structure that avoids resonant frequencies excited by loading from waves and operation of the turbine itself.

Rotor speeds for 16 MW turbines are 4 to 8 rpm, resulting in a maximum tip speed of over 100 m/s.

In the UK, rotor clearance must be at least 22 m above mean high water spring (MHWS) tides.

What's in it

- Hub casting [T2.4]
- Blade bearings [T2.5]
- Pitch system [T2.6]
- Spinner [T2.7]
- Rotor auxiliary systems [T2.8]
- Fabricated steel components [T2.9]
- Structural fasteners [T1.13]

T2.1 Structural composite materials

Function

Composite materials are used to provide an efficient, strong and relatively light blade structure.

Who supplies this

3A Composites, Airtech, Diab, Gurit, Hexel, Owens Corning, PPG, SGL and Zoltek.

Key facts

One type of manufacturing process for a blade is to make two full-length aerodynamic-shaped shells using a resin infusion process, large moulds and consumable vacuum bags. These shells are either glued around a central load-bearing spar or structural elements are incorporated into the blade shells and a strong load-bearing connection between them is provided using shear webs Another solution is a single infusion process to form the whole blade in one step.

Some insert the blade root connection prior to infusion whilst some drill and fit this afterwards.

Compromises are made between optimum aerodynamic shape (generally low aerofoil thickness) and optimum structural shape (higher aerofoil thickness).

Key parameters that define blade shape along the blade are chord (length of aerofoil cross-section), thickness of aerofoil cross section, twist (angular rotation of aerofoil) aerofoil shape and position of aerodynamic centre. These parameters are optimised during blade design.

A stepwise testing strategy for new blade designs is normally employed, where in turn blade materials, structural samples, blade sections and complete blades are tested under fatigue and extreme loads in order to verify design and ensure sufficient strength, a process that takes many months.

Repeatable blade quality and manufacturing time are two critical considerations during blade manufacture.

What's in it

- Glass fibre, in uni-directional or woven fabric mat and/or prepreg form
- Carbon fibre (generally in prepreg form)
- Resin (either epoxy or polyester)
- Adhesive
- Closed-cell foam or balsa bulk fill
- Consumables

T2.2 Blade root

Function

The blade root acts as the interface between the main composite section of the blade and the steel blade bearing.

Figure 23 Wind turbine blade roots, courtesy of GE Vernova.

Who supplies this

An integral element of a blade design, blade roots are designed then manufactured by the blade supplier using bought-in items.

Key facts

The design of the connection to the Blade Bearings is critical due to the attachment of a relatively soft composite structure to the stiff bolting and bearing structure.

Differing arrangements are used to provide threaded connection for fasteners connecting the blade bearing. In some cases, a ring is set into the root of the blade. In other cases, inserts are either bonded into holes drilled in the root or inserts are infused during manufacture. Finally, other designs use a single or double row of “IKEA-type” threaded bars, set perpendicular to the direction of orientation of studs.

The composite structure near the blade root is designed to apply even loading around the blade root as well as smooth transfer of load into each insert. The root of the blade must be sufficiently flat so as not to apply excessive uneven load to the blade bearing.

Loading of the root-end and fasteners at the blade root is critical due to the complex geometry, especially of the hub and bearing under load. Development testing of root end strength is common.

What’s in it

- Metal inserts
- Composite structure

T2.3 Environmental protection

Function

Lightning protection systems provide a level of protection for the blades and the rest of the turbine.

Leading edge tape / metal or ceramic inserts protect blade tips from erosion.

Paint or gel coat protects the rest of the surface of the blade against erosion and UV damage.

Who supplies this

Lightning protection systems are an integral element of a blade design and the design of other turbine components in the conduction path to earth. They are manufactured by the blade and other relevant component suppliers using bought-in items.

Leading edge protection: 3M.

Coatings: Akzo Nobel, Bergolin and Mankiewicz.

Key facts

Different suppliers have different strategies for the capture and transfer of high currents at high voltages from point of impact through to the hub and rest of the turbine, depending on blade materials and aspects of blade design.

Lightning receptors are normally fitted at the tip and other points on the blade. In some cases, a conducting mesh is incorporated into the structure of the blade.

It is generally considered advantageous not to allow lightning to pass through blade bearings and into the hub and hence to the main structural load path to tower base.

Systems are used to gather data about the severity of lightning strikes.

What's in it

- Lightning receptors
- Lightning conductor arrangement
- Tape
- Metal / ceramic inserts
- Data capture

T2.4 Hub casting

Function

The hub connects the blades to the main shaft.

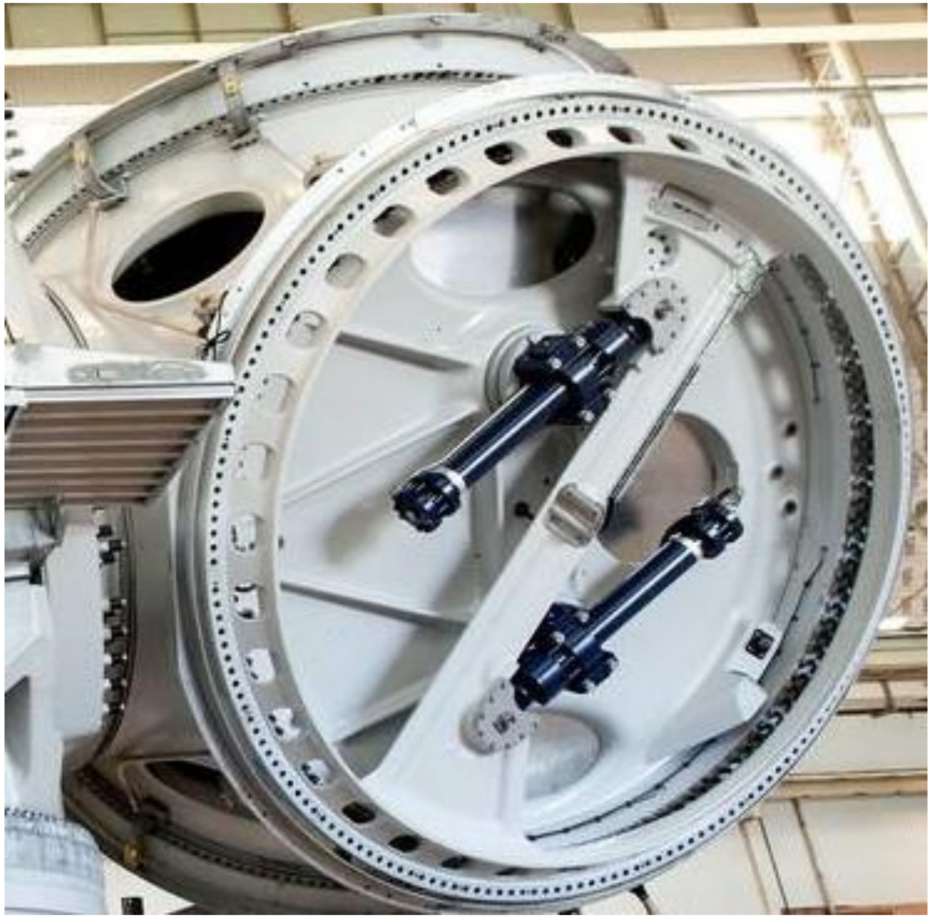


Figure 24 Hub casting (shown assembled with pitch system and blade bearings), © Vestas.

What it costs

The hub casting cost varies significantly with rotor designs.

Who supplies this

Fonderia Vigevanese, MeuselWitz Guss, Sakana, Siempelkamp and Silbitz. Only some can manufacture the largest hubs for offshore turbines today.

Key facts

The hub is made of SG iron and weighs over 75 t. It houses the Pitch system [T2.6] and provides stiffened support for the Blade bearings [T2.5].

Generally, hubs are approximately spherical, with offset inner and outer surfaces to provide additional strength at the rear of the hub around the connection to the Main shaft [T1.3]_T.1.3_Main_shaft.

Openings are provided for personnel access. Lifting points for use during installation, support locations for pitch system components and other auxiliary systems and blind tapped holes are generally required.

SG iron is typically of grade EN-GJS-400-18U-LT, cast without the need to heat-treat. SG iron is chosen above cast steel due to superior pouring and shrinkage properties.

What's in it

- Casting
- Non-destructive testing
- Machining
- Painting

T2.5 Blade bearings

Function

The blade bearings enable adjustment of blade pitch angle to control power output from the turbine, minimise loads and start/stop turbine as required.

Figure 25 Blade bearings, courtesy of Rollix.

What it costs

The cost for a set of blade bearings varies significantly with rotor design.

Who supplies this

Dover Precision Components, IMO, Liebherr, Rollix, SKF and thyssenkrup.

Key facts

Bearings are typically double-row 4-point contact ball bearings or three-row roller bearings made from forged rings, typically of a 42CrMo4 steel, quenched and tempered. Rolling elements are typically material 100Cr6. Total bearing mass may be up to 7.5 t.

Raceways are hard-turned or ground after induction hardening.

Bearings see a complex, reversing load pattern and operate with long periods of reversing movement over only a few degrees.

It is critical to ensure relatively low friction torque to enable safe shutdown of the turbine via 90 deg pitching movements under all conditions.

Some designs incorporate gear teeth to mesh with an electric pitch drive.

Relatively soft support structures and high loading lead to substantial deflections of bearings during operation.

Special greases have been developed in response to lubrication issues due to the high loading and intermittent movement experienced by blade bearings.

Seals are made from rubber extrusions with complex cross sections to retain grease whilst minimising friction.

What's in it

- Forged rings, machined, hardened and surface finished
- Balls
- Cages / spacers
- Seals
- Grease
- Metal sprayed and/or painted finish

BVGAssociates

T2.6 Pitch system

Function

The pitch system adjusts the pitch angle of the blades to control power output from the turbine, minimise loads and start/stop turbine as required.

What it costs

The pitch system cost varies significantly with rotor design.

Who supplies this

See details of hydraulic and electric systems, below.

Key facts

Pitch systems are either hydraulically or electrically operated, with little external difference in functionality.

Typically, blade pitch angle is adjusted almost constantly in medium-to-high winds to regulate rotor speed and aerodynamic loading while the turbine is extracting maximum (rated) power. Adjustment is over a range of approximately 20 deg at rate of a few deg/s.

In lower winds, the pitch system operates to maximise aerodynamic efficiency, which requires substantially less movement.

Each blade has an independent pitch system that incorporates a fail-safe function that enables it to pitch quickly through 90 deg without using grid power - from providing power to acting as a brake. This action is independent for each blade to avoid a single failure causing catastrophic damage to the wind turbine.

In some cases, blade pitch angles are adjusted independently to different angles on each blade to minimise aerodynamic loading on the rest of the turbine.

Power and control signals for the pitch system are provided from the Nacelle [T.1] through a bore in any Gearbox [T1.4] and the Main shaft [T1.3].

What's in it

- Hydraulic pitch system [T2.6.1] or Electric pitch system [T2.6.2]

T2.6.1 Hydraulic pitch system

Function

The pitch system uses hydraulic actuators to adjust pitch angle of the blades.

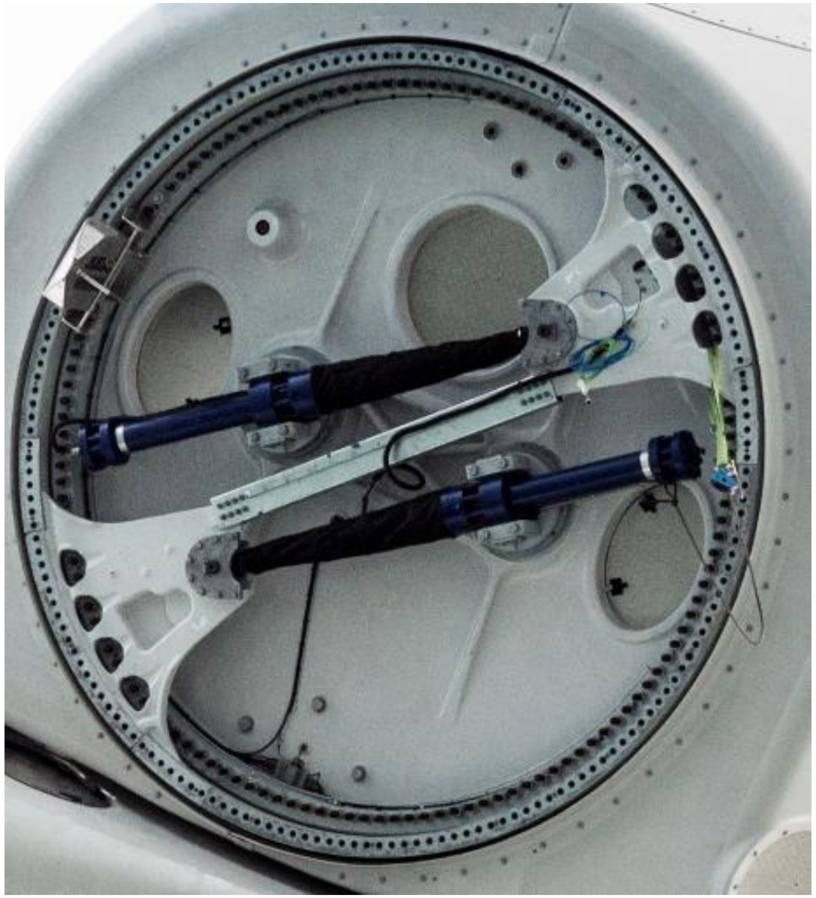


Figure 26 Hydraulic pitch actuators (rest of pitch system not visible), © MHI Vestas Offshore Wind.

Who supplies this

Bosch Rexroth, Fritz Schur and Hydratech Industries.

Key facts

Hydraulic actuation uses linear hydraulic cylinders, typically controlled by proportional valves. These actuators are generally trunnion-mounted to the hub and a plate fixed to the inner (rotating) ring of the blade bearing.

Maximum pressures are about 250 bar and total system mass is of the order of 3 t.

Back-up energy to facilitate safety shutdown even without grid power is provided by accumulators.

The main hydraulic tank is normally located in the Nacelle [T.1], with pressure and return lines passing through the Gearbox [T1.4] and the main shaft along with control signal and control power cables.

What's in it

- Power pack
- Hydraulic actuators
- Rotating union
- Manifold blocks
- Accumulators
- Hoses
- Electrical slip rings

T2.6.2 Electric pitch system

Function

The pitch system uses geared electric motors to adjust pitch angle of the blades.

Who supplies this

MOOG and SSB Wind Systems.

Key facts

Electric actuation normally uses high-speed DC electric motors controlled by 4-quadrant drives.

These motors drive Blade bearings [T2.5] via speed-reducing gearboxes and pinions meshing with either internal or external gear teeth on the blade bearing.

Back-up energy to facilitate safety shutdown in the event of no grid power is provided by batteries used to drive the AC motors.

Blade pitch angle is measured through absolute encoders mounted on the pitch drive motors.

All electric pitch items are mounted in panels or directly on the hub casting.

The electric pitch system for a 15 MW turbine has total mass of about 10 t.

What's in it

- Motors
- Gearboxes
- Electrical panels
- Batteries
- Battery chargers
- Position sensors

T2.7 Spinner

Function

The spinner, also known as a nose cose, provides environmental protection to the hub assembly and access into the hub and blades for maintenance personnel.

Figure 27 Wind turbine rotor spinner, © MHI Vestas Offshore Wind.

What it costs

The spinner cost varies significantly with rotor design.

Who supplies this

Bach Composites Industry, Eikboom.

Key facts

Generally, the spinner is made from fibreglass in sections and bolted together on a galvanised steel frame. Fibreglass cuffs are frequently fitted round blades to provide environmental protection to blade bearings.

Consideration is given to maintenance activities in and around the hub when designing the spinner. In some cases, personnel access is needed between the spinner and hub.

The spinner may be up to about 10 m diameter.

What's in it

- Fibreglass mouldings
- Fabricated steel support frame

T2.8 Rotor auxiliary systems

Function

Auxiliary systems may be incorporated to lubricate bearings and provide condition monitoring and advanced control inputs.

What it costs

The rotor auxiliary systems cost varies significantly with rotor design.

Who supplies this

Automatic lubrication systems: Lincoln and SKF.

Key facts

All offshore wind turbines have automatic lubricated Blade bearings [T2.5]. A central lubrication pump connected to a metering distribution system provides a consistent volume of grease to ports around the circumference of the bearing each day. Grease purged from the system is collected from exit ports to avoid over pressurising seals.

Turbines also have blade load measurement as an advanced control input, facilitating reduction in turbine loading, normally at the expense of extra pitch system duty and blade bearing loading.

Lighting and other maintenance support features are also provided in the hub.

What's in it

- Automatic lubrication system
- Blade load measurement system
- Maintenance support features

T2.9 Fabricated steel components

Function

Fabrications are often required to stiffen the blade bearing support and provide a connection for hydraulic pitch system actuators.

Other items are required for personnel protection, to facilitate access and maintenance activities and to provide a lightning path from the blades into the nacelle.

What it costs

The fabricated steel component cost varies significantly with rotor design.

Who supplies this

These items are supplied by a range of steel fabricators and machinists including: Gartsherrie, George Mcdade and Sons, Granfab, Harry Maiden, Miller Steel and Moretube Engineering.

Key facts

Stiffening plates are circular, flame-cut plates of the same diameter as blade bearings, with a ring of boltholes and a central cut-out to provide access from the hub to the Blade root [T2.2]_T.2.1.2_Blade_root. These are metal sprayed and painted.

Other steelwork is of simple fabrication from box and other section, galvanised to provide corrosion protection.

What's in it

- Steel fabrications
- Surface treatment

T.3 Tower

Function

The tower is typically a tubular steel structure that supports the nacelle. It also provides access to the nacelle and houses electrical and control equipment. Also provides shelter and storage for safety equipment.

Figure 28 Wind turbine towers, courtesy of GE Vernova.

What it costs

The tower cost for a 15 MW wind turbine is about £1.4 million.

Who supplies this

CS Wind, Gestamp Renewable Industries, Global Energy Group, GSG Towers, Haizea Wind Group, Hutchinson, Titan Wind Energy and Welcon.

Fasteners: Cooper & Turner

Polymer solutions: Nylacast

Key facts

Fabricators manufacture towers to designs provided by wind turbine suppliers, sometimes using free-issue materials (both steel and internal components).

Towers are normally made at coastal locations to avoid road transport .

Once fabricated, the tower sections are shot-blasted and painted before fit-out with other internal components then prepared for transport and storage.

The hub height is about 135 m above mean sea level minimum depending on the rotor diameter, so each tower is about 120 m high and has a mass over 800 t.t. About 90% of the mass is steel plate with forged steel flanges making up most of the rest.

Towers are generally tapered, with a top diameter of about 6 m and a base diameter of about 10 m for a 15 MW turbine. Design is driven by fatigue and extreme loading plus natural frequency requirements and avoidance of bucking.

The optimum tower height is normally as low as needed to comply with maritime safety regulations for blade clearance above the water. This is because the wind shear is low offshore (the wind speed does not increase very much with increasing the hub height), meaning there is no cost benefit for using a taller tower. The tower height to achieve blade clearance needs to take account of the tidal range. Permitting at some sites has required taller towers to reduce the risk of bird strikes.

Integrated design of substructures and towers is increasingly seen as desirable with the transition from substructure to tower predicted to be less distinct. The tower, though, continues to be a discrete component supplied with the wind turbine.

What's in it

- Steel [T3.1]
- Tower internals [T3.2]

T3.1 Steel

Function

Steel is the most commonly used material for the manufacture of towers.

What it costs

The steel cost for a wind turbine tower varies significantly by tower design.

Who supplies this

CASC, Dillinger Hütte, Ilsenburger, Rukki, Salzgitter, Siegthaler, Severfield, Tata Steel and thyssenkrupp. Agents are also used to source and manage supply.

Key facts

Towers are manufactured by cutting and rolling steel plate, welding to make "cans" then welding these to make tower sections, with bolted flanges each end.

Steel plate of grade S355J2G3 NL and thickness up to 150 mm is typically used.

Steel thickness is varied for each "can" in steps down to its thinnest at the upper part of the tower. Thickness is optimised by considering overall natural frequency of the support structure (including foundation) and fatigue life and other design drivers for each "can".

Flanges are generally forged and rolled from grade S355 EN10.113-2 NL steel with weld necks in order to improve the weld fatigue class. Tower top flanges are machined post welding to ensure top flange flatness is within tolerances required for the yaw bearing.

Other specialised steel is used for the door frame at the tower base, typically of grade S235 J2G3 NL. The frame needs to compensate for the cutaway of important amounts of material for personnel access [T.3.2.1] at this fatigue-critical location.

What's in it

- Steel plate
- Steel flanges
- Surface finish

T3.2 Tower internals

Function

Provide various access, safety, maintenance and storage functions.

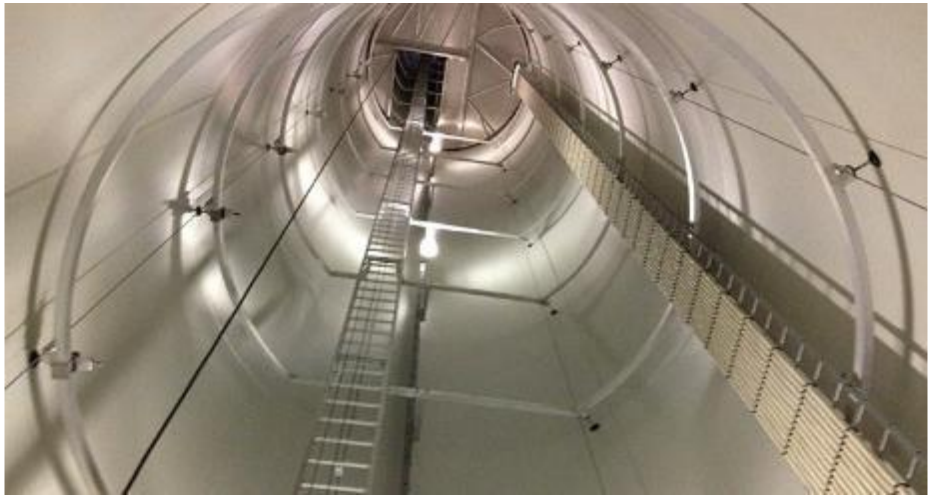


Figure 29 Tower internals, courtesy of Steel Wind Tower.

What it costs

The internals cost for a 15 MW wind turbine tower varies significantly by tower design.

Who supplies this

Various including: Global Energy Group, Granfrab, Energy Integrity Services, Sedwell and JR Dynamics.

Key facts

The tower internals provide means of access, lighting and safety for maintenance and service personnel, plus means of transferring hand tools and components to the nacelle. They provide support for control and electrical cables and housing of switchgear, transformers, and other elements of power take-off.

Tower internals also provide storage for survival equipment. A tuned damper may be located at the top of the tower to aide damping of tower and structure resonances.

Design of doorways and attachments points for components is critical for the fatigue life of the tower.

Magnets can be used to attach some components in order to avoid stress concentrations.

What's in it

- Personnel access and survival equipment [T3.2.1]
- Tuned damper [T3.2.2]
- Electrical system [T3.2.3]
- Tower internal lighting [T3.2.4]
- Coatings [T3.2.5]

T3.2.1 Personnel access and survival equipment

Function

Safe access to the nacelle is required for most maintenance activities.

Who supplies this

Elevator: Avanti, Hailo and Power Climber Wind.
Fall arrest: Avanti, Latchways, Limpet Technology, Prisma Components and Uniline Safety.

Key facts

Though ladders are always required by regulations, larger turbines also have an elevator. Offshore turbines are usually also equipped with offshore survival equipment in case weather conditions stop the crew leaving the turbine as planned.

Elevators typically operate at rates of up to 20 m/min and with load capacities of between 250 and 2,000 kg.

Ladders are generally of standard aluminium profile. Fall arrest devices running on rails or wires supported by the ladder and connected to body harnesses are used at all times by maintenance staff.

Platforms of aluminium or steel support with checker plates are positioned to meet local health and safety requirements, providing rest points and protection from falling tools etc.

Survival kits may contain distress flares, food, drink and other essentials for minimum 3 days.

What's in it

- Fall arresters
- Ladders
- Elevator
- Platforms

T3.2.2 Tuned damper

Function

In some cases, a large damper is fitted at the top of the tower in order to reduce tower and foundation loading.

Who supplies this

Tuned dampers are generally made from bought-in items.

Key facts

Typically, dampers are liquid-filled. The natural frequency of 'sloshing' is tuned to have maximum effect in reducing tower fatigue loading due to varying aerodynamic loads from the rotor and wave loading from the foundation.

Dampers can also reduce transient loads during turbine shutdowns.

What's in it

- Support structure
- Liquid container
- Damping liquid (generally water-based)

T3.2.3 Electrical system

Function

All wind turbines have a control panel at the tower base in order to facilitate on-site control of the turbine by maintenance staff without climbing the turbine. For many turbines, the space near the base of the tower is used to mount various elements of the power take-off including convertor and cooling systems.

Who supplies this

These items are generally supplied by the turbine manufacturer to the tower manufacturer for fit-out.

Key facts

The only access to the inside of the tower base is via the access door, so if the transformer is mounted in the tower base, it is essential to be able to replace it via the door in case of failure.

If sensitive electrical systems are placed at the tower base, then these are protected by a local air conditioning system.

What's in it

- Power take-off [T1.6]
- Control system [T1.7]
- Tower internal lighting [T3.2.4]
- Air conditioning

BVGAssociates

T3.2.4 Tower internal lighting

Function

Lighting is provided to facilitate safe personnel access and egress from the nacelle and tower.

Who supplies this

All parts are standard, with many suppliers, for example Chalmit.

Key facts

Luminaires are frequently fitted to ladders and platforms or in some cases via magnets to
the tower wall to avoid welding on lugs (hence introducing stress concentrations) in tower
wall sections.

In the event of loss of grid, an Uninterruptible power supply (UPS) powers emergency lighting, often a subset of standard lights.

What's in it

- Luminaires
- Low voltage wiring
- Cable trays
- Emergency backup including UPS

T3.2.5 Coatings

Function

Surface finish is routinely metal spray followed by high build epoxy spray and polyurethane spray finish (total up to approx. 1000 microns).

Who supplies this

AkzoNobel, BASF, Hempel, NOF Metal Coatings Europe, PPG and Teknos.

Key facts

Satisfactorily applied coatings are essential for lifetime protection especially for external surfaces and to avoid putting maintenance personnel in potentially hazardous situations.

Specialised coatings have been specifically developed to protect components in the seawater splash zone.

Coatings are tested and certified against international standards.

The component manufacturer usually undertakes the coating application..

What's in it

- Resin
- Metal spray
- Application equipment

B Balance of plant

Function

The balance of plant includes all the components of the wind farm except the turbines. It also includes the transmission assets built as a direct result of the wind farm.

What it costs

About £1.1 billion for a 1 GW wind farm.

Who supplies this

See relevant sections below.

Key facts

Much of the benefit of larger capacity wind turbines on a wind farm is realised by the reduction in balance of plant costs. Although larger capacity wind turbines may require larger and more robust supporting structures and cabling, fewer turbines, supporting structures and cables required per GW typically results in a net benefit in terms of cost. Like-for-like balance of plant costs will increase as wind farms are built further from shore, in deeper water and in more challenging sea conditions.

What's in it

B.1 Cables

Function

The cables deliver the power output from the wind turbines to the grid.

What it costs

About £345 million for a 1 GW wind farm.

Who supplies this

Cable manufacturers include Apollo, Hydro Group, Hellenic Cables, ICS2, JDR Cable Systems, LS Cable & System, Nexans, NKT, Prysmian, Sumitomo Electric and TKF.

Key facts

Offshore wind farms use array cables to deliver power from the wind turbines to the offshore substation, and export cables to deliver power from the offshore substation to the onshore substation. Subsea cables are used for the array cables and the offshore section of the export cable. Onshore cables are used for the export cable section between the shore and the onshore substation.

A standard subsea cable used in offshore wind is made up of a stranded, profiled conductor with a combination of sealing layers, insulation, fillers, and protective armouring. Subsea AC cables have three cores (one for each phase). Onshore AC cables have single cores and are laid in groups of three. DC cables (land and subsea) have single cores (two, one positive and one negative, for each circuit).

There are three main insulated power core design types:

Dry, with an extruded lead sheath over the insulation

Semi-wet, with a polyethylene sheath over a non-fully impervious metallic screen, and

Wet design, without a sheath over a non-fully impervious metallic screen.

Wet designs have the advantage of being lighter and more flexible. Currently, cables with voltages above 66 kV are only available as dry designs.

The terms for voltage ratings are not formally defined by the industry. Low voltage (LV) typically refers to cables rated up to 11 kV, medium voltage (MV) typically refers to cables rated up to 66 kV, high voltage (HV) typically refers to cables rated up to 220 kV and extra high voltage (EHV) typically refers to cables rated higher than 220 kV.

HV and EHV cables are generally associated with transmission networks and export cables, whereas MV is associated with array cables. The wind turbines generate at LV with a transformer at the base of the tower stepping up exported power to MV.

Cables have a specified minimum bend radius. Failure to maintain this during transportation, installation, and operation greatly increases the risk of damaging the cable, potentially leading to cable faults.

In terms of production, a single extrusion line can produce around 200 km of core per year (this equates to around 40 cm per minute).

The cable lengths are delivered on drums with sealed ends in order to prevent entry of moisture and other damage.

To avoid unnecessary handling, cables that will be installed subsea are ideally loaded directly onto an installation vessel from the factory.

What's in it

- Export cable [B.1.1]
- Array cable [B.1.2]
- Cable protection [B.1.3]

B.1.1 Export cable

Function

The export cable connects the offshore and onshore substations to transmit power from the wind farm to shore. It also provides auxiliary power to the wind farm when it is not generating and provides fibre communications.

Figure 30 Static export cable. Image courtesy of JDR. All rights reserved.

What it costs

About £269 million for a 1 GW wind farm.

Who supplies this

Export cable manufacturers include Hellenic Cables, LS Cable & System, Nexans, NKT, Prysmian and Sumitomo Electric.

Key facts

The initial length of export cable hangs from the offshore substation to the seabed. The remainder and majority of the cable length runs along the seabed to shore. Soon after landfall, the subsea export cable is jointed to the onshore export cables in a transition joint bay (see I.3 for further information). Onshore export cables run from the transition joint bay to the onshore substation. Onshore export cables are manufactured and laid as single-core cables, meaning that three individual onshore cables are jointed to a subsea three-core cable.

High voltage alternating current (HVAC) export cables are now typically rated at 220 kV, allowing the export of approximately 300 MW per three-core subsea cable. Future wind farms may use higher voltages of up to 275 kV. The voltage chosen balances the cost of the cable, the number of circuits required, and the number of offshore substations required. Wind farms tend to have more than one export cable circuit for redundancy.

Medium voltage alternating current (MVAC) cables may be used for export for small wind farms close to shore. Their use for commercial-scale projects in the future is therefore unlikely, but MV export is attractive for demonstration projects.

High voltage direct current (HVDC) connections are used to connect larger projects, typically those of more than 1 GW installed capacity, and those located further from shore, typically further than 80 to 100 km. For example, there are already 10 HVDC substations operating in German waters. Floating projects that are large and/or located far from shore are also expected to use HVDC connections.

HVDC significantly reduces losses caused by high levels of reactive power that is seen in long distance HVAC cables, which increases the net annual energy production. The full capacity of the cable system can be used for transferring active power because there is no reactive power flow in DC systems and the current flows at a constant level rather than fluctuating as a sine wave.

HVDC converter stations are expensive, and the savings from the use of HVDC cable are not realised until the cable route between the substations is 80 to 100 km. Even beyond 100 km, project-specific considerations can make the final choice complex in deciding between HVAC and HVDC. New technology is steadily reducing the cost of HVDC.

A subsea HVAC export cable is a three-core design, whereas a typical subsea HVDC system has a bipolar design with two single-core cables, a positive and a negative. For a given capacity, HVDC cables are lighter with positive implications for the ease and cost of installation. This is because the voltage is at a steady maximum - it is not at a lower average value because it is alternating - and none of the cable's capacity is taken up by carrying reactive power. Overall export cable costs, therefore, for an HVDC offshore wind farm are usually lower than for an HVAC wind farm.

The first commercial scale HVDC projects in UK, for example the Dogger Bank projects, are using 320 kV export cables. A pair of single-core 320 kV cables can export up to 1,200 MW per pair. A 220 kV three-core copper AC export cable has a mass of approximately 110 kg/m. Two 320 kV single-core copper DC export cables have a mass of approximately 80 kg/m. In time, the voltage may increase to 525 kV for even larger projects.

Several cable manufacturers have cable installation equipment and vessels (see I.2 for further information) and typically lead export cable EPCI packages.

What's in it

- Cable core [B.1.1.1]
- Cable outer [B.1.1.2]
- Cable accessories [B.1.1.3]
- Cable jointing and testing [B.1.1.4]

B.1.1.1 Cable core

Function

The cable core contains the conductor through which power is transferred. The rest of the core consists of screens, insulation, and sheathing to protect the conductor and prevent short circuits.

Who supplies this

Cable cores are typically manufactured by the cable manufacturer such as JDR Cables. Usually, complete cable cores are manufactured and assembled at the same site to reduce the transportation costs of the different components.

Key facts

The core is typically made up of the conductor, a screen, insulation and a protective sheath.

The conductor may be stranded copper or aluminium. Both have low resistance, excellent conductivity, are ductile, and are relatively resistant to corrosion. Copper has a higher conductivity, 60% greater than aluminium for the same cross section, but is more expensive and the price is more volatile. Aluminium is lighter, and therefore easier to handle. The cable should at least have a conductor cross-section adequate to meet the system requirements for power transmission capacity. Energy losses can be reduced by using a larger conductor with a greater current carrying capacity but at a greater capital cost.

The conductor screen is a semiconducting tape that surrounds the conductor, maintains a uniform electric field, and minimises electrostatic stresses on the cables.

Most subsea cables used in offshore wind are insulated with cross-linked polyethylene (XLPE). This is due to its excellent strength and rigidity. HVDC systems have traditionally used mass impregnated cables with paper-based insulation as they can be manufactured and installed in long lengths and are available at higher voltages. Modern HVDC cables mostly now use XLPE insulation as it can operate at a higher temperature and are lighter so easier to handle during installation. Surrounding the insulation is a further screen, similar to the conductor screen.

The sheath has historically been lead but alternatives are being developed on environmental grounds.

A 220 kV AC subsea cable conductor typically has a cross-sectional area of between 800 mm2 and 1,600 mm2 with 23 mm of insulation.

A 320 kV DC cable conductor typically has a cross-sectional area of between 1,000 mm2 and 2,500 mm2 with 25 mm of insulation.

What’s in it

- Conductor
- Conductor screen
- XLPE insulation
- Insulation screen
- Lead sheath

B.1.1.2 Cable outer

Function

The cable outer surrounds the core and contains materials to protect the cable and house the fibre optic cable.

Who supplies this

Commodity suppliers.

Fibre optic manufacturers: Hexatronic, Huber+Suhner.

Fibre optic jointers and systems: Aceda and CCL UK.

Key facts

For a three-core cable, the cores are surrounded by non-conductive filling and packing material made from polypropylene. Its purpose is to maintain the cable's shape and structure. All are then bound together with tape into a single cable.

A layer of polypropylene string is applied over the assembly as bedding for the armour wires.

The armouring is usually made up of helical metal wires surrounding the cable. Three-core subsea cables usually have stainless steel wire armour and single-core cables usually have non-magnetic galvanised steel armour. The choice of armouring is important as impacts the cable's protective, handling, and electrical properties.

Bitumen may be applied over the armouring to protect against corrosion and to provide additional adhesion.

Polypropylene yarn covers the armour, to provide resistance to abrasion and to reduce friction during laying. It is applied with a black and yellow pattern to make the cable visible during laying.

Single-core cables can be laid separated or close. Close laying gives lower losses. Separation eliminates mutual heating but means higher losses in the armour.

At least one fibre optic cable is integrated into the power cable for communications. The cable is multimodal, meaning that it can carry a wide range of data at different frequencies, typically for voice, turbine, switchgear, condition monitoring and security information. A fibre optic cable typically has 48 strands.

What's in it

- Bitumen
- Polypropylene strings
- Steel wire

B.1.1.3 Cable accessories

Function

Cable accessories are used to provide electrical termination and mechanical support for cables both during and after installation.

Figure 31 Cable connector, © Nexans.

What it costs

About £36 million for a 1 GW wind farm.

Who supplies this

Interface plugs: Pfisterer, Ridderflex and TE Connectivity.

Hang-off clamps: BMP, Vos Prodect and WT Henley.

Cable connectors: Nexans and Pfisterer.

Cable terminations: Prisma Components

Cable grips: Prisma Components

Key facts

Pulling heads enable the safe installation of the cable to the platform. It typically connects directly onto the cable armouring to ensure that all mechanical forces associated with pulling the cable via the J-tube are borne by the armour rather than the core. They are usually made from machined steel and hot dipped galvanised and zinc plated.

Kellums Grips are often used for lighter weight or lower tension installations

Hang-off clamps are installed where the cable connects to the turbine's foundation or that of the substation. They ensure that the cable is mechanically secured after installation and that the mechanical stresses expected to occur during service life are safely borne by the cable armouring and not by the core.

Terminations boxes connect the cable conductors to the electrical switchgear above the hang-off assemblies. Terminations connect to inline or T-connectors at the switchgear. Interface plugs are typically fitted at the end of the cable to form the connection point between the cable and the termination box.

Coupling connectors installed in piggy-back assembly to a T-connector allow a second cable connection. Surge arresters could be also installed in piggy-back assembly to a T-connector. These are insulated using ethylene propylene diene monomer (EPDM).

J-tube seals are used to seal the interface between the inside of a J-Tube and the riser. Water containing a corrosion inhibitor is normally introduced into the J-tube void.

Cable protection systems (CPS) are often employed to ensure the cable is not subjected to excessive loadings through the cable route as the cable departs the foundation and continues onto the sea bed.

What's in it

- Interface plug
- Hang-off clamp
- Cable connector, T-connector
- Cable cleats
- Cable trays
- CPS

B.1.1.4 Cable jointing and testing

Function

Jointing the segments of cable and testing during manufacturing.

Who supplies this

In house by cable manufacturers.

Independents: Maillefer, Power CSL and WT Henley.

Key facts

There are two types of joints:

- The factory flexible joint connects individual segments of cable core into one continuous length during the lay-up process. Crucially, the joint must have the same electrical, mechanical and thermal properties as the rest of the cable and result in a joint that it does not hamper installation or increase the risk of cable failure.
- The field rigid joint is a manufactured product. It may be supplied to the wind farm owner or the offshore transmission owner (OFTO) with the cable in case of failure during operation or supplied as a planned joint to link sections of the export cable.

Field rigid joints have generally been bespoke products because of the substantial variations in cable design between wind farms. There is growing interest, particularly by OFTOs, in developing joints that are suitable for a range of designs.

Cables undergo a series of tests before dispatch, dependent on the cable type and voltage class, including:

- Cable (and accessories) pre-qualification tests
- Cable (and accessories) type tests

- Cable routine electrical tests on each manufacturing length before jointing and armouring
- Sample tests
- Routine factory splice tests, and
- Tests on complete cable lengths including factory installed joints (if any).

What's in it

- Joints
- Electrical test and diagnostics devices

B.1.2 Array cable

Function

The network of array cables transfers power from the wind turbines to the offshore substation. It also provides auxiliary power to the turbines when they are not generating and provides fibre communications.

Figure 32 Dynamic array cable. Image courtesy of JDR. All rights reserved.

What it costs

About £76 million for a 1 GW wind farm.

Who supplies this

Array cable manufacturers include Hellenic Cables, JDR Cable Systems, LS Cable & System, Nexans, NKT, Oceaneering, Prysmian, Sumitomo Electric and TKF.

There are other cable manufacturers based in China and Japan, but they have yet to be used widely for UK projects.

Key facts

Array networks are most often designed as "strings" which connect several turbines to the substation. They can also be designed in loops to increase redundancy.

Each turbine is linked to the next with at least 1.5 km of array cable, assuming a 15 MW turbine with 224 m rotor diameter and seven times diameter spacing between turbines.

Array cables are typically rated at 66 kV. In the next few years, array cable voltages are expected to increase to 132 kV. This is to accommodate more efficiently turbines rated at and above 16 MW and to reduce the number of array cable strings required.

Array cables are typically supplied with cable accessories, although the manufacture of accessories may be outsourced. Cable protection may also be included in the supply scope but it is more often part of the installer's scope.

Cables may be supplied as pre-cut lengths or as a continuous length, depending on the project's requirements.

Some larger cable manufacturers have cable installation equipment and vessels (see I.5 for further information), but EPCI array cable packages have typically been led by marine contractors.

What's in it

- Conductor
- Insulator
- Electrical screen
- Optical fibre cable
- Mechanical and chemical protection

B.1.3 Cable protection

Function

Cable protection provides protection to cables at vulnerable locations, from the wave and tidal action and when the cable enters the wind turbine or offshore substation aperture or J-tubes.

Figure 33 Cable protection system on vessel deck, courtesy of Tekmar.

Who supplies this

Suppliers for cable protection include Balmoral, CRP Subsea, First Subsea, Subsea Energy Solutions Subsea Protection Systems, Tekmar, Trelleborg, Protectorshell, Vos Prodect and WT Henley.

Key facts

J-tube seals provide a seal at the ends of the J-tube to prevent seawater entering the J-tube. Passive seals consist of a series of disks that are pulled up into the J-tube. Active seals require inflation after they have been pulled through into the J-tube, requiring a remotely operated vehicle (ROV). Seals are not used in all cases, but a sealed J-tube may be filled with a corrosion inhibitor.

Some suppliers offer a J-tube-less solution for monopile foundations by providing a clamp that enables the cable to be routed through a hole in the monopile.

Bend stiffeners are conical devices fitted over the cable that limit the movement of the cable to a permitted range (dependent on the cable's minimum bend radius). These are typically fitted at connection points such as the J-tube.

Bend restrictor prevent damage caused by excessive bending between flexible cable lengths and fixed structures such as the turbine foundation. Protection from bend stiffeners is only applied when a set bend radius is reached. At this point bend restrictors lock to avoid further bending.

Abrasion, touch down and impact protection are provided by protection matting and protection sleeves. These protect the cable where it lies exposed on the sea bed, where it enters or exits the sea bed, or where it crosses other cable routes.

What's in it

- J-tube seals
- Bend restrictors
- Bend stiffeners
- Cable mattresses
- Rock placement

B.2 Turbine foundation

Function

The foundation provides support for the wind turbine, transferring the loads from the turbine at the tower interface level (typically around 20 m above water level) to the sea bed where the loads are reacted. The foundation also provides the conduit for the electrical cables, as well as access for personnel from vessels.

What it costs

About £424 million for a 1 GW wind farm of 15 MW turbines using monopiles at 50 m water depth.

Who supplies this

Design: Atkins, Ballast Nedam, COWI, Ramboll, and Wood Thilsted.

Monopiles: CS Wind, Dillinger Hütte, Dajin Heavy Industries, EEW, Haizea Windgroup, SeAH Wind Limited, Sif and Riggs Distler.

Transition pieces: CS Wind, EEW, Smulders and Sif.

Jackets: Eni, Harland and Wolff, Lamprell, SK Oceanplant and Smulders.

Gravity bases: Ballast Nedam. BAM Nuttall, Bilfinger, Bouygues Travaux Publics and Per Aarsleff A/S.

Key facts

Foundation design is a complex engineering task. Design requirements include gravity load, thrust and associated overturning moment, natural frequency, fatigue strength, verticality (over time), personnel access, cable entry and support. Design needs to take account of both wind and wave loading and in some circumstances must consider other environmental conditions such as earthquakes, typhoons and sea ice.

Around 80% of the fixed offshore wind capacity currently being installed, or installed to date, outside of China, has been supported by monopiles driven into the sea bed, with jacket foundations representing approximately 15%. Gravity bases are the least common design and most were deployed at early offshore wind farms in water depths of less than 10 m. However, gravity bases continue to be used sporadically on nearshore projects and have been installed on a commercial scale project at 30 m water depths.

Monopiles require more steel than jackets but they are easier to manufacture and install in volume and they are well suited to the geology of the North and Baltic Seas. For larger monopiles, a key design driver is their stiffness, as the natural frequency of the complete wind turbine structure needs to be kept between blade passing frequencies over a range of wind speeds and above wave loading frequencies in order to minimise dynamic magnification and control fatigue loading.

For larger turbines and in deeper water, the cost of monopiles rises substantially. However, increased efficiencies and capabilities in monopile manufacture have meant that monopiles continue to be utilised at increasing depth. Monopiles are currently thought to be limited to about 60 m water depths, this depth may continue to increase, especially if novel concepts such as tethered monopiles are utilised.

Jacket designs become cost competitive at around 40 m water depth and are suited to a wider range of ground conditions. As they have been less prominent, serial production has not been optimised in the same way as monopiles, but as projects are installed in deeper waters with harsher ground conditions serialisation is expected to become more efficient. The latticed steel structure of a jacket is secured to the seabed utilising pin piles or suction buckets. It is easier to design a stiffer jacket structure for larger turbines to meet natural frequency requirements, which can offer an edge over monopiles.

For a 15 MW turbine at 55 m water depth, indicative mass for a monopile (including transition piece) is around 3,100 t. For a 15 MW turbine at 55 m water depth, indicative mass of a jacket (including pin piles) is 2,200 t.

In shallower waters and where ground conditions make piling or drilling less feasible or economical, gravity bases have been used successfully. Fécamp is the largest project globally to have utilised gravity bases at 498 MW. This comprised of 71 foundations each with a mass of 5,000 t (pre-ballasting) to support the 7 MW turbines in water depths of 25-30 m.The Blyth Offshore Demonstrator Project used concrete gravity bases in waters of 36-42 m, but at relatively high costt. Concrete material prices generally are less volatile than steel, meaning that when steel prices are high concrete is more attractive. In some regions, they can also offer higher levels of local content.

In water depths greater than about 60 m, floating solutions may compete with fixed foundation and beyond 100 m they will be the preferred option. Commercial deployment is expected in the late-2020s.

What's in it

- Monopile [B.2.1]
- Jacket [B.2.2]
- Transition piece [B.2.3]
- Corrosion protection [B.2.4]
- Scour protection [B.2.5]

B.2.1 Monopile

Function

The primary function of a monopile is to support the static and dynamic loads of the wind turbine through anchoring it firmly to the sea bed using the embedded part of the monopile. Secondary functions include supporting the wave loads on the monopile itself and enabling cable entry.

Figure 34 Monopile foundations, courtesy of EEW SPC, © Andreas Duerst, STUDIO 301.

What it costs

About £266 million for the monopiles for a 1 GW wind farm.

Who supplies this

Cambridge Vacuum Engineering, CS Wind, Dillinger Hütte, Dajin Heavy Industries, EEW, Haizea Windgroup, SeAH Wind Limited, Sif and Riggs Distler.

Key facts

Monopiles are the most commonly used foundation type to date and are considered to be a proven technology by the offshore wind industry in water depths up to approximately 50 m and this is expected to increase to closer to 60 m by the end of the decade.

The monopile is a cylindrical steel tube made up of several welded steel cans that is usually driven into the sea bed. The embedded section of the monopile is of constant diameter to allow entry into the sea bed. Along the rest of its length the monopile will taper from the widest section at the bottom to its narrowest section at the top.

Monopiles are made in highly automated factories with little work on top of rolling and welding of parallel cans. Two thirds of the cost is steel. They do not generally have a surface finish to resist corrosion and have Corrosion protection (B2.4) applied to suit the installed conditions.

Monopiles need to withstand the impact of pile driving into the sea bed. The pile needs to be designed to account for these impact loads, which will use up a percentage of its fatigue life. As it is a simple cylindrical structure it is relatively easy to transport and move into its vertical orientation. Increasing sizes of monopiles are leading to vessel obsoletion and the need for larger vessels for transport and installation.

For a 15 MW turbine in 60 m water depth, the dimensions will be up to 11.5 m diameter, 120 m overall length and 2,700 t. More typically, for a 15 MW turbine in 40 m water depth the dimensions will be up to 10 m diameter, 90 m overall length and 1,850 t. A number of suppliers have the capability to mass-produce this type of monopiles.

Although monopiles are considered an established technology, innovation continues. Fabrication capabilities in terms of diameter and wall thickness continue to increase to achieve the requirements of longer monopiles. Novel concepts such as tethered monopiles suggest that installation depths of 100 m can be reached, and alternatives to driving which is currently limited by available equipment and comes with an increased buckling risk for larger monopiles are being investigated.

A monopile will normally have a transition piece (TP) between it and the bottom of the turbine tower. These are typically separate pieces bolted to the monopile, limitations on bolted connections may lead to alternative connection types or the advancement of TP-less monopiles – see B.2.3 Transition piece.

What's in it

- Steel plates
- Flange
- Joints

B.2.2 Jacket

Function

The primary function of a jacket is to support the static and dynamic loads of the wind turbine by anchoring it firmly to the sea bed using a set of pin piles or suction buckets. Secondary functions include supporting the wave loads on the jacket itself and enabling cable entry.

A jacket foundation does not have a separate transition piece. The upper part of the jacket performs many of the functions of the transition piece, which are described in 0 and its sub-sections.

Figure 35 Jacket foundation, courtesy of Bladt Industries.

What it costs

About £476 million for the jackets for a 1 GW wind farm at 50 m water depth. This cost includes the pin piles and the upper part of the jacket, which performs many of the functions of the transition piece. Suction buckets are typically more expensive than piles and ground conditions are the main driver of selection.

Who supplies this

Jacket suppliers include Cedeco, Eni, Lamprell, Navantia Windar, SK Oceanplant, Smulders and W3G Marine.

Key facts

Jacket foundations make up approximately 15% of current installed capacity and are typically used at depths greater than 55 m.

There are several different versions of jacket structures, three legged are the most widely used. Others include, four legged, “twisted” and “true X-braced”. Jackets are steel structures with small struts welded to larger legs creating a latticed structure. Most jackets are secured to the sea bed using pin piles, with suction buckets providing another option. Both are typically installed at the base of each leg.

Pin piles are essentially mini monopiles which are driven through apertures in the base of the jacket’s legs into the sea bed. These can be designed for most soil conditions by varying pin dimensions such as length and diameter. For hard ground conditions drilling and grouting can be used as an alternative to driving.

Suction buckets are inverted buckets connected directly to the jacket which are secured to the seabed using suction. This force is created by pumping water out of the bucket as the structure is lowered into the seabed resulting in a vacuum which resists upward force acting on the suction bucket. Suction buckets have the advantage of little or no piling noise. They have the disadvantage of only being able to be installed in medium sand or clay. Sites with very shallow bedrock or the presence of boulders in clay soils are not suited to suction buckets.

Suction buckets are typically wide and short whereas pin piles are narrow and long. For comparable conditions a suction bucket may be 11 m diameter by 10 meters in length, whereas a pin pile may be 3 m by 45 m in length.

For commercial scale projects multiple fabricators tend to be required for jacket, pin pile and suction bucket supply.

For a 15 MW turbine in 55 m water depth the approximate dimensions of a jackets will be: 40 m footprint, 85 m height, with jacket mass of 1,500 t and total pin pile mass of 600-700 t.

The main reason for utilising jackets is water depth. There are a number of other reasons which include:

- Ground conditions which are too hard for monopiles, as it is easier to drive small piles compared to large monopile foundations into the sea bed.
- Ground conditions which are too soft for monopiles as the load can be more effectively transferred to the ground by a jacket due to it having a wider footprint and spreading of the load across at least three piles or suction buckets.
- Lower noise emissions, driving smaller diameter pin piles creates less noise than driving a single large monopile.
- For sites where moderately shallow bedrock means that monopiles are not a viable solution, jackets can be used in conjunction with drilled and grouted piles or suction buckets.

Manufacturing savings can be achieved because jackets use less steel than monopile for an equivalent turbine. This improvement is partially offset by the increased complexity of welded nodes, the joints between pin piles and jacket base and the transition at the top between the lattice structure and the tubular tower base.

Jackets may make up a higher percentage of future installed capacity if:

- The cost of steel increases,
- Further automation can reduce the cost of fabrication,
- There is an increase in the proportion of sites with more than 55 m water depth, and/or
- The combination of load sets at a particular site favours them as a design solution.

What’s in it

- Steel lattice
- Struts
- Nodes
- Pin piles
- Protective coating

BVGAssociates

B.2.3 Transition piece

Function

The transition piece provides the connection between the foundation and the tower, typically extending around 20 m above mean sea level (MSL). It also supports secondary steelwork which provides functions such as allowing personnel access via a work platform, supporting cables and supporting the corrosion protection system.

Figure 36 Transition pieces, courtesy of EEW OSB.

Figure 37 Example of secondary steel, courtesy of Hutchinson.

What it costs

About £124 million for the transition pieces for a 1 GW wind farm using monopile foundations.

Where jacket foundations are used, the function of the transition piece is fulfilled by the upper part of the jacket structure. The cost is therefore included in the supply of the jacket.

Who supplies this

Transition piece suppliers include CS Wind, EEW, Smulders and Sif.

Often supplied through a joint venture with the monopile supplier.

Secondary steel suppliers include CASC, CRC Evans, Global Engineering, Hutchinson and Severfield.

Key facts

All foundation types have an upper part which is described as a transition piece (TP). The main functionality of the TP is to ensure verticality of the turbine. It also supports secondary steel work such as a boat landing, cable entry (J-tube), anodic corrosion protection cages, working platforms and personnel access systems.

Monopiles typically have a separate TP. For jackets this will typically be an integral part of the structure. Gravity base structures may have an integrated or separate TP.

For monopiles, separate TPs are typically connected with a flange and bolt connection. Concerns exist in the industry about the applicability of bolted connections as turbines and monopiles become ever larger and alternatives such as crimping or slip joints are being considered. A separate TP means that the monopile can be pile driven pre TP installation to avoid excessive forces being experienced by the TP. Another alternative is to avoid using a TP altogether. This is known as a TP-less monopile. Advantages of TP-less monopiles are that they remove the risk of failure and need for maintenance at the flange and bolt connection and potentially reduce installation times. However, secondary steel which is traditionally installed onshore pre-connection would need to be installed offshore.

Typically, the top of the transition piece needs to be approximately 20 m above the highest astronomical tide (HAT) to keep the working platform above the worst expected combination of wave height, splash height, tide height and storm surge. It is finished at the top with another flange that will mate to the flange at the base of the turbine tower. For a 15 MW turbine, a monopile transition piece will weigh approximately 480 t and have an upper diameter of about 8 m.

Protective surface coating is mandatory in the atmospheric zone (that part which is exposed to air) and splash zone (that part which is exposed to both sea and air), which accounts for nearly all of the transition piece. They are normally painted a bright yellow colour for visibility.

Most projects have installed davit cranes on the transition piece to transfer equipment, small replacement parts and consumables from the support vessel.

What's in it

- Crew access system and work platform [B.2.3.1]
- Internal platforms [B.2.3.2]
- Davit crane [B.2.3.3]
- J-tubes, I-tube or monopile entry point [B.2.3.4]

B.2.3.1 Crew access system and work platform

Function

The crew access system and work platform enable operations service personnel to gain safe access to the turbine platform and allows loading, unloading and storage of equipment.

Figure 38 Jacket foundation crew access system and work platform, courtesy of RWE.

Who supplies this

The crew access system and work platform are usually supplied as part of the transition piece, see suppliers of transition pieces [B.2.3].

In practice, the steelwork for the crew access system and work platform may be subcontracted to a smaller steelwork supplier.

Key facts

Adverse weather conditions can limit access to turbines and delay essential maintenance, leading to revenue loss. Currently, most crew transfer vessels (CTV) are able to offload crews in wave heights of 2 m. Some turbines have systems to enable helicopters to drop crew but if used routinely, this is an expensive solution with health and safety concerns.

The simplest and cheapest option for turbines located close to shore is to use a small CTV. In this case, the vessel will press up against the boat landing, which consists of a pair of strong parallel vertical beams (known as "bumper bars") mounted onto the transition piece. This allows the service personnel to step across to a ladder located between and slightly behind the boat landing, clip into the fall arrest system, and hence gain access to the main work platform and the turbine. Intermediate rest platforms may also be included between the boat landing and platform access. This method of access is limited to significant wave heights (Hs) of approximately 1.5-2.0 m. There are a number of systems which extend the range of sea conditions under which it is safe for personnel to transfer across to the access ladder.

Service personnel may also arrive on a larger service operation vessel (SOV) equipped with a motion compensated gangway. In this case, they can step straight from the gangway onto the main work platform. Motion compensated gangways allow turbine access with Hs of up to approximately 3-4 m.

The main work platform is typically located about 25 m above MSL in order to be clear of splashes during storm surges, even at high tide. It is sized to allow the storage of small ISO containers, which are frequently used to transfer parts and equipment to offshore wind turbines. They could also be used to store a generator, which is commonly needed before the turbine is connected to the grid.

The main work platform is surrounded by guardrails and will have lights and textured non-slip decking to provide a safe working environment.

What's in it

- Steel framework
- Decking
- Guardrails

B.2.3.2 Internal platforms

Function

Internal platforms are used to support equipment housed in the transition piece and to provide personnel access for installation and maintenance purposes. They are also used to seal the upper reaches of the transition piece.

Who supplies this

These are usually supplied by the supplier of transition pieces [B.2.3].

In practice, the steelwork for the internal platforms may be subcontracted to a smaller steelwork supplier.

Key facts

The lower platform provides an airtight seal between the monopile and the TP. This is because hazardous gases can accumulate inside the lower part of the monopile from the corrosion protection system.

The upper platform provides access to the bolted connection between the transition piece and the tower base. It may also include the cable hang-off, this may alternatively be included on an intermediate platform.

Further platforms may be included:

- To provide access to the bolted connection between the monopile and transition piece, or
- To support the turbine transformer, switchgear and a personnel refuge, although these can alternatively be located in the lower reaches of the turbine tower.

What's in it

- Lightweight structural steel frame and decking

B.2.3.3 Davit crane

Function

Davit cranes are used to lift equipment from a workboat up to the main external work platform.

Figure 39 Davit crane, courtesy of Granada Material Handling.

Who supplies this

Suppliers of davit cranes include CraneSolutions, Demag Cranes, Granada Material Handling, Liftra, Palfinger Marine and Sparrows Group.

Key facts

A davit crane is a crane, which can lift loads from a workboat and slew them around to lower them onto the main work platform. They have become almost universally adopted on offshore wind turbines to lift tools, auxiliary generators and smaller spare parts of up to approximately one t.

They are particularly useful when a small CTV is used to access the wind turbine, as these vessels do not have a crane capable of lifting onto the main external work deck.

Tools and parts can also be moved onto offshore turbines using a motion compensated gangway, vessel crane or helicopter.

What's in it

- Steelwork

B.2.3.4 J-tubes, I-tube or monopile entry point

Function

The J-tube or I-tube routes the array cables from the outside to the inside of the foundation and provides protection to the cables from wave action.

Figure 40 J-tube, courtesy of Optimus Aberdeen.

Who supplies this

These are usually supplied by the supplier of jacket [B.2.2] or transition piece [B.2.3].

In practice, the steelwork for the J-tubes or I-tube may be subcontracted to a smaller steelwork supplier. A monopile entry point will be formed in the monopile by the monopile supplier.

Key facts

For a monopile, a J-tube is a steel tube of diameter approximately 300 mm attached to the transition piece extending from platform level to a few metres above the sea bed. It is called a J-tube because the lower end is curved like a letter J so that the cable bends smoothly towards the horizontal, where it will enter the sea bed. Both ends of the J-tube have a bell mouth shape to allow easy cable entry. The cable will enter the lower end close to the sea bed, pass up through the tube where it will be protected from the action of waves, and will commonly exit around the level of the top of the transition piece. There are a variety of ways for the array cables to pass from the outside to the inside of the wind turbine. Both ends of the J-tube are normally sealed after the cable has been pulled through – see Cable protection [B.1.3].

In deeper water, the top of the monopile finishes higher above the sea bed so an I-tube can be used. An I-tube has a vertical lower end, because it is many metres above the sea bed. A cable protection system will need to be used for the exposed cable between the buried section and where it enters the I-tube to stop it flexing in tidal currents.

Another alternative is to have a monopile entry point in the side of the monopile a couple of metres above the sea bed. This will be sealed after the cable has been pulled in. These same options are used to route and protect cables for jacket foundations and for gravity base foundations.

What's in it

- Tubular steel

B.2.4 Corrosion protection

Function

Corrosion protection protects the foundation from corrosion to the extent that is required.

Figure 41 Corroded monopile structure, courtesy of Materialenkennis.

What it costs

About £28 million for the foundation corrosion protection for a 1 GW wind farm using monopiles.

Who supplies this

Suppliers of corrosion protection coatings suitable for use on offshore foundations include CRC Evans, Gorilla Corrosion, Hempel, International Paint and Jotun.

Suppliers of cathodic protection systems include CORROSION, Cathelco, Imenco Corrosion Technology and Impalloy.

Key facts

In offshore wind, corrosion predominantly occurs when sea water interacts with metallic surfaces. This can lead to oxidation (or rusting) of metallic surfaces, which can compromise the strength and performance of metal structures such as substructures. Corrosion protection mitigates general and localised wall loss in steel substructures and is a prerequisite for attaining the fatigue of the structure. Corrosion can also occur from microbiological activity.

Methods for corrosion protection include cathodic protection and corrosion protective coatings. Other methods for corrosion control, such as corrosion allowance and use of corrosion resistant materials, are important considerations in the design of foundations but are not covered in this section. Corrosion protection must also account for fabrication, transport and installation to avoid damage even before the wind turbine is operational. The corrosion protection system mitigates general and localised wall loss and is a prerequisite for attaining the fatigue of the structure.

The external surfaces of the atmospheric and splash zones are normally coated with high performance marine coatings. Although the atmospheric zone coating can be accessible for repair, it is costly to repair any coating offshore, more so in the splash zone. For this reason, the coatings are combined with a design corrosion allowance to give maintenance-free service at least for the foreseen lifetime of the wind turbine.

Cathodic protection systems are typically used to provide corrosion protection to the part of the foundation in the submerged zone. The application of a negative current to the steel structure reduces the voltage on the structure to a level at which oxidation, and hence corrosion, is suppressed.

There are two types of cathodic protection systems:

- Galvanic anode cathodic protection systems (GACP) which comprise several sacrificial anodes made of aluminium or zinc-based alloys that are fixed to the steel structure below the waterline. The more active alloy in the anodes is consumed in preference to the structural steel. This galvanic action provides a self-regulating current source that protects the structural steel and other metal components of the foundation. The zinc or aluminium bars can be designed to be replaced periodically to extend the useful lifetime of the corrosion protection.
- Impressed current cathodic protection system (ICCP) which uses an external power source and rectifier to supply a negative current to the steel structure and a corresponding positive current to non-consumed anodes mounted adjacent to the structure. An ICCP is substantially lighter than GACP and causes less drag in the water than the numerous sacrificial anodes required by a traditional cathodic protection system. A reliable power supply and associated instrumentation is required, and the design needs to be robust enough to withstand possible damage from sea conditions such as waves and currents as well as from maintenance and operational activities.
- Unprotected structures, particularly embedded in the upper layers of the sea bed, may be subject to microbiological influenced corrosion related to naturally occurring bacteria. The resultant damage can reduce fatigue life of these areas.

Reactions between the foundation, the sea and the sea bed material, together with reactions from the cathodic protection system can generate noxious gases, which will accumulate inside a monopile. The lower deck of monopiles will be sealed for the safety of maintenance technicians working above, whilst gas detection and ventilation systems may be used to monitor and safely vent the concentrations of the noxious gases.

In closed internal compartments, such as in jacket tubes, which have been welded shut, corrosion may be mitigated by control of humidity or depletion of oxygen. The inside of a monopile is not considered to be a closed internal compartment.

What's in it

- Paints and thermal metal spray coatings
- Zinc or aluminium based sacrificial anodes
- Impressed current cathodic protection systems

B.2.5 Scour protection

Function

Scour protection prevents scour of the sea bed caused by the speed-up of water moving around the foundation, which safeguards the performance and integrity of the foundation.

Figure 42 Novel scour protection system visualisation, immediately after installation, courtesy of Scour Prevention Systems.

What it costs

About £5.4 million for a 1 GW wind farm.

Who supplies this

Rock installation firms: Boskalis, DEME, Peter Madsen Rederi and Van Oord Offshore Wind.

Scour mat suppliers: Exo Engineering, Naue, Norfolk Marine and SSCS.

Rock bag suppliers: Ridgeway and Pipeshield.

Key facts

Scour is erosion caused by the presence of a structure changing flow patterns and increasing sediment transport locally around the structure. Scour is therefore an important factor for all foundation types. If sea bed material around the foundation is removed by the action of scour then:

- For a monopile or jacket foundation, the loads from the turbines will be resisted by a shorter embedded length of pile in the sea bed. This will reduce the stiffness of the foundation and will reduce the maximum load the piles can withstand.
- For a gravity base foundation, the foundation could rest on a smaller footprint, which increases the chances of leaning, or in the worst case, toppling.
- For any foundation type, the action of scour will change the frequency response of the structure and may push it into closer to wave or blade driving frequencies, which would amplify loads and accelerate fatigue.

The ground conditions have a consequential impact on the scour assessment and scour protection design. The particle size distribution and the strength are key considerations for both. Non-cohesive sediments (such as sand) do not resist scour whereas cohesive sediments (clay and silt) and bedrock are better able to resist it. Other key factors are waves, currents, water depth and the structure dimensions. All of these need to be considered when estimating scour depths.

In non-cohesive sediments scour depth increases with pile diameter, with design scour depth applied as 1.3 times the diameter of the pile. Scour will therefore be a bigger problem with larger turbines, which require larger diameter piles to transfer loading into the ground.

Depth of non-cohesive sediments is therefore very important in determining accurate scour depths as these inhibit scour.

Jacket structures are expected to be less susceptible to scour due to the smaller diameters of the pile footprint. However, total scour around the foundation also needs to consider the spacing of the vertical legs and lower horizontal members.

The rate of increase in scour depth slows with time until it reaches an equilibrium depth, typically within the first year.

Once an estimate of the scour depth has been calculated, a decision can be made to:

- Design the foundation to cope with the scour estimate including an allowance for the scour depth, or
- Design and install scour protection (which will prevent the scour from occurring).

The additional cost of initial scour protection and repairs over time should be balanced against the cost of designing to cope with the anticipated level of scour. Routine monitoring is required in either scenario to monitor the scour depth development or the effectiveness of scour protection to avoid the risk of movement to the foundations structures.

Crushed rock is most commonly used for scour protection. However, in some cases, rocks can sink into the sediment, and secondary scour around the scour protection can also occur which needs to be considered in the design. Alternatives to rock are available, for example concrete mattresses and geotextile sand containers.

Options for installation of scour protection vary according to design and include pre-pile installation, post installation or a combination of the two.

Scour protection, as well as the turbine structures, become habitats for a number of marine species. However, this may not always be seen as a positive impact as the habitats created are a change to the baseline environment which scour protection was designed for.

What's in it

- Rock or geotextile sand containers

B.3 Offshore substation

Function

The offshore substation connects the array cable system to the export cables. It contains a step-up transformer and power factor compensation equipment to reduce losses. For longer export cables the substation may also convert the power from alternating current (AC) to direct current (DC) to minimise losses further. It also provides switchgear to protect the grid from the wind farm, and vice versa, for fault conditions.

Figure 43 Offshore substation, courtesy of Equinor, © Ole Jørgen Bratland.

What it costs

About £238 million for a 1 GW wind farm, considering an HVAC system.

Who supplies this

Electrical system: Hitachi Energy, GE Grid Solutions and Siemens Energy.

Topside structure: Aibel, CS Wind, Smulders and Seatrium.

Systems integrators: Engie Fabricom, Iberdrola, Ørsted, Petrofac and Semco.

Structural designers: Arup, Atkins, ISC and Ramboll.

Key facts

Offshore substations consist of a main electrical power system, auxiliary systems, a topside structure to house the systems, and a foundation. Offshore substations are often delivered as one element of a contract to connect the wind farm generating assets to the onshore transmission grid.

An HVAC substation topside (everything above the substructure) weighs between 1,200 and 3,000 t. A 450 MW wind farm is likely to have one offshore substation. Single HVAC substations of up to approximately 700 MW have been used.

An HVDC substation topside weighs between 12,000 and 18,000 t. A 1 GW wind farm would only have one HVDC offshore substation but could be connected to the turbines by several AC convertor stations which would transform the 66 kV output from the turbines up to 132 kV or higher to feed the HVDC substation. It is unlikely to be commercially attractive to use an HVDC connection for a single 450 MW wind farm that is 60 km from shore.

A developer typically works closely with its chosen HV engineer after the turbine has been chosen to optimise the export system as a key opportunity to reduce the cost of energy. By reducing the number of circuits, the substations need less switchgear and fewer transformers. This provides an opportunity to dispense with a substation or to reduce topside and foundation costs.

Standardisation of offshore substation design offers the potential to lower costs, although few developers have the project pipelines to justify the upfront costs.

With 66 kV subsea cables, near-shore wind farms up to 300 MW can be built without an offshore substation.

A typical HVAC platform is about 25 m above the sea and has an area of 800 m².

Although many offshore substations are not being used primarily as service platforms, they will still have a modestly equipped workshop and frequently a helideck.

In the UK, the offshore substation is ultimately owned and operated by a transmission operator (OFTO), although the wind farm owner has access and responsibility for the array cable entry and wind farm switchgear

What's in it

- Electrical system [B.3.1]
- Auxiliary systems [B.3.2]
- Topside structures [B.3.3]
- Substation foundation [B.4]

B.3.1 Electrical system

Function

The electrical system integrates AC power output from individual turbines and transforms to a higher voltage for export to onshore substation.

An HVAC system will increase output from individual turbines from for example 66 kV to 220 kV for transmission to shore via the export cable. An HVDC system will increase and convert the output from individual turbines from for example 66 kV to 320 kV DC for transmission to shore via the export cable.

Figure 44 Gas-insulated switchgear, © ABB.

What it costs

About £80 million for a 1 GW wind farm.

Who supplies this

Hitachi Energy, GE Grid Solutions and Siemens Energy.

Key facts

Offshore substations located more than 80-100 km from the onshore substation may use HVDC to reduce transmission losses. Concerns about the reliability of offshore HVDC convertor stations, and the higher capital costs have led some developers to implement technology solutions to allow AC transmission to be used over longer distances. Some sites have used additional reactive power compensation equipment, located on offshore platforms part way along the offshore cable route, or in onshore substations close to the coast.

Key components include:

- HV switchgear sets to isolate and protect each array and export connection to the substation.
- Transformers (if AC) in order to transform to higher voltage for onward transmission. A typical offshore substation will have two or more transformers to improve availability. Transformers are oil cooled, requiring the use of fire and blast protection.
- Converters (if HVDC) in order to convert AC to DC for onward transmission.
- Passive and active reactive power compensation, typically large coils and power electronics, to improve stability of the local grid system.
- Earthing systems including lightning protection connecting electrical components and the substation structure.
- Cable trays, tracks, clamps and supports to protect electrical items.

What's in it

- HVAC system [B.3.1.1] or HVDC system [B.3.1.2]

B.3.1.1 HVAC system

Function

An HVAC system converts and transmits the electrical power generated by the wind turbines, at say 66 kV, to the onshore substation through the export cables at say 220 kV.

Who supplies this

Acrastyle, Hornbill Engineering, Hitachi Energy, GE Grid Solutions, Linxon UK, Nucore Group and Siemens Energy.

Key facts

Key components of an HVAC system include:

- HV switchgear sets to isolate and protect each array and export connection to the substation
- Transformers to transform turbine voltage to a higher voltage for onward transmission. A typical offshore substation has two or more transformers to improve availability. Transformers are oil cooled, requiring the use of fire and blast protection.
- Passive and active reactive power compensation, typically large coils and power electronics, to improve the stability of the local grid system.
- Earthing systems including lightning protection connecting electrical components and the substation structure.
- Cable trays, tracks, clamps and supports to protect electrical items.

An HVAC transmission system, including the export cables and offshore and onshore substation, typically offers a lower lifetime cost (when also taking into account electrical losses) than the equivalent HVDC system for wind farms where the distance to the onshore substation is less than about 80 to 100 km. The factors used in choosing between HVAC and HVDC, however, are complex.

Technology is being developed to allow AC transmission to be used over longer distances, such as lower frequency AC transmission. Some wind farms have used additional reactive power compensation equipment, located on offshore platforms part way along the offshore cable route, or in onshore substations close to the coast.

HVAC electrical systems use standard technology and systems, which may be customised for use in a marine environment.

What's in it

- HVAC switchgear
- Transformers
- Passive and active reactive power compensation
- Earthing systems
- Auxiliary electrical, control and monitoring systems
- Industrial waterproof enclosures
- Cable trays, tracks, clamps and supports to protect electrical items

B.3.1.2 HVDC system

Function

An HVDC system converts and transmits the electrical power generated by the wind turbines. For example, turbines generate at 66kV AC, this is transformed to 132kV AC and then converted 320 kV DC which is transmitted to shore via the export cables. Equipment in the onshore substation converts the voltage back to say 275kV or 400kV for connection to the onshore transmission grid.

Who supplies this

A&T Enclosures, Acrastyle, Hornbill Engineering, Hitachi Energy, GE Grid Solutions and Siemens Energy.

Key facts

Key components of an HVDC system include:

- HV switchgear sets to isolate and protect each array and export connection to the substation.
- Converters to convert AC to DC at a higher voltage for onward transmission.
- Earthing systems including lightning protection connecting electrical components and the substation structure.
- Cable trays, tracks, clamps, and supports to protect electrical items.

An HVDC transmission system, including the export cables and offshore and onshore substations, typically offers a lower lifetime cost (when also taking into account the lower electrical losses of an HVDC system over these distances) than the equivalent HVAC system for wind farms where the distance to the onshore substation is greater than about 80 to 100 km. The factors used in choosing between HVAC and HVDC are, however, complex.

HVDC systems use relatively new technology and systems that are custom designed for the transmission of high power, say over 750 MW, over long distances. HVDC systems currently only operate point-to-point and require the use of a matched pair of converters at each substation (one onshore and one offshore).

Cost reductions have been seen in recent years and are expected to continue, driven by new technology and the increase in the use of interconnectors, as well as by offshore wind.

What's in it

- HV AC and DC switchgear
- Transformers
- Converters
- Passive and active reactive power compensation
- Earthing systems
- Auxiliary electrical, control and monitoring systems
- Industrial waterproof enclosures
- Cable trays, tracks, clamps and supports to protect electrical items

B.3.2 Auxiliary systems

Function

Auxiliary systems are facilities that support the operation and maintenance of the substation and enable some wider wind farm maintenance activities.

Figure 45 Offshore substation crane and storage facilities, courtesy of Equinor, © Ole Jørgen Bratland.

What it costs

About £13 million for a 1 GW wind farm.

Who supplies this

Building monitoring systems (fire and gas detection, CCTV, access, security) suppliers include

- Communications and networking: Atos, Cisco, Cobham Wireless, Motorola and Semco Maritime.
- Crane: Demag, Granada and Kenz Figee.
- Diesel generator: Aggreko, Caterpillar, Iveco, Midas and Mitsubishi.

- Fire and blast protection: Mech-Tools (steel) and Solent Composite Systems (composites).
- Heating, ventilation and air conditioning: Heinen & Hopman and Oteac.
- Helicopter fuelling systems: Imenco.

Supply of general facilities is often local to assembly of the substation.

Key facts

Like any other complex industrial facility, this offshore building needs fire detection and suppression systems along with security, safety, communications, and other monitoring systems.

Fire and blast protection is required because the transformers contain oil and coolants and present a fire risk. They need to be protected from fires elsewhere on the platform.

A standby generator is required to provide auxiliary power and lighting in the event of loss of connection to the onshore substation and to provide power to restart and reconnect to the onshore substation.

Also required are a control room, health and welfare and refuge for visiting crews, clean and black water systems, fuel tanks, LV power supplies, navigational aids, and safety systems.

What's in it

- Auxiliary electrical systems
- Monitoring systems
- Communication system
- Fire and blast protection systems
- Standby generator (normally for HVDC substations)
- Crane
- Control room & refuge
- Clean and black water systems (normally for HVDC substations)
- Fuel tanks (normally for HVDC substations)
- Heating, ventilation and air conditioning equipment

B.3.3 Topside structures

Function

The topside structure provides support and protection for the electrical and other systems.

What it costs

About £123 million for a 1 GW wind farm.

Who supplies this

Aibel, Babcock, CS Wind, Smulders and Seatrium.

Key facts

The topside is a complex steel structure, incorporating many safety considerations and services.

A helideck is generally specified to enable helicopter landing (see 0 for further information). Offshore helidecks are generally aluminium to minimise corrosion and weight. An accident during take-off or landing can result in hundreds of litres of jet-fuel spilling from ruptured fuel tanks so stringent safety regulations are in place with the requirement for an integrated fire-fighting system. The use of helicopters for crew transfer is an integral part of maintenance and service operations for some but may only be used for emergency access or egress by others.

What's in it

- Helideck and/or heliwinch
- Steel structure

B.4 Substation foundation

Function

The offshore substation foundation supports the topside structure.

What it costs

About £22 million for a 1 GW wind farm.

Who supplies this

Dajin Heavy Industry Corporation, Eversendai, Lamprell and Smulders.

Key facts

Substation foundations are likely to be jackets. These are steel lattice structures with usually three or four legs that are anchored to the sea bed using pin piles or suction buckets. See B.2.2 Jacket for more information.

What's in it

- Jacket [B.2.2]
- Pin piles or suction buckets

B.5 Onshore substation

Function

The onshore substation transforms power to grid voltage, for example up to 400 kV. Where a HVDC export cable is used, the substation converts the power to three-phase AC. It also provides switchgear to protect the grid from the wind farm, and vice versa, for fault conditions.

Figure 46 Onshore substation, courtesy of Trant Engineering.

What it costs

About £44 million for a 1 GW wind farm. This includes the buildings, access and security as well as electrical systems.

Who supplies this

They are generally contracted to the same main contractor as the offshore substation electrical system [B.3.1].

Suppliers include: AJ Engineering & Construction Services, Linxon, and Morgan Marine.

Key facts

The onshore substation is often the first part of the wind farm to be built, about a year before offshore construction. In some cases, work may start ahead of FID for the wind farm to mitigate the risk of stranded generation assets.

Typically, they are two parts to the substation: the wind farm side owned by the offshore transmission owner (OFTO in the UK) and the grid side owned by the relevant grid operator (National Grid Electricity Transmission in England and Wales, SSE Networks or SP Energy Networks in Scotland, or Northern Ireland Electricity Networks).

The wind farm side of the substation is larger, consisting of the majority of the electrical system and a building with a control room, office and storage. The grid side of the substation may be an extension to an existing facility or a new one if this is not practical.

Many of the electrical components are similar in specification to the offshore substation, but constraints on weight and space are not as critical. The substation will contain metering equipment to measure electricity exported to the grid.

The onshore substation is ideally located close to the offshore export cable landfall to limit the length of the onshore cable route, but it may be up to 60 km from landfall.

The area of the onshore substation is likely to be about 5 ha for an HVAC system and 7.5 ha for an HVDC system.

The onshore substation is likely to be contracted to a supplier of transmission systems with a substantial amount of the work contracted to a civil engineering contractor.

What's in it

- Electrical system [B.5.1]
- Buildings, access and security [B.5.2]

B.5.1 Electrical system

Function

The onshore substation electrical system converts the power generated from the wind farm into a form that can be integrated into the wider transmission network.

What it costs

About £31 million for a 1 GW substation.

Who supplies this

They are generally contracted to the same main contractor as the offshore substation electrical system [B.3.1].

Key facts

The onshore substation has the same types of electrical system components as the offshore substation. This typically includes switchgear, transformers (if HVAC), converters (if HVDC), reactive power compensation and earthing systems.

What's in it

- HVAC system [B.3.1.1]
- HVDC system [B.3.1.2]

B.5.2 Buildings, access and security

Function

Buildings, access and security provide physical protection and security for the onshore electrical equipment that connects the wind farm to the onshore transmission network.

What it costs

About £13 million for a 1 GW substation.

Who supplies this

Buildings: any provider with a suitable track record of constructing architect-designed industrial buildings can respond to a tender to construct the building and compounds.

Access and security: industrial fencing, security including CCTV, access control systems, industrial LV systems, HVAC (short for heating, ventilation and air-conditioning) will be put out to tender and can be supplied by any pre-qualified supplier.

Key facts

The buildings and associated compounds are custom designed to suit the specific technical and planning requirements of the project.

For an HVAC substation, indoor space is required for housing some of the switchgear, monitoring systems, and associated LV systems and welfare facilities for visiting technicians. Often about the same area of outdoor space is required for compounds for outdoor HV switchgear, termination of HV overhead lines, storage, and car parking.

For an HVDC substation, indoor space, typically at least two storeys high, houses the HVDC converter, monitoring systems, and associated LV systems and welfare facilities for visiting technicians. Outdoor space is also needed for compounds for outdoor HV switchgear, termination of HV overhead lines, storage, and car parking.

What's in it

- Monitoring systems
- Auxiliary and LV system
- Welfare facility

B.6 Operations base

Function

The operations base supports the operation, maintenance and service of the wind farm.

Figure 47 Operations base, courtesy of Corstorphine and Wright.

Who supplies this

The wind farm owner is likely to choose a local construction company for the construction of the operations base.

Key facts

The specification for an operations base depends on whether the owner has chosen a shore-based maintenance and service strategy (using crew transfer vessels) or an offshore maintenance and service strategy (using service operation vessels).

For a shore-based strategy, the operations base consists of offices, warehousing, workshops, car parking and vessel berths. The total area of the site is likely to be about 8,000 m2.

A 1 GW wind farm with a shore-base strategy is likely to require up to 10 CTV berths. Fewer than this will be needed on a day-to-day basis but the owner will want to ensure that there is capacity to support peak turbine maintenance and service activity and for the use of balance of plant maintenance contractors.

CTVs use purpose-built concrete pontoons with mooring, electrical and water systems and a fast fuelling system. One CTV needs a berth of about 30 m. The berths are likely to be built ready for the construction phase before being reutilised for operation.

For an offshore maintenance and service strategy, a base may be used to support several wind farms. Although, an SOV will only visit port every 14 or 28 days, the owner is likely to want a dedicated berth of about 100 m. In theory, the administration of the wind farm does not need to be within the port but it is likely that owners will choose to locate it close to offshore operations.

What's in it

- Warehouse
- Workshop
- Vessel berths

I Installation and commissioning

Function

All installation and commissioning of balance of plant and turbines, including land- and sea-based activity. For offshore activities, the process starts by transporting components from the nearest port to manufacture to either the Construction port [I.7] or straight to site. Activities are complete by the wind farm construction works completion date, where assets are handed over to operational teams.

What it costs

About £1 billion for a 1 GW wind farm. This includes the installation of the balance of plant and turbines, with related offshore logistics. It also includes developer's insurance, construction project management and spent contingency (not itemised in sections below).

Who supplies this

Installation: Suppliers listed in relevant sections below.

Full engineer, procure, construct and install (EPCI) services: Boskalis, DEME Group (A2Sea, GeoSea and Tideway), Jan de Nul, MPI Offshore, Subsea 7 (Seaway Heavy Lifting, Seaway Offshore Cables) and Van Oord Offshore Wind.

Key facts

Today, the typical process for installation is to install the wind farm in the following sequence, with overlaps where possible:

- Onshore substation and onshore export cables
- Foundations
- Offshore substations
- Array cables
- Offshore export cables, and
- Turbines.

The installation period for a 1 GW wind farm is typically between two and three years from the start of onshore works.

Weather downtime is a key cost consideration for any offshore activity with a third of time often lost through waiting on weather.

Wave height is the most widely used metric to assess the limitation of offshore activities. In reality, this needs to be combined with wave periodicity, direction, persistence (the length and frequency of suitable weather windows), wind speed and direction and tidal flow to define the fraction of workable and non-workable days for different activities.

Sites with deeper water and farther from shore are typically associated with more adverse weather conditions and higher weather downtime.

The opportunity for innovation to reduce costs is substantial and increasing the operating range of offshore operations is key as this increases vessel utilisation and shortens project installation time. Improvements in forecasting models, vessel capabilities, and installation techniques can help optimise scheduling and reduce delays. Already, the season for installation is being extended, even though this increases weather downtime.

There can be considerable risk in introducing new processes and technologies to reduce weather downtime and demonstration will be difficult in some cases. A concern is that some innovations in installation aimed at reducing costs tend to push the boundaries of what can be achieved in adverse conditions. Addressing health and safety considerations needs to remain a focus.

Installation services are supplied on a day rate or lump sum basis, principally for the vessels and the crew and equipment onboard. Additional costs are fuel and harbour dues.

Developers vary in strategy but contracts are usually let for the cable laying (separately for subsea export and array, and onshore), offshore and onshore substation installation, foundation installation and turbine installation. They may award a single EPCI but this has been less favoured in the UK, particularly by experienced developers that can manage the interface risks between packages.

What's in it

I.1 Foundation installation

Function

Foundation installation consists of the transport and fixing of foundation in position.

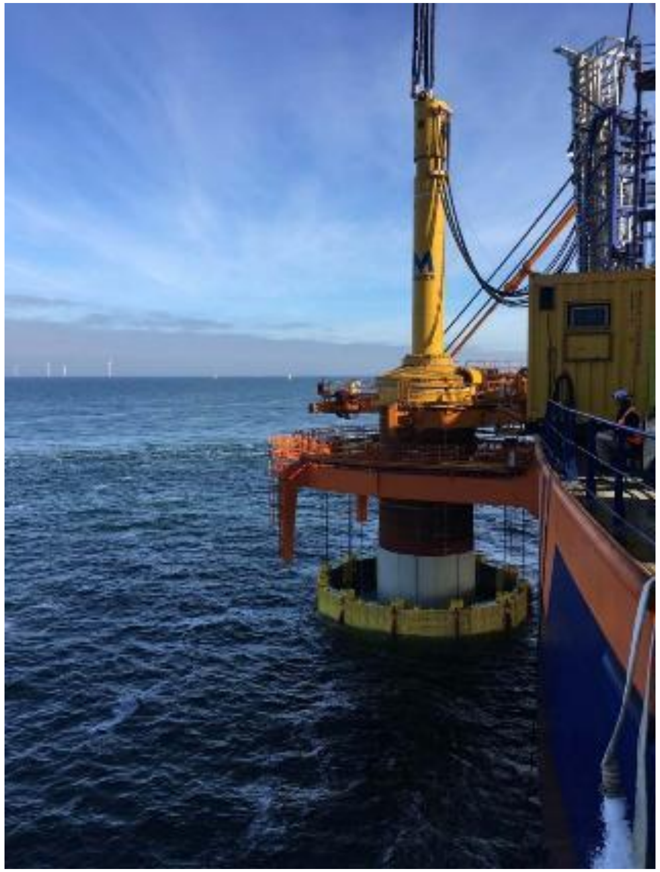


Figure 48 Foundation monopile piling operations, courtesy of Menck.

What it costs

About £165 million for a 1 GW wind farm.

Who supplies this

Bauer Offshore Technologies, Boskalis, Foundocean (grouting only), Fred. Olsen WindCarrier, GeoSea (DEME Group), Jan de Nul, Jumbo Offshore (transition pieces only), Newwaves Solutions, Osbit, SAL Heavy Lift (transition pieces only), Saipem, Scaldis Salvage & Marine, SeaJacks, Seaway Heavy Lifting (Subsea 7), Swire Blue Ocean and Van Oord Offshore Wind.

Key facts

The process involved varies with the foundation technology employed. Offshore substation foundations may be installed in a similar way to turbine foundations but are substantially larger.

Monopiles

Monopiles may be installed from a jack-up vessel or a floating vessel. The transition piece is usually lifted and grouted or bolted in place from the same vessel but two-vessel strategies have been used successfully.

Monopiles (up to 10 m diameter) are generally moved into position using the main crane and upending tool and held in position by a gripper tool. They are the driven into the sea bed using a hammer and anvil system before mounting and grouting transition pieces.

Transition pieces are usually carried and installed by the same vessel, although a two-vessel strategy in which transition pieces are installed by a separate vessel has been used on several occasions. This focuses the utilisation of the monopile installation vessel, which is likely to have higher day rates than the transition piece vessel. A disadvantage is the costs of mobilising and demobilising two vessels.

Feeder strategies have been used for monopiles, notably with Van Oord's Svanen, which has no useable deck space for transporting components. In this case, the monopiles are floated to site using tugs or transported using platform supply vessels.

An approximate timetable for installation of monopiles once at the wind farm site is:

- Transport and positioning: 2 hours for floating vessels; 4 hours for jack-ups
- Preparations: 1 hour
- Lifting and pile positioning: 1 hour
- Driving: 6 hours, and
- Grouting: 2 hours.

The full cycle time is 2-3 days per monopile, a figure that takes into account mobilisation and demobilisation, loading and waiting on weather.

Under some ground conditions, monopiles are grouted into a pre-drilled rock socket. Where boulders are present, a combination of drilling and driving is required.

Jackets

Jacket foundations may be installed by floating vessels or jack-ups. Installation usually involves pre-piling using a reusable template. The jacket is then lowered into place over the pin piles and grouted. Post-piling, in which the pin piles are driven (or lowered into pre-drilled sockets) through a sleeve on the jacket legs, may alternatively be used. Pre-piling has the advantage of decoupling the piling and jacket installation, enabling a lower cost vessel to be used for piling and maximising the use of deck space of the main jacket installation vessel.

An approximate timetable for installation of jackets once at the wind farm site is:

- Transport and positioning: 2 hours for floating vessels; 4 hours for jack-ups
- Preparations: 1 hour
- Lifting and pile positioning: 4 hours
- Driving: 8 hours, and

- Grouting: 2 hours.

The full cycle time is 3-5 days per jacket, a figure that takes into account mobilisation and demobilisation, loading and waiting on weather.

There is growing interest in suction bucket foundations, particularly under jackets. These are potentially faster and therefore cheaper, to install and avoid the need for expensive noise mitigation. This technology offers potentially lower installation costs because less equipment is needed. It also allows installation in areas with lower sediment depth to bedrock as the buckets do not need to go as deep. Suction buckets have been deployed commercially with jacket foundations but can be used with monopiles as well.

Gravity bases

Gravity base foundations may be installed by floating crane vessels (such as a sheerleg crane vessel) or specialist barges to support float out.

Concrete gravity foundations can weigh substantially more (3,000 t) than steel foundations and may be floated out to position before being submerged. The sea bed must be levelled to receive such foundations.

Large scale installation of gravity bases has not been attempted in UK waters. Cycle times are likely to be similar to jackets, but floating transportation can result in considerably more weather downtime and requires more onshore manufacturing space.

Floating foundations

To learn more about floating foundations, please see BVGA's Guide to Floating Offshore Wind.

Scour protection

Scour protection is generally provided by dumping of rocks, bags of stones or other materials (such as tyres) around the base of the structure. Rock dumping may use a fall-pipe vessel that are widely used in the dredging industry. Bags are likely to be lowered into position using an offshore construction vessel.

What's in it

- Foundation installation vessel [I.1.1]

I.1.1 Foundation installation vessel

Function

The foundation installation vessel transports the foundations from the quayside fabrication facility or construction port [I.7] to the site and secures them to the sea bed. Heavy lift vessels, floating sheerleg vessels and self-propelled jack-up vessels are all used.

Figure 49 Foundation installation vessel, courtesy of Jan de Nul.

What it costs

These costs are typically included in the foundation installation contract. A monopile installation vessel for a 1 GW wind farm will cost around £75 million. A TP installation vessel for a 1 GW wind farm costs around £41 million.

Who supplies this

Operators: Boskalis, Fred. Olsen WindCarrier, GeoSea (DEME Group), Jan de Nul, Jumbo Offshore, SAL Heavy Lift, Saipem, Scaldis Salvage & Marine, SeaJacks, Seaway Heavy Lifting (Subsea 7 Group), Swire Blue Ocean and Van Oord Offshore Wind.

Vessel manufacturers: as for Turbine installation vessel [I.6.1].

Key facts

Foundation installation vessel fleets have overlapped with turbine installation fleets in the past but these are diverging due to the increasing size and mass of components and the relative merits of jack-ups and floating heavy lift vessels.

Foundation installation has made considerable use of vessels originally built for other sectors, including oil and gas, bridge building and near-shore construction.

With the mass of monopiles increasingly exceeding 1,000 t, few jack-up vessels have the necessary lifting capacity. With the jacking process lasting several hours and the lower weather sensitivity of the installation process (compared with turbine installation), a floating installation vessel has notable advantages. Disadvantages have been the relatively high charter rates and low availability of heavy lift vessels with a maximum crane capacity of 1,500 t or greater. The recent investments in heavy lift vessels for the offshore wind market by Boskalis and GeoSea are considerable. A typical specification for a latest generation heavy lift vessel is:

- Length: 260 m, beam: 50 m, draft: 12 m
- Crew berths: 150
- Crane: 2,000 t

- Maximum transit speed: 14 knots
- Component capacity: Up to 7 foundations, and
- Dynamic positioning system.

Jacket foundations are typically lighter than monopiles for equivalent depths and the choice of vessel is driven by a number of factors including deck space and lift capacity. Installation using jack-ups is affected in particular because the position of the legs limits the flexible use of deck space. One of the advantages of three-legged jackets is that they enable better use of deck space.

What's in it

- Foundation handling equipment [I1.1.1]
- Foundation installation equipment [I1.1.2]
- Sea fastenings [I1.1.3]
- Cranes
- Auxiliary cranes
- Dynamic positioning system
- Propulsion systems
- Jack-up system
- Spud cans
- Helideck
- Gangway

I1.1.1 Foundation handling equipment

Function

Foundation handling equipment is used to manoeuvre the foundations into position before driving them into the sea bed.

Figure 50 Monopile upending tool, courtesy of Houlder.

What it costs

The crane, upending frame, pile gripper, pile guiding positioning frame and monopile plug are part of the contractor's equipment. Lifting tools, are usually rented.

Who supplies this

Suppliers include Houlder, IHC IQIP and Temporary Works Design.

Key facts

Monopiles are transported in the horizontal position.

A lifting tool grips a flange at the top of the monopile, to which the crane hook is secured.

The base of the monopile is gripped by an upending frame while the monopile is raised into the vertical position.

The crane then lifts the monopile and moves into position for piling. A pile guiding and positioning frame is used to position the monopile accurately and ensure verticality. The pile must be installed within 0.25° of vertical.

If a floating vessel is used for piling, a motion-compensated pile guiding and positioning frame may be used.

If the monopile is floated out to site, a monopile plug is used to maintain buoyancy and provide a towing point.

Jackets are transported in the vertical position if a heavy-lift vessel with deck space is used. If the jacket is to be installed in relatively benign conditions, a sheer leg crane vessel may transport a single jacket to site from port.

Equipment may be designed and built for a specific project or installed more or less permanently on the vessel with the flexibility to be used for a range of different projects.

Equipment may be owned or rented by the installation contractor.

What's in it

- Crane
- Lifting tool
- Upending frame
- Pile gripper
- Pile guiding and positioning frame
- Monopile plug

I1.1.2 Foundation installation equipment

Function

Foundation installation equipment is used to secure the foundation to the sea bed.

Figure 51 Jacket foundation pin piling operations, courtesy of Menck.

What it costs

Equipment, third party crew to operate, bolting tools or grouting spread, generators, survey equipment and ROV are usually rented for the duration of the project, rental rates vary significantly depending on the characteristics of the wind farm.

Who supplies this

Piling equipment: Cape Holland, Fistuca, IHC IQIP, Menck and PVE.

Noise mitigation: IHC IQIP and W3G Marine.

Key facts

Vessels have a range of onboard tooling, depending on type of foundation to be installed.

For monopiles, on-board hammer and anvil systems are used to drive the piles. On-board drilling systems are used where hammering is not possible due to ground conditions or environmental restrictions. In such conditions, monopiles are then grouted into position.

A hammer and anvil system may be rated up to 4,000 kJ and deliver 30-60 impacts per minute via a steel ram. Hammers can pile up to 9 m diameter piles. Larger piles may be tapered at the top to avoid any constraint.

A novel system in development is the use of a water column to drive the pile. The reported benefits are lower noise, fewer moving parts and less installation fatigue. Vibro piling has also been trialled and offers the potential of less noise and faster, lower impact piling.

Turbine locations are typically chosen to avoid areas where piling is likely to be problematic. For some sites, a vessel will be mobilised with drilling equipment to mitigate the risk to the project schedule in cases of pile refusal.

For pre-piled jackets, a reusable piling template is lowered to the sea bed and the pin piles hammered into the sea bed using the same process as for monopiles.

There is concern about the ecological impact of pile driving on marine mammals and the harbour porpoise in particular. Piling restrictions have been most common in Germany and the Netherlands.

There are three approaches to minimising the environmental impact of piling: avoidance, deterrence and mitigation.

For avoidance, the aim is to choose foundation technologies (for example, jackets or suction piles) and installations strategies (for example, timing or vibro piling) that have reduced impact.

For deterrence, the aim is to displace animals from areas of high noise levels by means of a ‘soft start’ or using a deterrence device. ‘Pingers’ emit aversive sounds into the marine environment for about 40 mins before piling. ‘Seal scarers’ are similar but emit higher density sounds for about 30 mins before piling.

The two main mitigation technologies are bubble curtains and noise mitigation screens. Other approaches are foam-wrapped piles, hydrosound dampers and resonator systems.

Mitigation systems are expensive both in terms of equipment and time and there has been a large amount of research to understand the enduring impacts of piling on marine mammal populations. Projects may monitor impacts during installation as part of this activity.

What’s in it

- Hammer
- Anvil system
- Noise mitigation equipment

I1.1.3 Sea fastenings

Function

Sea fastenings are used during the transport of heavy and costly components from the Construction port [I.7] to site.

What it costs

Included in installation subcontract cost.

Who supplies this

Suppliers include ALE, Durham Sheet Metal, MC Construction, Semco Maritime and Temporary Works Design.

Key facts

Sea fastenings are typically designed and fabricated specifically for a project, although there is increasing interest in reusable sea fastenings that reduce cost of design and manufacture and shorten mobilisation time. Turbine component sea fastenings are well suited to this approach because the dimensions do not vary substantially for a particular turbine model.

Sea fastenings are typically welded steel structures that are welded to the vessel deck during mobilisation. They have locking devices to ensure safe transit and rapid release at the installation site.

What's in it

- Monopile cradle
- Transition piece cradle
- Crane sea fastening

I.2 Offshore substation installation

Function

The installation of the offshore substation consists of the transfer of the substation from its quayside fabrication site and the installation on the foundation.

What it costs

About £43 million for a 1 GW offshore wind farm.

Who supplies this

The installation often forms part of the substation supply contract.

Marine contractors include Boskalis, DEME, Heerema, Saipem, Scaldis Salvage & Marine, Seaway 7, Van Oord and ZPMC.

Key facts

Offshore substation installation is a heavy lift operation (2,000 t plus) requiring vessels with sufficient crane capacity. Vessels with the necessary lift capacity typically do not have the deck space to accommodate a substation platform. The substation is therefore floated out of the substation fabrication facility on a barge, usually directly to the wind farm site.

The substation foundation, which is installed prior to the topside structure, may be a monopile or a jacket and the installation may form part of the turbine foundation installation package.

Figure 52 Topside structure of an offshore substation being lifted onto a jacket foundation. Image courtesy of ScottishPower Renewables. All rights reserved.

What's in it

- Substation installation vessel[I.2.1]

I.2.1 Substation installation vessel

Function

The substation installation vessel allows the transport and lift of offshore substation, in order to position it on pre-installed foundation.

Figure 53 Substation installation vessel, courtesy of ScottishPower Renewables.

What it costs

Included in the substation installation contract.

Who supplies this

Operators include Bonn & Mees, Heerema, Huisman, Saipem, Scaldis Salvage & Marine, Seajacks, Seaway 7 and ZPMC.

Key facts

Four main types of vessel may be used:

- Sheerleg crane vessel

- Barge
- Heavy lift vessel, and
- Semisubmersible vessel.

The choice of vessel is likely to be driven by market factors and, in many cases, the vessels serve other markets. As a result, there has been little investment in vessels for the offshore wind market specifically.

Heavy lift vessels used in offshore wind include Rambiz, Stanislav Yudin and Samson.

Crane ratings are from 900 t to over 3,000 t.

What's in it

- Crane
- Auxiliary cranes
- Dynamic positioning system
- Propulsion systems
- Helideck
- Gangway

I.3 Onshore substation construction

Function

The construction of the onshore substation consists of the construction of the infrastructure and the installation of electrical equipment.

What it costs

About £29 million for a 1 GW wind farm.

Who supplies this

Balfour Beatty, J Murphy and Jones Bros.

Key facts

Enabling works to level the site and provide road access are completed early, to ensure that the work can begin promptly. They may also address constraining features of the site, such as the existence of overhead power lines or underground pipes. Subcontracted work may include fencing, curbing, tree cutting and the demolition of existing structures.

This work may form part of the main civil construction contract.

The civil contractor will typically work to an engineering design supplied by the main contractor. About 20-25 % of the work will be subcontracted, including steelwork, flooring, fencing and sealing roads and car-parking areas, access tracks, gravel paths and hard-standing.

Local suppliers will generally be used unless there are specialist requirements, as they have valuable knowledge of local contractors and good contacts in the local authority and Environment Agency office.

Contractors will recruit local operatives and hire local equipment if they are operating at large distances from their fleet's base.

Electrical works and commissioning will typically be led by the main electrical supplier but substantial work is likely to be subcontracted to a high voltage electrical contractor.

What's in it

- Civil works
- Electrical works

I.4 Onshore export cable installation

Function

The installation of the onshore export cable completes the connection between the offshore export cable and the onshore substation.

What it costs

About £8.4 million for a 1 GW wind farm, depending on distance and complexity of route.

Who supplies this

Construction companies: Balfour Beatty, J Murphy and Sons, NKT, Nexans, Powertek Utilities Group and VolkerStevin.
Marine contractors: DeepOcean and Global Offshore.

Key facts

The subsea cables terminate a short distance inland at the transition joint bay. This could be located on the beach, behind a sea defence, or up to 1 km inland.

Onshore cabling is generally underground to address local concerns over the siting of overhead power lines.

There are a range of local services used before and during the cable installation. These include wheel washing, road cleaning, traffic management, signage and temporary bridges over rivers and ditches.

At least one site compound will be established along the cable route. These sites will provide equipment storage, car parking and welfare facilities for staff. Typically, they will be 100 m by 100 m in size.

Before construction, site investigation and environmental work is undertaken to plan the installation and minimise impact on the surroundings.

A cable corridor is used during installation, which comprises the cable trench, storage for spools and access road.

Installation can be carried out using open trenches, typically around 1 metre wide and up to 1 km in length (depending on the cable) or by placing ducts into the trenches and covering them over more quickly. With ducting, it is typical to use medium density polyethylene (MDPE) ducts which are laid in the trench and the cable pulled through the ducts at a later time in up to 1 km lengths. This option allows excavation, duct installation and backfilling to be completed in sections of up to 120 m in a day. This minimises the amount of excavation left open outside working hours, which can help reduce environmental, and safety concerns.

Where the cable crosses obstacles such as roads or railways or encounters difficult or highly sensitive conditions, directional drilling may be used to route and pull the cable under the obstacle without the need for trenching.

Specialist drilling equipment creates a bore that passes the obstacle and can be up to 1,000 m in length. Drilling mud is used as lubrication and this is recycled through a temporary mud lagoon during construction and disposed of after construction. Once drilled, a cable duct is then pulled through and the cable is then pulled through again using specialist equipment.

The cable is tested to ensure a complete circuit is in place. Once fully installed, an energised test is carried out to verify operation at or close to the intended voltage.

Care is taken to reduce the impact on endangered species, including species such as newts, bats and dormice, which might require specialist environmental monitoring and/or mitigation.

Figure 54 Onshore export cable trenching process. Image courtesy of Ørsted. All rights reserved.

What’s in it

- Drilling equipment
- Trenching equipment
- Cable-laying equipment

I.5 Offshore cable installation

Function

The installation of array cables enables the connection of the wind turbines to the offshore substation whilst the installation of the export cable enables the connection between the offshore and onshore substations.

Figure 55 Offshore cable installation works, © Seaway Offshore Cables.

What it costs

About £193 million for a 1 GW wind farm. This includes cable-laying vessel, cable burial, cable pull-in and electrical testing and termination. It also includes survey works, route clearance and cable protection systems (not itemised in sections below).

Who supplies this

Marine contractors: Aquatic Engineering and Construction, Boskalis, DEME, DeepOcean, Global Marine, Global Offshore, Huisman, IKM Testing, Jan de Nul, Oceanteam, Seaway 7 and Van Oord.

Cable manufacturers with installation capabilities: Nexans, NKT and Prysmian.

Key facts

All offshore cable installation activities are preceded with a survey to define the route and identify any unexploded ordnance (UXO). This is followed by a pre-lay grapnel run (or alternative method) to clear debris from the cable route.

Offshore cable installation involves cable laying, and in some cases cable burial and trenching. This typically involves one or two runs depending on the ground conditions, the equipment available and the preferences of the developer and contractor.

Test and inspection typically include independent observation of all cable handing and laying operations, often with subsea video recording.

To avoid unnecessary handling, it is preferred that subsea cables are loaded directly onto an installation vessel from the factory. Lengths may be pre-cut.

Cable protection typically falls within the installer's scope of work (B.1.3 Cable protection). Other techniques like rock dumping and mattresses are also used to ensure burial and protection on cable crossings.

What's in it

I.5.1 Export cable installation

Function

The installation of export cables enables the connection between the offshore substation and the onshore export cable.

Who supplies this

Marine contractors: Boskalis, DEME, DeepOcean, Global Marine, Global Offshore, Huisman, Jan de Nul, Oceanteam, Seaway 7 and Van Oord.

Cable manufacturers with installation capabilities: Nexans, NKT and Prysmian.

Key facts

Export cable installation starts with the shore pull-in (first-end pull-in) (see B.1.2 for further information). The CLV then moves off, laying the cable as it goes.

Export cables are laid in sections which are as long as possible to avoid expensive subsea joints.

Export cables are typically buried 1 to 4 m below the sea bed. Burial usually takes place simultaneously as the cable is laid using a cable plough, as immediate burial and protection is obtained in a single pass which reduces costs. A two-stage process may also be used where the cable is first laid on the sea bed, after which a vessel with a trenching remotely operated vehicle (ROV), and a vertical injector and jetting sled, undertakes the burial. The approach taken depends on a number of factors including the availability of equipment, cost and ground conditions.

At the offshore substation, the cable is either set down and wet-stored for subsequent pull-in to the substation, or immediately pulled-in which is preferred. Electrical terminations are made after pull-in.

Most export cable manufacturers have CLVs and install export cables themselves.

Figure 56 Offshore array cables installed at landfall. Image courtesy of Jan de Nul. All rights reserved.

What's in it

- Cable-laying vessel [I.5.3]
- Cable burial [I.5.4]
- Cable pull-in [I.5.5]
- Electrical testing and termination [I.5.6]

I.5.2 Array cable installation

Function

The installation of array cables enables the connection of the installed offshore wind turbines to the offshore substation.

Who supplies this

Marine contractors: Boskalis, DEME, DeepOcean, Global Marine, Global Offshore, Huisman, Jan de Nul, Oceanteam, Seaway 7 and Van Oord.

Cable manufacturers with installation capabilities: Nexans, NKT and Prysmian.

Key facts

Array cables are installed after the offshore wind turbine has been installed.

Array cable installation:

- This starts with the cable pull-in at the offshore substation, if it is the first connection in the array loop or string, otherwise it starts at an offshore wind turbine.
- The cable is then laid away using the CLV towards the next turbine. The array cable is either laid on the sea bed or buried using a cable plough or a trenching ROV.
- The cable is pulled-in at the next turbine through a J-tube to complete the single array length.

Array cables are usually installed by marine contractors.

What's in it

- Cable-laying vessel [I.5.3]
- Cable burial [I.5.4]
- Cable pull-in [I.5.5]
- Electrical testing and termination [I.5.6]

I.5.3 Cable-laying vessel

Function

The cable-laying vessel lays the cables between the wind turbines and offshore substation and between the offshore substation and the onshore transition joint pit at cable landfall.

Figure 57 Cable-laying vessel Maersk Connector, courtesy of DeepOcean.

What it costs

Included in the offshore cable installation contract.

Who supplies this

Marine contractors: Boskalis, DEME, DeepOcean, Global Marine, Global Offshore, Jan de Nul, Oceanteam, Seaway 7 and Van Oord.

Cable manufacturers with installation capabilities: Nexans, NKT and Prysmian.

Key facts

The same vessels may be used for export and array cable installation, although export cable-laying vessels will typically have larger carousels to accommodate longer cables. The vessels may need to have a shallow draft to install the cables in shallow water.

Simultaneous lay and burial can be carried out with a variety of burial tools. In that case, the cable is buried during the lay to obtain immediate protection. Otherwise, a post-lay burial is required. See [I.5.2] for more details on cable burial.

Cable-laying vessels are characterised as follows:

- Up to 30 m (breadth) by 140 m (length) and can operate at a speed up to 14kn (transit speed).
- Accommodation for a crew of up to 90.
- The current capacity of carousels is of up to 7,000 t. Some contractors offer vessels with a double carousel (for example Jan de Nul's Isaac Newton).
- Likely to be equipped with a 3D motion compensated crane with up to 25 t and a 25 t A-frame.
- Generally equipped with a personnel transfer gangway (for example Ampelmann system) and a helideck.

What's in it

- ROV [I5.3.1]
- Cable-handling equipment [I5.3.2]
- Crane
- Personal transfer gangway

I5.3.1 ROV

Function

ROVs have many uses including visual inspections of subsea structures such as cable entry locations on foundations or cable routes, feeding the cable through the J-tubes and monitoring operations such as grouting of piles.

What it costs

Included in the installation contract.

Who supplies this

ROVs are usually provided offshore contractor. Manufacturers include Forum Energy Technologies, Louis Dreyfus Travocean, Saab Seaeye and SMD.

Key facts

ROVs are generally used not only to monitor the subsea structures but also to assist the laying and pull-in of the cables during which they carry out a touchdown monitoring.

Cable installation contractors usually seek to avoid using ROVs to minimise costs. In deeper water, the use of ROVs avoids the high costs associated with the use of divers to work at depths requiring specialist equipment and extended decompression.

What's in it

- Propulsion system
- Control system
- Remote camera
- Lighting system
- Power supply
- Manipulator arm

I5.3.2 Cable-handling equipment

Function

The cable-handling equipment ensures that the cable is safely deployed from the vessel to the sea bed.

Figure 58 Cable on carrousel, courtesy of RWE.

What it costs

The equipment is usually provided by the cable installation contractor; in that case, it is either part of the vessel or can be rented.

Who supplies this

Cable-handling equipment is usually provided by the cable installation contractor; in that case, it is either part of the vessel or must be mobilised.

Manufacturers: Fraser Hydraulic Power, Hulst Cable Equipment, Royal IHC, MacArtney SMD, Oceaneering and Sparrows.

Rental: Caley Ocean Systems, CWind (Global Marine Group), Demanor, Drammen Yard, Oceaneering, Osbit, RentOcean and Sparrows.

Key facts

Cable handling equipment is designed to protect the cable's integrity and to ensure the cable is deployed in a controlled manner and at the correct speed.

The cable is stored either on a carousel, in a static tank or on a reel. To exit the storage area, a tensioner is used to grip and move the cable toward the chute where the cable is deployed onto the sea bed whilst ensuring no bending at less than the minimum allowed bend radius.

During a second-end pull-in or pull-in at the substation, a quadrant is used to deploy the end of the cable on the sea bed before it is pulled in.

What's in it

- Cable storage: carousel, tank or reel
- Cable lay equipment: tensioners, cable highway (rollers), chute and quadrant

I.5.4 Cable burial

Function

The cable is buried to a predefined depth under the sea bed to ensure protection from external aggression (for example fishing and anchoring) as well as to prevent exposure due to sea bed mobility.

What it costs

Cable burial for a 1 GW wind farm costs around £44 million.

Who supplies this

The burial and burial tools are usually provided by the cable installation contractor.

Vessel contractors: Assodivers, Boskalis, Canyon Offshore (Helix ES), Global Marine, Jan de Nul and Van Oord Offshore Wind.

Manufacturers include Canyon Offshore (Helix ES), Osbit, Royal IHC and SMD.

Key facts

Burial can be achieved either at the same time as the lay of the cable (simultaneous lay and burial) or afterwards (post-lay burial). If the former method is used, a Cable plough [I5.4.2] is used simultaneously during the cable lay to create a trench in which the cable falls and is immediately buried. In the case of a post-lay burial, the vessel will move along the laid cable, using a or Vertical injector and jetting sled [I5.4.4] to fluidise the sediment and allowing the cable to be buried.

Burial depths are determined based on an industry standard (burial protection index and/or cable burial risk assessment). Generally, cables are buried at a depth of 1-4 m below the sea bed.

What's in it

- Cable burial vessel [I5.4.1]
- Cable plough [I5.4.2]
- Trenching ROV [I5.4.3]
- Vertical injector and jetting sled [I5.4.4]

I5.4.1 Cable burial vessel

Function

The cable burial vessel undertakes cable burial post laying of the cable on the sea bed.

Who supplies this

Cable burial vessels are provided by a number of offshore vessel operators such as Canyon Offshore (Helix ES), Global Marine and Van Oord Offshore Wind.

Key facts

Burial vessels vary in size based on the required burial tools to be mobilised and the water depth. Generally, most types of vessels can be utilised as long as burial tools can be mobilised. Dynamically positioned vessels are generally used although barges may be used in shallower waters in the case of near-shore burial work.

Post-lay burial is undertaken using a Trenching ROV[I5.4.3]. Vertical injector and jetting sled [I5.4.4] can also be used.

What's in it

- Crane or A-frame
- Personnel transfer gangway
- Burial tools and equipment

I5.4.2 Cable plough

Function

A cable plough is normally used to simultaneously lay and bury a cable but it can also be used in post-lay burial and pre-trenching.

Figure 59 Cable plough, courtesy of Royal IHC.

What it costs

The provision of the cable plough is usually part of the cable installation contract scope.

Who supplies this

The cable plough is usually provided by the cable installation contractor, either as part of the vessel or mobilised specifically.

Manufacturers: ETA Subsea Specialists, Osbit, Royal IHC and SMD.

Rental: ETA Subsea Specialists and Pharos Offshore.

Key facts

Cable ploughs can bury the cable down to 3-4 m below sea bed level.

The plough will require a tow force to pull the plough through the soil depending on the soil conditions and the required burial depth. Using a barge (for shallow water operations), this force is supplied by an anchor or a tow tug. For a dynamically positioned vessel, a specialist vessel with an appropriate bollard pull is required. It is often not possible to plough close to the turbine or substation. In that case, a Trenching ROV[I5.4.3].may be used.

What's in it

- Plough share
- High pressure jetting nozzles
- Skids
- Bell mouth
- Cable depressor

I5.4.3 Trenching ROV

Function

A trenching ROV forms a trench in which to bury the cable. This tool is generally used in post-lay burial but can be used during simultaneous lay.

Figure 60 Trenching ROV, courtesy of DeepOcean.

What it costs

The provision of the trenching ROV is usually part of the cable installation contract scope.

Who supplies this

The trenching ROV is usually provided by the cable installation contractor, either as part of the vessel or mobilised specifically.

Manufacturers: Forum Energy Technology, Louis Dreyfus Travocean, Osbit, Royal IHC, SIMEC and SMD.

Rental: Dockstr, James Fischer Marine Services and Oceaneering.

Key facts

ROVs can have either a jetting system or a mechanical cutter. A high pressure jetting system is used to fluidise the sea bed and allow the cable to sink to the required depth (only in sandy sediments and softer clays). For rocky or hard clay sea bed conditions, a mechanical cutter is used.

What's in it

- Pressure and flow water jetting system and/or mechanical cutter
- Power supply and control system
- Propulsion system
- Camera and lighting system
- Sonar
- Cable tracker

I5.4.4 Vertical injector and jetting sled

Function

Vertical injectors and jetting sleds are used to bury the cable where the sediment can be fluidised (for example sand, soft clays). Vertical injectors are used for simultaneous lay and burial of the cable. Jetting sleds are mostly used for post-lay burial.

What it costs

The provision of the vertical injector or jetting sled is usually part of the cable installation contract scope.

Who supplies this

The vertical injector or jetting sled is usually provided by the cable installation contractor.

Manufacturers: Miah, Royal IHC and Seatools.

Rental: ETA Subsea Specialists, Global Marine and Modus.

Key facts

Vertical injectors can bury the cable down to 10 m below sea bed level using a high pressure jetting system in soft sediment. They are generally fixed on the side of the vessel. A vertical injector is made up of a header and extension section as well as a burial section, the shoe injector, which contains the jetting nozzles.

Jetting sleds can bury the cable down to 4 m below the sea bed. They are usually equipped with a hydraulic actuation system that ensures the cable is buried at the required depth. An eduction system allows the removal of excess material in the trench once the fluidisation has been carried out. Jetting sleds are deployed using a crane and can therefore be mobilised on a large range of vessels.

What's in it

- Shoe injector
- High-pressure jetting nozzles
- Cable depressor detector
- Pressure sensors
- Skids
- Positioning system receptor

I.5.5 Cable pull-in

Function

For the array cable, the pull-in consists of the pulling of the cable into the offshore substation or turbine foundation.

For export cables, the pull-in consists of pulling the cable into the onshore transition joint pit as well as into the offshore substations.

Figure 61 Cable pull-in operations, courtesy of DeepOcean.

What it costs

About £7 million for a 1 GW offshore wind farm.

Who supplies this

The cable pull-in is usually provided by the cable installation contractor (see[I.5]).

Horizontal Directional Drilling: Eco Drill, Joseph Gallagher and McCormack Drilling.

Key facts

The installation of the export cable starts with the onshore pull-in at the beach, during which the CLV is anchored offshore. A pull-in head is attached and the cable winched on floats or through a pre-laid duct to the onshore transition joint pit, where it is eventually jointed to the onshore cable. The CLV then moves off, laying the cable as it goes. Depending on the landfall site, some projects require horizontal directional drilling which may extend to the first short length of burial offshore. In other cases, the cable may be transferred to a third-party shallow draft barge or amphibious vehicle to bring the cable to shore.

At the offshore substation, it is preferred to pull-in the export cable to the substation immediately after it has been laid by the CLV. It may however be necessary to wet store the cable if, for example, the substation is not yet installed or if the CLV is not equipped to conduct the second-end pull-in at the substation. The offshore pull-in process is normally as follows:

- End-fitting and pull-in head is installed onto the cable end
- Bend stiffener is installed onto the end-fitting and the cable
- The cable is lowered into the sea
- A messenger wire that was placed in the I-tube/J-tube is attached to the pull-in head using an ROV
- Pull-in head is pulled into the I-tube/J-tube using a winch, and
- End fitting is connected to the hang-off at the substation or the foundation.

The array cable installation process is undertaken after the offshore wind turbines have been installed. It starts with the pull-in at the substation using a similar process to that described above. Pull-in at the foundation is carried out in a similar way. Once the cable has been pulled-in the CLV then moves off to the next location, laying the cable as it goes and pulling it in once it arrives at the following location. For second-end pull-ins, a quadrant is generally used.

What's in it

- Barge
- Amphibious vehicle
- ROV
- Messenger wire
- J-tubes
- Horizontal directional drilling
- Winches
- Quadrant
- Floats

I.5.6 Electrical testing and termination

Function

The electrical testing is designed to test and prove cable integrity whilst the termination enables the electrical connection between the offshore cable and either the wind turbine, the substation or the onshore cables.

Figure 62 Installation support vessel carrying out electrical termination and testing works, courtesy of Subsea7.

What it costs

About £9 million for a 1 GW offshore wind farm.

Who supplies this

The electrical testing and termination is usually provided by the cable installation contractor (see [I.5]).

Manufacturers of electrical testing equipment and termination tools: 360 Wind, Axess Group, Baur, JDR, Megger, Pfisterer, Tekmar, V&SH Offshore and WT Henley.

Key facts

Cables undergo a series of tests before dispatch from the manufacturer, dependent on the cable type and voltage class, including:

- Cable (and accessories) pre-qualification tests and type tests
- Cable (and accessories) type tests
- Cable routine electrical tests on each manufacturing length before jointing and armouring
- Sample tests
- Routine factory splice tests, and
- Tests on complete cable lengths including factory installed joints (if any).

Terminations are made after the cable has been pulled into the offshore substation or floating substructure. The armouring and insulation of the cables is stripped back and the cores are connected to a termination plug. The plug is then interfaced into a designated junction box or switchgear using a connector. A similar procedure is conducted for the fibre optic cable.

Terminating high-voltage cables is a highly skilled process that takes time to learn.

Prior to making terminations, a series of electrical tests are performed to prove the cable's electrical integrity. These include low frequency tests, insulation resistance tests, time-domain reflectometry tests and optical time-domain reflectometry.

After the cable is pulled into the transition joint pit on shore, it is connected to the onshore portion of the export cable

What's in it

- Test and diagnostics device
- Connection cables
- Power supply
- Termination plug
- Cable trays
- Hang-off clamp

I.6 Turbine installation

Function

Turbine installation involves transportation of the turbine components from the Construction port [I.7] and installation of the turbine components onto the foundation.

Figure 63 Installation vessel Seajacks Scylla, courtesy of Seajacks.

What it costs

About £132 million for a 1 GW wind farm.

Who supplies this

A2Sea/GeoSea (DEME Group), Fred. Olsen WindCarrier, Jan de Nul, MPI Offshore, Newwaves Solutions, Seajacks, Statkraft UK, Swire Blue Ocean and Van Oord Offshore Wind.

Key facts

Installation methods vary depending on the turbine supplier and the relative size of turbine and vessel. Installation methodologies aim to reduce as far as practical offshore operations. Typically, the turbine tower is pre-assembled onshore and transported with the nacelle and blades for final assembly offshore.

Three variations in the rotor installation process have been used repeatedly:

- Placing the nacelle on the tower then lifting the pre-assembled rotor in one piece to mate with the nacelle (a single rotor lift)
- Mounting the hub and two blades on the nacelle "bunny ears" at port, before mounting the nacelle on the tower onsite and then fitting the final blade, and
- Placing the nacelle plus hub on the tower then lifting individual blades to mate with the hub, turning the rotor each time to repeat the same lift three times.

The third method is current preferred practice, even though this involves more offshore operations.

Tower sections are typically preassembled onshore with any internal components and the completed structure is transported vertically to site for installation. Offshore turbine installation is undertaken by jack-up vessels due to the need for a stable platform to perform offshore lifting operations and mating of components at height.

The installation of a turbine from positioning the vessel at the site to departure takes about 24 hours, depending on location and weather conditions. The cycle time is between 1.5 and 4 days, depending on the project (factoring in mobilisation, demobilisation, loading and waiting on weather).
A constraint during transportation and installation is the acceleration limit defined by the turbine supplier to avoid damaging the turbines and invalidating warranties. This is typically about 0.5g.

Blade installation is constrained not only by the operating range of the vessel but also the wind speeds, and the limit has been gradually increased with innovations in blade lifting equipment. The current maximum is normally 13 m/s at hub height and any increases beyond this may be limited by health and safety risks.

Turbine installation is beginning to be explored through the use of floating vessels for turbine component installation, which aims to shorten installation times further. The movements of the lifting hook at hub heights greater than 110 m on a floating vessel have the potential to be substantial, however. Progress on floating installation methodologies will depend on collaboration between turbine suppliers and installation contractors.

Turbine installation is undertaken jointly by the turbine supplier technicians and the installation contractor. The turbine supplier is usually responsible for the lifts along with mechanical and electrical completion.

What's in it

- Turbine installation vessel [I.6.1]
- Commissioning [I.6.2]

I.6.1 Turbine installation vessel

Function

The turbine installation vessel transports the turbine components to site and supports the erection of the turbine on the foundation. Similar jack-up vessels are used to those for foundation installation.

Figure 64 Lifting of third blade during turbine installation, courtesy of Seajacks.

What it costs

These costs are typically included in the turbine installation contract. A turbine installation vessel for a 1 GW wind farm costs about £98 million.

Who supplies this

Operators: A2Sea/GeoSea (DEME Group), Fred. Olsen WindCarrier, Jan de Nul, MPI Offshore, Seajacks, Swire Blue Ocean and Van Oord Offshore Wind.

Vessel manufacturers: generally in China, Korea, Singapore or the Arabian Peninsula.

Key facts

Recent turbine installation on commercial-scale projects to date has normally been undertaken with a self-propelled jack-up vessel designed primarily for the purpose, though in some cases, jack-up barges have been towed with tugs.

Vessel contracts are typically placed by the wind farm developer or the turbine supplier.

An example of specification for these vessels is:

- Length: 130 m, Beam 40 m, Draft 5 m
- Crew berths: 100
- Crane: 1,500 t
- Carrying capacity: 9,300 t
- Maximum transit speed: 12 knots
- Jack-up depth: 45 m
- Wind turbine component capacity: 5 sets
- Number of jack-up legs: 4-6
- Jack up speed: 1 m/min, and
- Dynamic positioning system (DP2).

Most of the vessels in operation have been used for both turbine and foundation installation. Increasingly the fleets are diverging. The increase in turbine capacity (and therefore rotor diameter) is associated with a higher hub height. At the same time, foundation mass is increasing and they can now be installed more rapidly from a floating vessel.

Investment in new vessels requires careful consideration due to:

- Developments in turbine size are associated with a declining vessel market because vessel carrying capacity in MW increases with turbine rating and installation time per MW drops
- Turbine ratings are likely to continue to increase, meaning that vessels become obsolete for installation, and
- Investment costs for a vessel suitable for turbine and foundation installation are high but lower cost vessels can only target one or other of the markets.

A number of vessel cranes have undergone modification but unless upgrades were considered in the original design, they can have an impact on other aspects of the vessels' performance.

Feeder vessels could be used to limit the transit time of the main installation vessel but this is only likely to be cost effective if the transfer of turbine components from low cost floating feeder vessels can be achieved without increasing risk and if the feeder vessel has a considerably lower charter rate than the main installation vessel.

Floating vessels are considered a natural next step for turbine installation, offering theoretically faster installation than jack-ups. Hook height movements at 110 m or higher can be important, thereby limiting the operability of the vessel for installation work. A floating installation vessel could also be used efficiently for foundation installation thereby reducing investment risk.

Vessels no longer suitable for turbine installation in Europe could be further utilised in the service market and in new installation markets such as Asia, where turbine size has so far lagged behind that in Europe.

What's in it

- Turbine handling equipment and sea fastenings [I6.1.1]
- Crane
- Auxiliary cranes
- Dynamic positioning system
- Propulsion systems
- Jack-up system
- Spud cans
- Helideck
- Gangway

I6.1.1 Turbine handling equipment and sea fastenings

Function

Turbine handling equipment is used to assist in the lifting and manipulation of turbine components during loading in port and installation offshore. Handling equipment is typically developed by the turbine supplier to be specific to a given task and component. There are several handling tools required for offshore installation including tower handling tools, nacelle handling tools and blade handling tools.

Sea fastenings are used during the transport of heavy and costly components from the Construction port [I.7] to site.

Figure 65 Sea fastenings, courtesy of SubC Partner.

What it costs

Included in turbine installation cost.

Who supplies this

Component handling tools are often provided to the offshore contractor by the turbine supplier as the tool is specific to a turbine type and installation methodology.

Key facts

There are several approaches to reducing the sensitivity of turbine component lifts (especially the blades) to high winds, thereby reducing weather downtime:

- The blade still hangs from the crane hook, but is supported in a frame with a hydraulic assembly to allow the blade to be rotated remotely to the preferred orientation, the position of the blade also being constrained by a series of remotely controlled ropes
- A lifting tool with a four-part attachment: two tag lines from the crane and a third running from a bracket fixed to the tower enables the blade position to be controlled in wind speeds up to 13 m/s regardless of direction
- Rigid support of the blade so that at no point is its position influenced by wind loading, and
- Hook stabilisation tools that reduce hook movements due to wind.

Currently, blades can be lifted in winds in wind speeds up to 13 m/s. Although this limit could be raised in theory, there comes a point where high winds make work on deck hazardous, even if the turbine installation can, in theory, be continued.

Sea fastenings are structures located on the deck of the installation vessel, which allow for the safe transportation of turbine components from the Construction port [I.7] to the installation location. Typically, large steel fabricated structures and frames secured to the main deck of the installation vessel.

Sea fastenings are designed to transfer the load of the component into the vessel structure and keep the component in position without damaging the component or vessel. Sea fastenings must also be designed to allow safe access of technicians both during transportation for inspections and to release the component to allow lifting.

What's in it

- Remotely controlled electro mechanical systems
- Remote controls operated by installation technician on deck of the vessel
- Winches
- Turbine frame
- Blade rack sea fastening
- Tower grillage
- Crane sea fastening
- Tag-line systems

I.6.2 Commissioning

Function

Final commissioning is a set of mechanical and electrical checks and tests on the installed offshore wind turbine. It results in all systems having been put to work in a safe manner prior to handover of the installed floating offshore wind turbine to the client.

Figure 66 Operative carrying out commissioning works on substation, courtesy of RWE.

What it costs

These costs are included in the wind turbine / substation supply contract.

Who supplies this

Final commissioning is expected to be split between the EPCI contractor for the array cable installation and hook-up, and the wind turbine supplier for the wind turbine.

Key facts

As much pre-commissioning as possible is performed on the various subsystems prior to offshore installation, to minimise the time and cost of final commissioning offshore.

The key steps in commissioning the offshore substation and cabling include visual inspection, mechanical testing, protection testing, electrical insulation testing, pre-energisation checks, trip tests and load checks.

Assuming grid connection to the turbine is complete, key steps in turbine commissioning include:

- Check of installation activity and documentation
- Mechanical and electrical completion
- Check of communication systems (SCADA, VHF radio)
- Energisation of all subsystems
- Testing of each link in safety and emergency system chains
- Exercising of all safety-critical and auxiliary systems
- Slow rotation of the rotor to confirm balance and smooth operation of the drive train
- Overspeed sensor and other safety-critical checks
- First rotation then first generation and checks on normal operation of all systems, and
- Checks on critical components and connections after a period of attended operation, then after a longer period of unattended operation.

If the installed offshore wind turbine has not been connected to the grid then final commissioning of the turbine can be carried out using a generator and a load bank, or power from a service operation vessel (SOV).

Even after first generation, it is routine to have several punch lists for each turbine and substation containing outstanding issues that need to be addressed before handover to the customer and operation, maintenance and service (OMS) teams. Handover will also normally require demonstration of performance and reliability over an agreed length of time.

What's in it

- Electrical testing device
- Generator

I.7 Construction port

Function

The construction port is the base for pre-assembly and construction of the wind farm. Separate locations may be used for feeding foundations and the wind turbines to a wind farm. Location is critical as it affects the time spent in shipment and sensitivity to weather windows.

Figure 67 Port of Hull, courtesy of Siemens Gamesa.

What it costs

Included in installation contracts.

Who supplies this

UK ports used so far include Able Seaton, Barrow, Belfast, Great Yarmouth, Harwich, Hull, Mostyn and Sheerness.

Non-UK ports used for UK projects include Cuxhaven, Eemshaven, Esbjerg, Ijmuiden, Ostende and Vlissingen.

Heavy lifting services: Heavy Lift Projects and Mammoet.

Health and safety: CASC.

Support services: Boston Energy, Clarkson port services, Texo and Doyle Shipping.

Key facts

Construction port requirements are typically:

- At least 8 hectares suitable for lay down and pre-assembly of products, more if the port is handling both foundations and turbines
- Quayside of length 200-300 m length with high load bearing capacity and adjacent access
- Water access to accommodate vessels up to 140 m length, 45 m beam and 6 m draft with no tidal or other access restrictions, although as turbine sizes and in turn vessel sizes increase, this requirement will grow, and
- Ideally no overhead clearance to sea, or a minimum of 100 m (to allow vertical shipment of towers).

Sites with greater weather restrictions or for larger scale construction may require an additional lay-down area, up to 30 hectares.

Large areas of land are required due to the space taken when turbines are stored lying down on the ground.

What's in it

- Quay
- Lay-down area
- Cranes
- Workshops
- Personnel facilities

I.8 Offshore logistics

Function

Offshore logistics involves coordination and support of offshore installation and commissioning activities.

What it costs

About £13 million for a 1 GW wind farm.

Who supplies this

High-level coordination is typically undertaken by the developer.

Construction management services: Asco, DNV, Global Wind Service, JET Engineering, LOC Renewables, Osprey, Rhenus Group, PSG Marine & Logistics, SeaRoc, Schmidbauer and Ventolines.

Key facts

Offshore logistics covers all the work needed to ensure that construction proceeds smoothly, safely and on time.

Construction management covers a wide range of services including contract management, health and safety and marine coordination. In many cases, contractors are embedded in the construction management team. In addition, in order to fulfil the insurer's requirements, a marine warranty surveyor (MWS) has to be appointed. The MWS ensures that all activities are compliant with the approved procedures and delivers the Certificate of Approval (CoA).

Specialist software tools are available to plan and monitor offshore activity.

Weather and metocean forecasting services provide visibility of weather windows a few days in advance. While meteorological buoys are typically owned and operated in the UK by the MetOffice, third-party providers with their own forecasting algorithms also offer services.

Support vessels include guard vessels (potentially drawn from local fishing fleets), crew transfer vessels and accommodation vessels. These vessels may be contracted by the developer of the marine contractor.

What's in it

- Sea-based support [I.8.1]
- Marine coordination [I.8.2]
- Weather forecasting and metocean data [I.8.3]

I.8.1 Sea-based support

Function

A number of vessels are used to support the installation process. These may include CTVs, anchor handling, barges, dive support and ROV handling vessels.

What it costs

About £6 million for a 1 GW wind farm.

Who supplies this

Vessel manufacturers: Alicat, Arklow Marine Services, Damen, Diverse Marine, Integrated Wind Solutions, Maersk, Wagenborg and Wight Shipyard

Vessel operators: Fred. Olsen, HST Marine, Mainprize Offshore, Maersk, Turner Iceni, Siem Offshore, Van Oord, Wind Energy Marine, Windcat Workboats and Zelim.

Key facts

Specialist vessels are used for crew transfer to the wind farm for installation and commissioning tasks. These are typically 15-20 m workboats of the kind regularly used during wind farm maintenance.

ROV support vessels are 80-100 m DP2 vessels with a moon pool and deck crane.

What's in it

- CTV
- Barge
- ROV

I.8.2 Marine coordination

Function

Marine coordination is necessary in order to manage heightened marine traffic as well as multi-vessel activity on an offshore construction site.

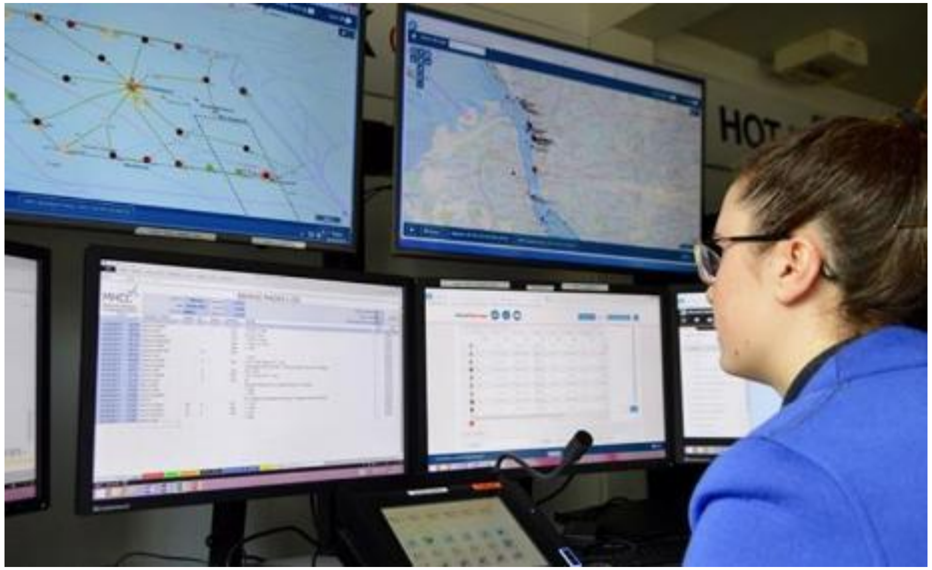


Figure 68 Marine coordination system, courtesy of SeaRoc.

What it costs

About £2 million for a 1 GW wind farm.

Who supplies this

Marine coordination is usually carried out by the developer or a subcontractor.

Suppliers of marine coordination: Asco, Livelink Aerospace, James Fisher Marine Services, Royal Dirkzwager, SeaRenergy, SeaRoc, Specialist Marine Consultants, Systematic, VisSim and WindandWater.

Key facts

A marine coordinator, usually located at the base harbour or operations base [B.6], is responsible for the coordination, control and exchange of information between all contractors working on the site. A marine management software system is used to plan and monitor vessel and personnel movements.

The main tasks of the marine coordinator include:

- Monitor all vessel and personnel (as well as helicopter) movement from, to and inside the offshore wind farm perimeter
- Ensure no conflict from simultaneous operations
- Ensure the authorisation and access of appointed persons on the site, and
- Communicate with all vessels and helicopters.

What's in it

- Marine management system software
- Marine coordination centre

I.8.3 Weather forecasting and metocean data

Function

Weather forecasts are needed for short-term planning of offshore activities (for example vessel transfers and lifts) and the closer the forecast is to the activity, the more reliable it gets. Metocean data recordings are used to provide real time data to support offshore activity, to verify forecast tools and to resolve disputes regarding weather downtime.

Key metocean parameters that impact installation and commissioning activities are wind speed, wave height and current.

Figure 69 Floating lidar, courtesy of EOLOS Floating Lidar Solutions.

What it costs

About £600,000 for a 1 GW wind farm.

The weather forecast supplier usually offers several options (both in the number of forecasts per day as well as forecasts for the different locations). For example, forecasts for the base harbour and the offshore site or a complete forecast for base harbour, the offshore site and transit route.

Metocean measurement devices can be rented or purchased.

Who supplies this

Anemometers and lidars: AXYS Technologies, EOLOS, Gill Instruments, Leosphere, ZX Lidars and Wood Group.

Current and wave buoys: AXYS Technologies, OSIL Sonardyne, Partrac and RS Aqua.

Weather forecast services: Clyde Space Ltd, Fugro, Met Office, Kjeller Vindteknikk, MetoGroup, StormGeo and Vento Maritime.

Aerial surveys: HiDef Surveying.

In addition, the vessel contractor generally provides wind measurements (for example via anemometer mounted on crane boom or lidar).

Key facts

Weather plays a crucial role in offshore installation and commissioning activities as it has an influence on the sequence and duration of planned activities (which need to be conducted safely that is all offshore activities have weather limits, exceeding these would be unsafe) and may lead to delays, which result in elevated costs.

Weather forecasts are generated through global meteorological models that may be improved in their accuracy with finer resolution local models. Forecasts usually include several different meteorological parameters such as wind speeds at different heights, wave and swell height and period as well as general weather information (for example visibility, lightning risk, fog, water and air temperature and rain).

The forecasts are used to plan activities based on when weather windows are available.

Wind parameters are usually measured with a lidar (on a fixed or floating meteorological station) or an anemometer (rotary or ultrasonic) on a fixed metrological station with tall mast. The advantage of the lidar is that wind speed and direction at different heights can be determined.

Ocean parameters can be measured with a wave buoy or current meter although there is a trend towards complete systems that combine both wave and current measurements.

What's in it

- Weather forecast report (and online access)
- Wave buoy
- Current meter
- Lidar
- Anemometer

O Operations and maintenance

Function

Operation, maintenance and service (OMS) are the combined functions which, during the lifetime of the wind farm, support the ongoing operation of the wind turbines, balance of plant and associated transmission assets. OMS activities formally start at the wind farm construction works completion date.

The focus of these activities during the operational phase is to ensure safe operations, to maintain the physical integrity of the wind farm assets and to optimise electricity generation.

What it costs

About £85 million per annum for a 1 GW wind farm. This includes insurance, environmental studies, compensation payments and other internal asset owner costs (not itemised in sections below).

Who supplies this

The wind farm owner will oversee and fulfil overall site operations activities.

In terms of wind turbine planned maintenance and service in response to faults, wind turbines are typically under warranty for the first five to ten years of operations and the wind turbine suppliers offer a service level agreement during this period to provide turbine maintenance and service.

After this initial warranty period, the wind farm owner may maintain and service the wind farm using an in-house team, contract to a specialist company or develop an intermediate arrangement where turbine technicians transfer to the wind farm owner at the end of the warranty period.

Key facts

The focus of OMS is to maximise the financial return from the owners' investment. Owners aim to optimise the balance between operational expenditure and turbine yield. By scheduling downtime during the summer months and low wind speed winter periods, owners can secure high availability during the winter months when wind speeds and energy outputs are typically higher. Contractual arrangements, which award energy production, are increasingly common.

Time-based turbine availability is the percentage of time the wind turbine is ready to produce power if the wind speed is within the operational range of the turbine. Modern onshore turbines have a wind-in-limits availability of around 98%. The performance of offshore wind turbines has improved with optimised design, and offshore turbines often have availabilities in a similar range to onshore. The planning of logistics and access is vital to securing higher availabilities. Where there are access restrictions then availability may be in the range 95-98%.

Operational support is provided to the wind farm 24 hours a day seven days a week, 365 days a year, including responding to unexpected events and turbine faults, weather monitoring and live turbine monitoring. Outside normal operating hours this support is provided from remote control rooms which monitor wind farm SCADA data.

Maintenance and service includes scheduled and unscheduled activities and requires the regular transfer of personnel and equipment to the wind turbines and offshore substation. Safe access to the turbines is a critical area for further focused innovation.

If required, specialist staff from the wind turbine supplier (more commonly) or 3rd party providers (less common) will carry out major repairs and replacement of main components. The wind turbine supplier and other third parties will carry out repairs of turbine blades.

In the UK, transmission assets (substations and export cables) are transferred to an OFTO within 18 months of wind farm commissioning. The OFTO may contract some maintenance and service functions to the wind farm owner because it has onsite personnel and has a strong interest in minimising transmission downtime. In other European territories, typically a transmission operator is responsible for building the offshore transmission.

What's in it

O.1 Operations

Function

Operations relate to management of the asset such as health and safety, control and operation of the asset including wind turbines and balance of plant, remote site monitoring, environmental monitoring, electricity sales, administration, marine operations supervision, operation of vessels and quayside infrastructure, and back office tasks.

What it costs

About £31 million per annum for a 1 GW wind farm. This includes training, onshore and offshore logistics support and management, overheads, health and safety inspections and insurance.

Who supplies this

The owner of the wind farm typically creates a special-purpose vehicle to operate the project. This may have several shareholders, one of which is likely to take a lead role.

Operations tasks for offshore wind farms are typically provided by the majority wind farm owner.

Some aspects of wind farm operations are contracted to companies such as Boston Energy, Deutsche Windtechnik, James Fisher Marine Services and 3Sun.

Key facts

An onshore control room provides access via SCADA and other systems to detailed real-time and historical data for the wind turbines, substation, met station, offshore crew and vessels. Systems ensure that the operations duty manager knows where all personnel and vessels are located.

Wind farms are monitored remotely on an ongoing basis using SCADA and condition monitoring systems and periodically by way of active inspections, including of subsea infrastructure.

A senior authorised person (SAP) is available at all times with coordination responsibility for the switching operations of all high voltage equipment.

Review of SCADA data and prognostic condition monitoring can help to time preventative maintenance before failure occurs. The industry is steadily adopting more advanced data driven approaches to maximising asset value, including the increased use of performance analytics, performance benchmarking and integrated digital systems.

In addition to hardware-related activity, environmental monitoring to understand the effect of the wind farm on the local environment and wildlife is also carried out.

Wind farms can be broadly categorised as having:

- An onshore base (at an OMS port), with day-to-day access to the wind farm via CTVs. An onshore base is typically used if the wind farm is less than 40nm from shore or if the wind farm is less than about 400 MW (where the number of technicians does not justify the cost of an offshore base), or
- An offshore base, for wind farms greater than about 40nm and greater than 400 MW, which is likely to be a SOV, although fixed platforms have been used.

In practice, wind farm operators adopt a flexible approach, particularly during peaks of activity. In both cases, helicopters may be used in addition to CTVs and SOVs. Careful planning of routine and unscheduled activities with due consideration of weather conditions and availability of spares and specialist vessels is critical.

What's in it

- Training [O.1.1]
- Onshore logistics [O.1.2]
- Offshore logistics [O.1.3]
- Health and safety inspections [O.1.4]

O.1.1 Training

Function

Training ensures that OMS personnel are qualified to fulfil the roles needed by the wind farm while ensuring their own safety and those of colleagues.

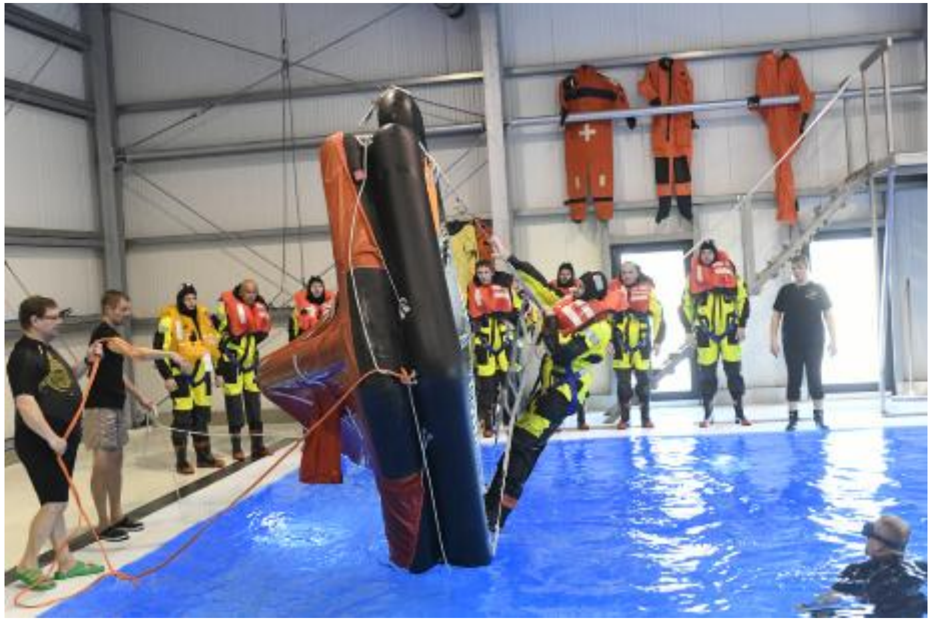


Figure 70 Sea survival training, courtesy of RWE.

What it costs

About £2.6 million per annum for a 1 GW wind farm.

Who supplies this

Typically training occurs at a local scale through Global Wind Organisation (GWO) certified organisations including: Advanced Industrial Training, ARCH, Boston Energy, CWind (Global Marine Group), Falck Safety Services, Fleetwood

Nautical Campus, Heightec, Maersk Training, MRS Training and Rescue, National Wind Farm Training Centres, Offshore Marine Academy, ProntoPort and VRAI.

The GWO training standards are now widely adopted in the offshore wind industry. The GWO is a non-profit body founded by leading wind turbine suppliers and/or operators.

Key facts

Training is related to both technical aspects and to health and safety skills and awareness.

A number of certificates are required by all personnel likely to be present on the wind farm site, including:

- Emergency first aid and advanced medical training
- Offshore survival training, including marine transfer
- Helicopter winch training
- Working at height
- Working in confined spaces
- Wind turbine rescue
- Manual handling
- Lifting and hoisting, and
- Electrical safety awareness.

The technical training required is dependent on the requirements of the client, but as a minimum will cover specific technician training for the relevant turbine model.

Other key training qualification requirements includes operational safety rules for high voltage switching and wind turbine operations.

What's in it

- Training courses
- Training examinations
- Certification

O.1.2 Onshore logistics

Function

Onshore logistics involves support and resources to the wind farm operations, including quayside infrastructure, warehousing, logistics and operational planning.

What it costs

About £1.3 million per annum for a 1 GW wind farm.

Who supplies this

The wind farm operator will establish OMS port facilities during the installation process, as many support vessels active during the operational phase will operate from local ports. The wind farm owner will typically occupy quayside facilities, operating on a long-term lease with the owner of the port infrastructure.

Key facts

Typically, wind farm owners will look to use the nearest port that meets its specifications to minimise transfer times and reduce the risk of time being lost due to bad weather. Nevertheless, owners will typically competitively tender the contract for the provision of port services. For wind farms further from shore, the use of offshore accommodation and other facilities (possibly shared with other wind farms) becomes more attractive.

Port location is critical – far from shore port requirements will differ from a wind farm that is operated using CTVs and workboats only.
Consideration is given to the scope for future expansion to support additional project phases.
Port facilities are required to be flexible to accommodate variable demand with maintenance and service campaigns and site activities. Ideally, the warehousing and logistics buildings are close to the quayside to minimise the time loading support vessels.

24/7 access from a chosen port in all states of tide will increase flexibility to perform maintenance and service operations without delay to enable weather windows to be exploited – this may require port agreements to include requirements for dredging to maintain adequate water depths.
Safe means of transfer onto vessels is needed – this often requires the installation of pontoons to ensure a level access route in all tidal conditions.

A 1 GW wind farm may employ up to 100 people onsite, of which about half will be turbine technicians. The availability of skilled and experienced technicians is a crucial factor in the successful operation of an offshore wind farm for wind farm owners and operators. OMS facilities need 24 hour access, 365 days a year.

As well as the port facility, operators will use remote land based support, such as specific engineering advice and support, performance monitoring and constant control room monitoring.

Each support vessel will need a berth of up to 30 m. A 1 GW wind farm may require the operation of between four and seven vessels, depending on the distance from the wind farm to shore and the maintenance and service strategies chosen, although up to 10 berths may be specified in order to provide capacity for peak periods. Uninterrupted access requires the availability of a non-drying harbour with minimal tidal restrictions.

An onshore base consists of:

- Administration facilities and operations room
- Lifting equipment, for example forklifts (600 kg) and small cranes (1 t) to move components from the harbour to the vessel
- Workshop facilities, workbench areas and tool storage
- Stores, with small components that do not need specialist vessels to facilitate use
- Wet and dry rooms, with space for personal protection equipment
- Oil store, gas bottle store and waste management facilities

- Fuel bunker or electric charging stations for vessels, and
- Parking spaces.

What's in it

- Facilities management

O.1.3 Offshore logistics

Function

Offshore logistics involves management and coordination of all marine based activities and operations.

What it costs

About £7.2 million per annum for a 1 GW wind farm.

Who supplies this

The wind farm owner will setup and manage a marine operations centre at the main OMS port. Third party suppliers of marine coordination services and software include ONYX Insight, SeaRoc (Fred. Olsen), Vissim, and Windandwater.dk.

Key facts

Marine coordination involves the 24/7 monitoring of the locations of all vessels and personnel within the vicinity of the project, including the supply and interpretation of specialist tools such as marine coordination software.

Cameras are often located on selected offshore structures to enable CCTV feeds to review conditions and monitor offshore activities.

Operators need to make judgements about the priority of activities based on the scheduled maintenance and unscheduled service workload and weather forecast. The industry is increasingly adopting software simulation tools to maximise operational efficiency in relation to scheduling tasks and deploying resources, taking account of weather conditions, sea state, vessel capability and operational priorities.

Bigger wind farms further offshore and with more complex operational systems will increase the logistical challenge.

Robust communication equipment and infrastructure is a key element of offshore logistics in order to ensure live communication between all personnel.

What's in it

- Crew transfer vessels [O.1.3.1]
- Service operation vessels [O.1.3.2]
- Turbine access systems [O.1.3.3]
- Helicopters [O.1.3.4]
- Weather forecasting and metocean data [I.8.3]
- Marine planning software
- Communications equipment including radio and asset tracking
- Safety planning and systems

O.1.3.1 Crew transfer vessels

Function

CTVs provide access for technicians and contractors to the wind turbines from the onshore OMS base to turbine locations and substation. CTVs are the preferred access solution for projects closer to shore.

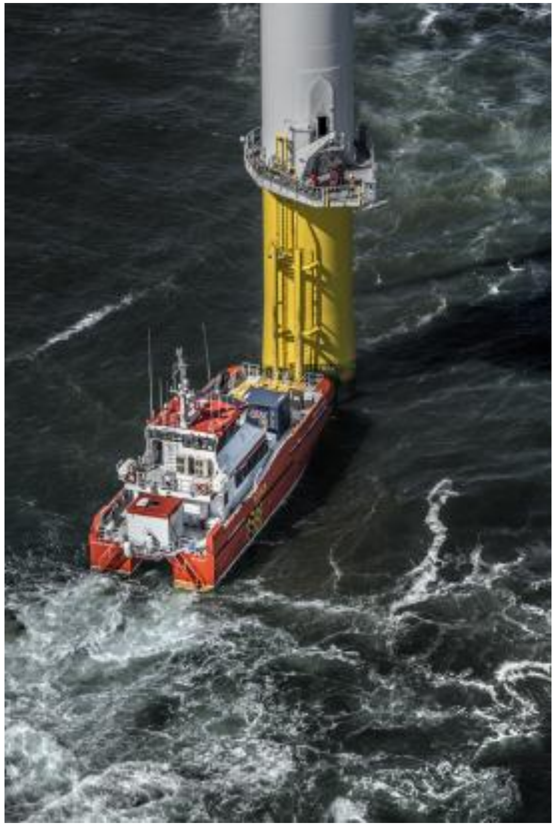


Figure 71 CTV during service operations, © MHI Vestas Offshore Wind.

What it costs

The charter day rate for a CTV varies significantly depending on specification, availability and contract period.

Who supplies this

Vessel operators: Acta Marine Wind Services, BA Technologies, Mainstay Marine Solutions, MJ Power, MPI Workboats, Njord Offshore, Northern Offshore Services, North Sea Logistics, OEG Renewables, Seacat Services, Turbine Transfers and Windcat Workboats.

Manufacturers: Alicat, Fjellstrand, Fred. Olsen WindCarrier, Manor Renewables, South Boats and Umoe.

Key facts

CTVs transport personnel to the wind farm on a daily basis and do not have overnight facilities.

Key requirements are robust vessels that can operate in adverse weather conditions. Wind farm operators typically use aluminium catamarans up to 30 m long with capacity for 12 to 16 technicians.

CTVs are typically Class I passenger ships, as classified by the Maritime and Coastguard Agency, which enable them to work further than 60 nm from a safe haven. These vessels can be built to carry up to 24 passengers. Vessel speeds can be up to 30 kn and are designed to transfer maintenance and service team members in comfort and safety to the wind farm ready to start work.

There is an oversupply of small CTVs (less than 20 m), with operators typically opting for larger vessels with longer ranges and better sea keeping.

There is interest in SWATH (small waterplane area, twin hull) and SWASH (small waterplane area, single hull) type vessels to increase technician comfort and lower weather downtime.

Electric Crew Transfer Vessels are beginning to be used to reduce emissions, with companies retrofitting existing vessels and developing new electric fleets.

CTVs may have fixed or controlled pitch propellers but operators may prefer the increased manoeuvrability of water jets. Vessels with a smaller draught (less than 2 m) may be used where harbours are more challenging to operate from due to water depths.

CTVs have a load capacity up to 30t for turbine components and consumables, as equipment. Fuel is not typically included in the charter cost and there is an important emphasis on fuel efficiency of vessels.

What's in it

- Turbine access systems [O.1.3.3]

O.1.3.2 Service operation vessels

Function

SOVs provide an offshore OMS base, with staff working from the vessel for periods of two to four weeks at sea. SOVs are the preferred way to maintain and service wind farms located far from shore.

Figure 72 SOV Esvagt Faraday, courtesy of Esvagt.

What it costs

Charter costs vary significantly depending on size and fit out (excluding fuel).

Who supplies this

Vessel operators: Acta Marine, Bernard Schulte, Bibby Marine, Esvagt, Louis Dreyfus Travocean, Østensjø Rederi and Vroon.

Manufacturers: Astilleros Gondanm Cemre, Damen, North Star, Royal IHC and Ulstein.

Key facts

SOVs offer accommodation, mess and welfare facilities for wind farm technician staff, as well as workshop and spares storage. SOVs will stay at the wind farm for up to four weeks at a time, at which point they will return to home port to restock and change crews.

Access to the wind turbines is achieved either by smaller crew transfer vessel, daughter craft, by helicopter, or directly from the SOV using a turbine access system.

SOVs have operational speeds of up to 15 knots. They are equipped with dynamic positions systems. Vessel manoeuvrability is a key requirement to reduce positioning time and therefore costs. For this reason, there is little use of surplus platform support vessels (PSVs) from the oil and gas industry. PSVs have a more important role in supporting installation and commissioning.

SOVs can typically accommodate between a crew between 50 and 100, of which up to 50 may be wind farm workers.

What's in it

- Accommodation berths
- Mess, welfare and leisure facilities
- Spares and tooling storage
- Workshop facilities
- Walk to work system

BVGAssociates

O.1.3.3 Turbine access systems

Function

Turbine access systems provide access to the turbine from a CTV or SOV. Systems are designed to permit access to the turbines in as wide a range of sea-states as possible, in the interests of maximising possible maintenance and service time and turbine availability.

Figure 73 Full motion-compensated turbine access system, courtesy of Ampelmann.

What it costs

Costs typically included in vessel costs.

Who supplies this

Suppliers include Ampelmann, Fjellstrand, Houlder, Osbit, Uptime, Pict Offshore and Windcat.

Key facts

Many SOV based systems are based on motion compensated gangways that react in real-time to changes in the sea surface, providing a stable platform to allow personnel to walk from the vessel onto the turbine. Motion compensating gangways have been trialled on CTVs.

Such systems are designed within operational limits, and will not permit access in the most severe sea-states.

What's in it

- Control systems
- Hydraulics
- Steel infrastructure

O.1.3.4 Helicopters

Function

Helicopters are used to provide access for technicians and contractors to the wind turbines and offshore substation.

Who supplies this

Operators: Babcock, Bond Aviation Group, Heli Service International and Northern Helicopter.

Manufacturers: Airbus, Leonardo and Sikorsky.

Key facts

Helicopters allow access in otherwise inaccessible sea state conditions. Their high speeds and low carrying capacities fits well with the dispersed nature of offshore wind projects and the high frequency of low effort interventions that make up a large proportion of offshore visits.

The high costs mean that helicopters are not used as primary means of technician transport. They may be cost-effective for projects at the limit of the effective range of CTVs for which the fixed cost of SOVs is unattractive.

Arrangements to use local airports need to be developed or a dedicated helicopter base set up at the operations port. This usually requires additional planning consent. It is important to locate the helicopter close to the operations base to reduce inefficiencies in journey time.

Helicopters rarely land on the offshore installations, with technicians being winched down to the turbine. Helicopters are limited by weight restrictions and typically carry two to six technicians depending on the type of helicopter. The type of spare parts and tools that can be carried is limited by weight and size.

Helicopters are normally contracted on a long-term basis, with either exclusive or shared access to the aircraft.

What’s in it

- Specialist offshore pilot training

O.1.4 Health and safety inspections

Function

Health and safety inspections are a crucial activity to ensure the ongoing safe operation of wind farm infrastructure and systems, and to fulfil statutory obligations to inspect safety critical systems on a regular basis.

What it costs

About £1 million per annum for a 1 GW wind farm.

Who supplies this

Suppliers include Bureau Veritas, DNV-GL, Sennen Tech, SGS and TÜV SÜD.

Key facts

Inspections of safety-critical devices and equipment including:

- Fall arrest systems
- Anchor points
- Davit cranes
- Turbine cranes
- Boat landing and ladders
- External gates and railings and floor gratings
- External evacuation and rescue equipment
- Fire fighting equipment and fire prevention equipment
- First aid supplies & equipment
- Pressure systems, and
- Navigation aids and aviation lighting.

Safety critical items are subject to a statutory inspection regime, where there are legal requirements including recommended inspection frequencies and method of inspection. Inspections are carried out by qualified personnel, either as part of the primary turbine maintenance works or by a team of independent inspectors. Inspection frequency will be six-monthly or annual, depending on the equipment. Drills of health and safety procedures are routine.

Most owners will train their own technicians for these roles as they are frequent but require minimal time. Where there is a requirement for periodic statutory inspections and certification, such as for fall arrest systems, independent certifiers will provide these services.

Owners will seek to perform inspections prior to other planned work being carried out in the summer months to minimise the likelihood of weather delays and ensure equipment remains certified for use.

What's in it

- Health and safety equipment [O.1.4.1]

O.1.4.1 Health and safety equipment

Function

Health and safety equipment provides personnel with access to vital equipment to reduce the risk of injury, and to provide equipment to assist in emergency situations.

Figure 74 Health and safety equipment, courtesy of RWE.

Who supplies this

Aspli, Trauma Resus, Viking Life Saving Equipment, Fennex, Pict Offshore and WFE Safety and Zelim.

Key facts

A comprehensive set of health, safety and personal protection equipment is carried in the project vessels or stored in each turbine. Running stock will be maintained at the onshore OMS logistics facilities.

Turbines have basic emergency equipment to permit overnight occupation in the turbine in the event of personnel being stranded due to access restrictions.

Typical health, safety and personal protection equipment includes:

- First aid kits for minor injuries
- Advanced medical kits
- Eye-washing kits
- Gloves and safety boots
- Ear defenders and safety eyewear
- Fuel and diesel spill kits
- Fire extinguishers and suppressants
- Survival suits, personal locator beacon, life-vests and floatation devices
- Emergency rations and water
- Emergency communications devices, and
- Rescue equipment including descenders, spinal boards and stretchers, hub rescue equipment.

What's in it

- Inventory tracking

O.2 Maintenance and service

Function

Maintenance and service activities ensure the ongoing operational integrity of the wind turbines and associated balance of plant, including planned maintenance and unplanned service in response to faults, either proactive or reactive.

What it costs

About £47 million per annum for a 1 GW wind farm.

Who supplies this

Maintenance and service activities are provided by a combination of the owner's in-house resources, wind turbine suppliers and third party service providers. These are further defined under the sub-headings below.

Suppliers include: Cognitive Business, James Fisher Marine Services, Boston Energy, ONYX Insight, Pict Offshore and Swire Renewable Energy.

Key facts

There is considerable focus in the industry on optimising maintenance and service activities to reduce OPEX whilst also achieving the targeted levels of availability and reliability.

This optimisation is best achieved by taking a lifetime view of the project economics, focussing on the levelised cost of energy. Operational management teams will consider the whole operational system in order to achieve this.

What's in it

- Turbine maintenance and service [O.2.1]
- Balance of plant maintenance and service [O.2.2]

O.2.1 Turbine maintenance and service

Function

Effective turbine maintenance and service ensures the long-term productivity of the turbines.

Figure 75 Technician carrying out turbine maintenance, courtesy of RWE.

What it costs

About £34 million per annum for a 1 GW wind farm.

Who supplies this

The wind turbine supplier, during the defect notification period (DNP) and for the duration of any agreed contract beyond the DNP.

The wind farm owner may seek to bring service capability in-house or to engage an independent service provider (ISP), which involves seeking agreement with the manufacturer for the supply of spares, software systems and specialist expertise.

ISPs include Aquaterra, Boston Energy, Deutsche Windtechnik, EchoBolt, James Fischer Marine Services, JR Dynamics, Pict Offshore, ONYX Insight, Sedwell, Swire Renewable Energy and 3Sun.

Key facts

The initial service agreement typically covers the period of the turbine defect warranty, which is usually five years. During this period, turbine technicians are typically employed by the wind turbine supplier. The service agreement may specify that on expiry technicians' contracts are transferred to the wind farm owner. This ensures continuity of staffing and removes technicians' disincentive to relocate to the wind farm site.

Activity is divided into preventive maintenance (scheduled) and corrective service (unscheduled) works. The bulk of preventive works will typically be carried out during periods of low wind speeds to minimise the impact on production, however, in practice, this is not always achievable.

Corrective service is performed in response to unscheduled outages and is often viewed as more critical, due to accruement of downtime until the fault is resolved. The primary skills required are mechanical or electrical engineering, with further turbine-maintenance training often provided by the relevant turbine provider.

Typical maintenance includes inspection, checking of bolted joints, and replacement of worn parts (with design life less than the design life of the project).

Unscheduled interventions are in response to events or failures. These may be proactive, before failure occurs, for example responding to inspections of from condition monitoring or reactive (after failure that affects generation has occurred).

What's in it

- Blade inspection and minor repair [O.2.1.1]
- Main component refurbishment, replacement and repair [O.2.1.2]
- Electrical transmission system maintenance

O.2.1.1 Blade inspection and minor repair

Function

Blade inspection and repair consists of the inspection of the condition of blades and replacing or repairing blades in a timely and cost effective manner.

Figure 76 Wind turbine technicians carrying out blade inspection, courtesy of Mistras Group.

Who supplies this

Service suppliers include Bladefence, Cyberhawk, Deutche Windtechnik, DNV-GL, FORCE Technology, GEV, Global Wind Service, James Fisher Marine Services, Mistras, Natural Power (Fred. Olsen), Swire Renewable Energy and 3Sun.

Inspection technology suppliers include ABJ, Anakata Wind Power, BladeBug, Cornis, Scoptico, SkySpecs and TSR Wind.

Key facts

Blade maintenance and service is an area of specific focus in the offshore wind industry. Issues such as leading edge erosion have been the source of availability issues in the industry and proactive blade inspection and preventative repair is now widely pursued in response.

Blade inspections are performed by drones equipped with high-resolution cameras, by rope-access technicians or by high-resolution camera equipment located on the transition piece or vessel.

Where substantial repairs or blade replacement are required, this is sometimes possible using rope access teams often using a blade platform suspended from the hub. Where a blade cannot be repaired in-situ a jack-up vessel is typically required in order to deliver the swap-out, although smaller vessels than those used during turbine installation can be used. Exchange is carried out in one visit, followed by off-site or deck-based repair. Retrofit programmes are carefully planned to ensure effective vessel utilisation taking into account repair turnaround times.

Blade inspection work typically requires the turbines to be stationary, therefore there is a focus on performing inspection work during the less windy periods of the year to minimise lost energy production. Specialist expertise is required to undertake damage diagnostics and repair activities.

Automation of blade inspection and damage diagnostics is an active area of innovation.

What's in it

- Unmanned aerial vehicle [O.2.1.1.1]

O.2.1.1.1 Unmanned aerial vehicle

Function

Unmanned aerial vehicles (UAVs) provide low cost and safer external inspections of turbines.

Figure 77 UAV operating offshore, courtesy of Aerial Vision.

Who supplies this

Manufacturers: Aerial Vision, Anakata Wind Power, ASV Global, DJI and SkyFront.

Operators: Cyvberhawk, Esvagt, Force Technology, Perceptual Robotics and SkySpecs.

Key facts

Most UAVs for wind turbine inspection are multi-rotor copter drones.

Drones are typically provided by specialist operators and are rented with qualified pilots.

Drones can perform an inspection in a fraction of the time required for a traditional rope-access inspection

The drone can be equipped with a digital camera, a thermographic camera or a combination, depending on the scope of the inspection task. A digital camera provides proof of the visual failures and damages to the tower, nacelle, rotor blades and bolt jointing.

Thermographic inspection is a non-contact and non-destructive inspection method that makes it possible to examine a large area of the blade for structural defects and weaknesses in the blade. With infrared thermography, the drone monitors variations in the surface temperature of, for example, the rotor blades.

A number of specialist suppliers supply the industry with integrated drone inspection, image diagnostics and data archiving services.

What's in it

- Flight planning
- Data storage and archiving

O.2.1.1.2 Autonomous vessels

Function

Various inspections are increasingly being carried out by autonomous vessels. These include Maritime Autonomous Surface Ships (MASS) and MiniMASS, are designed to perform various offshore wind farm operations such as surveys, inspections, and maintenance. These vessels operate with varying degrees of autonomy, enhancing operational efficiency, safety, and reducing the need for onboard personnel.

What it costs

The day rate for an autonomous vessel varies significantly with the type of equipment required.

Who supplies this

Suppliers include Fugro, Sulmara, Unmanned Survey Solutions, and Xocean.

Key facts

Autonomous vessels are classified based on size and degree of autonomy:

- MiniMASS (Maritime Autonomous Surface Ships less than 2.5 meters): These vessels are under 2.5 meters in length and are typically used for nearshore surveys and environmental monitoring. They are exempt from certain certifications due to their size, as outlined by the Maritime and Coastguard Agency (MCA).
- MASS (Maritime Autonomous Surface Ships over 2.5 meters): Vessels exceeding 2.5 meters in length, used for a broader range of offshore tasks, including geophysical and hydrographic surveys.

The International Maritime Organization (IMO) defines four degrees of autonomy for MASS:

- Degree One: Ships with automated processes and decision support, with seafarers onboard ready to take control as needed.
- Degree Two: Remotely controlled ships with seafarers onboard; the vessel is operated from another location, but crew members can take control if necessary.
- Degree Three: Remotely controlled ships without seafarers onboard; the vessel is entirely operated from a remote location.
- Degree Four: Fully autonomous ships capable of making decisions and determining actions by themselves.

Autonomous vessel adoption is accelerating in the UK offshore wind sector due to improved operational safety by reducing offshore personnel exposure, lowering overall operational costs, reducing environmental impact, and increasing survey efficiency. These vessels expand operational windows and support better data acquisition, allowing operators to manage project risks more effectively.

What's in it

- Autonomous or remotely operated vessel platform (surface or subsurface)
- Shore-based remote operation centres with satellite communications
- Advanced sensor and instrumentation suites (sonar, cameras, environmental monitoring sensors)
- Automated navigation, positioning, and control systems
- Onboard data acquisition, processing, and transmission systems
- Energy-efficient power sources, such as batteries or hybrid systems.

O.2.1.2 Main component refurbishment, replacement and repair

Function

Main component refurbishment, replacement and repair consists of the replacement of large components such as gearboxes, blades, transformers and generators in a timely and cost effective manner.

Who supplies this

Suppliers include Boston Energy, Fred. Olsen WindCarrier, James Fisher Marine Services, Seajacks and Ziton.

Key facts

Design methodologies for offshore turbines to facilitate easier large component repair and replacement with less external intervention.

On-board turbine service cranes can in some cases lift substantial loads. Some components on turbines however need a jack-up barge to enable replacement, although smaller vessels than those used during turbine installation can be used. Exchange is carried out in one visit, followed by off-site refurbishment. Retrofit programmes are carefully planned to ensure effective vessel utilisation taking into account repair turnaround times.

What's in it

- Large component repair vessel [O.2.1.2.1]

O.2.1.2.1 Large component repair vessel

Function

Large component repair vessels support the change-out of large nacelle and rotor components that need a stable hook height at hub height.

Figure 78 Jack-up vessel, courtesy of RWE.

Who supplies this

See Turbine installation vessel [I.6.1].

Key facts

Large component repair vessels are typically self-propelled jack-ups that can install, or have previously installed turbines.

Most large component repair vessels are installation vessels that are no longer able to install current turbine models or are suboptimal for the purpose. Given the large number of such vessels, day rates are competitive and owners typically seek to negotiate call-off contracts for vessel or charter them for several months for intensive maintenance or service campaigns.

Older installation vessels are not necessarily well suited for maintenance and service without modification. They may not be able to work at sufficient water depths for some projects and they may be over specified in terms of crane capacity and deck space. A Site Specific Assessment must be carried out prior to commencement to ensure the vessel can safely work with the site soil conditions, weather limitations and water depths.

What's in it

- Marine planning
- Vessel maintenance and service

O.2.2 Balance of plant maintenance and service

Function

Balance of plant maintenance and service is focused on ensuring the operational integrity and reliability of all wind farm assets other than the wind turbines, including the substation(s), foundations, array cables, export cables, scour protection and corrosion protection systems.

What it costs

About £12 million per annum for a 1 GW wind farm.

Who supplies this

3Sun, Acteon Group, Boston Energy, Briggs Marine, Correll Group, CWind (Global Marine Group), DORIS, First Marine Solutions, Fred. Olsen WindCarrier, James Fisher Marine Services, JDR Cable Systems, Maritime Developments, Oceaneering, Ocean Infinity, OEG Renewables, Pharos Offshore, Pict Offshore, Rotech Subsea, SMD, Sulmara, Synaptec, Venterra and W3G Marine.

Key facts

The balance of plant forms an integral part of the wind farm system. Proactive balance of plant maintenance is a key aspect of a reliability based preventative maintenance regime.

Regular inspections of all balance of plant elements are required to ensure emerging issues are highlighted and remedial service work is planned in order to avoid loss of generation.

What's in it

O.2.2.1 Foundation inspection and repair

Function

Foundation inspection and repair identifies and addresses corrosion and structural problems above and below the water line.

Figure 79 Technicians carrying out foundation inspection and repair works, courtesy of Muehlhan.

Who supplies this

Suppliers include CWind (Global Marine Group), Deutsche Windtechnik, Fugro, Global Wind Service, Mistras, Offtech Wind and Strainstall (James Fisher).

Key facts

Maintenance consists of visual inspections, non-destructive testing (NDT) and sea bed survey work with remedial service work completed when required.

Inspections focus on structural integrity, lifting, safety equipment, corrosion protection and scour protection.

Inspection work is managed by the wind farm owner, although is often subcontracted to a specialist third party provider.

Routine surveys are likely to be undertaken in the first two years but thereafter on a five or ten year cycle. Surveying the status of the protection installed to prevent sediment erosion, where the turbine foundation meets the sea bed (scour), can be carried out by side-scan sonar from a survey vessel or by using a ROV.

Regular inspections are required on secondary steelwork such as ladders, gates, grills and platforms. On some sites, cleaning is needed to remove sea bird guano, which can be a serious health and safety hazard.

Surface inspections and surveys include monopile internal inspections of the grouted or bolted connections and splash zone inspections. Activity needing subsea operations may include infrequent structural and J-tube cathodic protection inspections and weld inspections and can generally be carried out using ROVs.

Diving is required only in exceptional circumstances and efforts are being made to maximise the use of safer, remote techniques.

What's in it

- Remotely operated vehicle [O.2.2.1.1]
- Autonomous vessels[O.2.2.1.2]]

O.2.2.1.1 Remotely operated vehicle

Function

ROVs are used to inspect wind farm underwater structures.

Figure 80 Remotely operated vehicle, courtesy of BEAM.

Who supplies this

Manufacturers: ECA Hytec, Saab Seaeye and Seatronics.

Operators: BEAM, Fugro, James Fisher Marine Services and Verlume HonuWorx.

Key facts

Inspection class ROVs are used to inspect the foundation below the water line and the cable route, particularly in areas at risk of scour or other sea bed movements, and at other high risk locations, such as crossings with other cables.

Inspection ROVs typically have a speed of 3-5 kn, weigh 8-12 kg and have dimensions 1 m x 0.7 m x 0.5 m.

They are equipped with propulsion systems, lighting and a range of imaging equipment.

ROVs are launched form a DP2 vessel equipped with an A frame or moon pool.

The communication between the operator and the vehicle is controlled by an umbilical or tether cable, transmit electrical power, optical signals and mechanical payloads. It strengthened, usually with steel wire, to support the mechanical loads of the ROV underwater.

The development and use of unmanned subsea inspection vessels is an area of innovation.

What's in it

- Propulsion system
- Control system
- Remote camera
- Lighting system
- Power supply
- Manipulator arm

O.2.2.1.2 Autonomous underwater vehicle

Function

Provide low cost means of surveying below water, focussing on balance of plant assets such as cables and foundations.

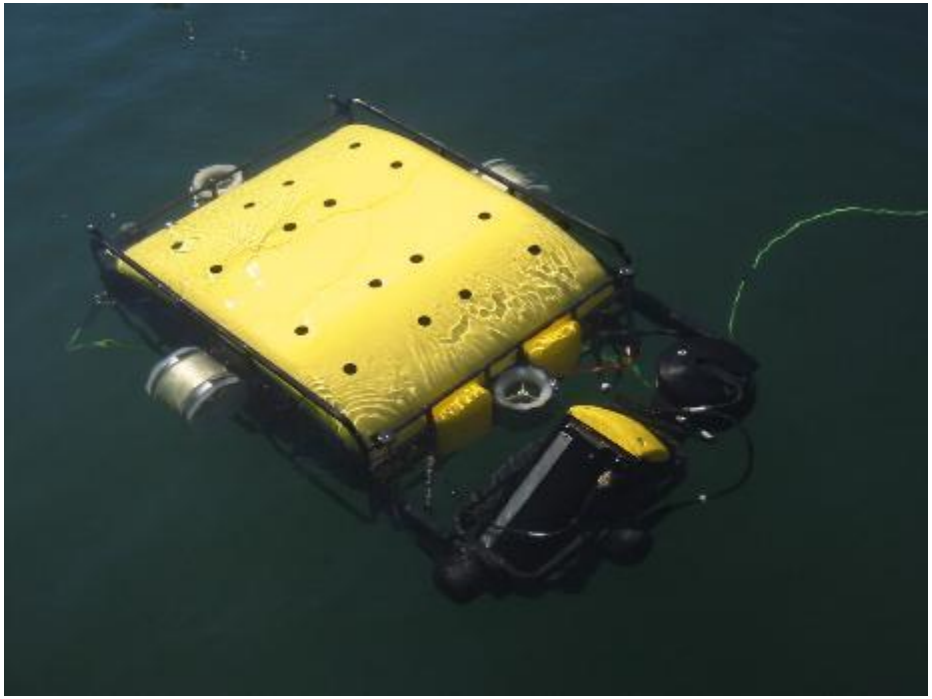


Figure 81 Autonomous underwater vehicle, courtesy of General Dynamics Mission Systems.

Who supplies this

Manufactures: ECA Hytec, General Dynamics, Teledyne Marine Gavia and Woods Hole Oceanographic Institution.

Operators: Fugro, Modus, Verlume and UTEC.

Key facts

Autonomous underwater vehicles (AUV) have the potential to replace vessel-based surveys. They are launched offshore from parent vessels.

AUVs can be launched from a CTV and therefore avoid the need for a larger vessel with the lifting capacity needed to launch and recover an ROV.

What's in it

- Vehicle maintenance and service

O.2.2.2 Cable inspection and repair

Function

Identify faults and replace whole or sections of cable.

Figure 82 Cable inspection and repair works, courtesy of NKT.

Who supplies this

Offshore works: Boskalis, Briggs Marine, CWind (Global Marine Group), Flexlife, Leask Marine, Offshore Marine Management, Oceaneering, Power CSL, Pharos Offshore and Seatech Commercial Diving.

Electrical works: Boskalis, Power Cable Services.

Key facts

The frequency of inspections depends on sea bed mobility and results of the initial surveys. Surface surveys can be used to detect substantial cable exposure, but ROV surveys will be required for more accurate burial depth data. Insufficient burial or cable exposure is typically resolved by remedial measures including protective mattressing and rock dumping, normally using a dynamically positioned fall pipe vessel, or occasionally side-dumping vessels.

Cable damage may come from the mechanical loads of wave and tidal action if the cable is exposed, from anchors or fishing gear, or as a result of handling during transport or installation that exceeds the cable's specification. Although cables typically come with a two-year warranty, none of the main causes of damage is covered by the warranty

The owner is therefore responsible for monitoring and surveying the cable and repairing it when required. The survey work and remedial work is likely to be subcontracted to a specialist provider. For array cables and export cables before the transfer of transmission assets to the OFTO (UK only, up to 18 months after works completion date), the wind farm owner is responsible. For the export cable the transmission operator or OFTO (UK only) is responsible, although the wind farm owner has a strong interest in ensuring that export cable faults are rapidly fixed to reduce and reduction in transmission capacity.

Some offshore wind farms have redundant export cables so a fault on one cable will not necessarily lead to loss of wind farm output.

Cable repair will normally require a full cable laying spread consisting of a cable laying barge with cable plough or jetting equipment, with a quadrant to ensure that the minimum bend radius is not exceeded.

On deck, the cable is cut and a new section inserted with cable joints linking the new and old sections. Unlike in subsea telecoms, where cables are largely standardised, subsea power cables may differ substantially. In the past, bespoke joints have been used but there is high interest by transmission operators in developing universal joints.

For array cables, shorter cable lengths and challenges in joining shorter cables mean that replacement of the cable may be more cost effective than repair. If so, the cable will be cut at the bases of the foundations, the internal section of cable removed, and a new cable laid using the same process as installation.

What's in it

- Maintenance and service record management

O.2.2.3 Scour monitoring and management

Function

Mitigates the risk of undermining sea bed movements on subsea structures.

Figure 83 Rock dumping operations, courtesy of Jan de Nul.

Who supplies this

Inspection: CodaOctopus, DHI.

Management: HR Wallingford, Norfolk Marine and Subsea Protection Systems.

Cable monitoring: Proserv and Synaptec.

Key facts

The presence of scour (erosion of the sea bed surface) around marine structures including offshore wind farm foundations is common.

Larger diameter structures are particularly prone to scour because of the deflection of water movement around the structure. Monopile foundations are at a higher risk of scour. Jackets may still suffer from scour but design features can mitigate the risk.

Scour is generally managed through rock (or grout, sand or gravel) dumping around the base of the foundation. Mats are generally laced on top and these stabilise the infill material and prevent secondary scour. Frond mats, tyre-filled sacks and tyre-based mats have also been used.

Concrete mattresses may also be used, potentially with protective mats, where cables have become exposed.

What's in it

- Sea bed inspection

O.2.2.4 Substation maintenance and service

Function

Ensures there is no interruption to transmission from electrical failures or structural problems with the offshore platform.

Who supplies this

High voltage electrical contractors such as ABB, Alstom, GE, Schneider Group and Siemens Power Transmission and Distribution.

Offshore contractors such as Deutsche Windtechnik, Petrofac

Key facts

Maintenance and service of the offshore substation primarily consists of non-intrusive inspections of topside switchgear and transformers, sampling of transformer oil, foundation and topside structural inspection and resulting infrequent service interventions.

The owner carries out paint repairs and secondary steelwork repairs (for example to railings, gratings, gates, stairs and ladders).

Serious repair operations, such as replacing transformers, require heavy lift vessels.

Rapid turnover parts and consumables are stored in a large warehouse at the onshore base.

Back-up diesel generators require periodic maintenance and refuelling.

Access to the substation may be by vessel or helicopter but since few failures require urgent attention, the weather downtime of vessels may not be an important consideration, as it is for turbines. During planned power outages to support detailed inspection and service operations, careful planning is required to ensure weather windows are used to avoid excessive wind farm downtime if work cannot be completed and assets re-energised.

Onshore substation maintenance comprises non-intrusive inspections of switchgear, transformers and any reactive power compensation equipment. Infrequent service in response may be required.

Unlike many of the systems of an offshore wind farm, the onshore substation is almost entirely non-offshore wind specific – consisting of standard high-voltage electrical equipment.

What’s in it

- Inspection
- Maintenance and service record management

D Decommissioning

Function

Removal or making safe of offshore infrastructure at the end of its useful life, plus disposal of equipment.

What it costs

The decommissioning of a 1 GW offshore wind farm will cost around £426million (gross, excluding any resale value of equipment removed).

Who supplies this

Contractors will be similar to those used for installation.

Likely also other offshore operators will enter the space, including players with offshore oil and gas decommissioning experience who will not get involved with new product installation.

Key facts

At the end of the nominal design life of an offshore wind farm, there are a number of options:

- Extend the operational life of existing assets through a programme of risk assessments, inspections, addressing regulatory aspects, and some component replacement.
- Repower the site with new (larger) turbines, likely meaning decommissioning of existing turbines, foundations and array cables, with the possibility to extend the life of electrical transmission assets. The MW rating of the wind farm and transmission system may be unchanged as the area of the wind farm and density of turbines (MW installed per square km) are likely to be unchanged.
- Fully decommission the site.

Properly financed decommissioning plans typically are required as part of gaining planning approval to construct the wind farm. In practice, permission is likely to be sought to deviate from decommissioning plans as the sector matures decommissioning techniques. UK Government acts as decommissioner of last resort so is ultimately responsible. As a result, it takes security for decommissioning.

Turbine decommissioning will require complete removal of the structure. For nacelle and tower components, the potential for recycling is considerable. There is no current process for recycling composite materials such as those used in the blades and nacelle cover, but is likely that methods will emerge by the time a large volume of offshore wind turbine commissioning is required.

The process for foundation decommissioning will depend on the technology adopted and its sea bed connection.

Decommissioning has only been carried out on a number of small, early offshore wind farms overseas.

Environmental surveys are typically required before and after decommissioning, along with post-decommissioning management of the site in line with the Energy Act 2004.

What's in it

D.1 Turbine decommissioning

Function

Complete removal and shipment to shore of turbine rotor, nacelle and tower.

Figure 84 Wind turbine decommissioning operations at Utgrunden offshore wind farm, courtesy of Ziton/Vattenfall.

What it costs

Around £105 million for a 1 GW offshore wind farm.

Who supplies this

Turbine installation contractors such as A2Sea/GeoSea (DEME Group), Seajacks and Van Oord Offshore Wind can provide turbine decommissioning.

Likely also other offshore operators will enter the space, including players with offshore oil and gas decommissioning experience.

Key facts

The process will be a reverse of the installation process, such as individual blades being removed, then hub and nacelle then finally tower.

In some cases where it is determined that the remaining life if sufficient, there will be a market for reuse of second-hand components, either as spares for other operating wind farms or possibly for re-installation elsewhere.

Similar lifting frames and arrangements will be used at installation to enable work in the largest envelope of weather conditions. For complex lifting operations, the same level of planning and health and safety management as at installation is required, with the added assessments and method statements to deal with the risks of damaged components or seized interfaces.

In general, the removal process may be quicker than for installation because minor damage to components will be less critical. If components are to be recycled rather than reused, then in some cases less care needs to be taken to preserve the delicate aerodynamic surfaces and the condition of other components, potentially enabling the use of different equipment or enabling operations in a wider operating environment.

Many turbine manufacturers are developing composite technologies that allow blades to be recycled. This will help reduce the impact of their disposal.

What's in it

- Turbine installation [I.6]

D.2 Foundation decommissioning

Function

Removal and shipment to shore or cut-off at sea bed level and making safe.

What it costs

Around £131 million for a 1 GW offshore wind farm.

Who supplies this

Foundation installation contractors such as Ashtead, Boskalis, Decom Engineering, Geosea (DEME Group) and Jan de Nul can provide foundation decommissioning.

Likely also other offshore operators will enter the space, including players with offshore oil and gas decommissioning experience.

Key facts

Decommissioning plans may define specific requirements for removal of components below the mud line which in turn may drive the choice or design of foundations and installation methods. It is possible that in some circumstances, structures could be left in position where they support ecosystems that in the opinion of the regulator must be safeguarded.

For monopiles or jackets, all elements above the sea bed will probably need to be removed with piles cut off at an agreed height (typically 1 m below the top of the sea bed). Initially, the process is likely to draw heavily on the oil and gas industry's experience of removing subsea structures and then be optimised for the offshore wind industry.

Removal of foundations is likely to involve the use of a work-class ROV fitted with a range of cutting and drilling tools including guillotine saws, hydraulic hole cutting tools (for making lifting holes) and abrasive waterjet cutting. Gravity base manufacturers stress the ease of decommissioning as the structures can be de-ballasted and lifted/floated off to be broken down or used as breakwaters, the basis for artificial reefs or similar.

The use of suction caissons has been put forward as a means of reducing fabrication and installation costs. Decommissioning could also be straightforward, using the suction system in reverse to raise the foundation from the sea bed. Early trials have shown positive results, but removal after many years of fatigue loading has not been tried yet in wind.

What's in it

- Foundation installation [I.1]

D.3 Cable decommissioning

Function

Removal and shipment to shore.

What it costs

Around £155million for a 1 GW offshore wind farm.

Who supplies this

Cable installation contractors such as Boskalis, Global Marine and Subsea 7 can provide cable decommissioning.

In addition, companies such as CRS Holland, Pharos Offshore, Rotech Subsea and Subsea Environmental Services can carry out subsea cable recovery.

Key facts

The value, especially of the main conductor material in array and export cables, is such that it is likely to remain worth removing the cable, rather than leaving it buried.

Cables will be disconnected each end then pulled from the sea bed and wound on to drums or chopped into short sections for storage on the decommissioning vessel. The method of gripping and pulling the cable will depend on the ground conditions and burial depth. For sandy conditions the approach is likely to involve fluidising the sea bed while the cable is pulled. The industry is likely to develop new tools for the process.

Particular care will be needed at cable crossings (power or telecommunications) to avoid damage to functioning assets.

What's in it

- Offshore cable installation [I.5]

D.4 Offshore substation decommissioning

Function

Decommissioning plans typically are required as part of gaining approval to construct. These may define specific requirements for removal of components below the mud line which in turn may drive the choice or design of substation foundations and installation methods.

What it costs

Around £35 million for a 1 GW offshore wind farm.

Who supplies this

Substation installation contractors such as Boskalis, Saipem and Seaway Heavy Lifting (Subsea 7) can provide substation decommissioning.

Key facts

The process is likely to be a reverse of the installation process, although it may prove cheaper to cut the substation into sections for removal to enable a series of smaller lifts that can be undertaken by a lower cost vessel.

In some cases, there will be a market for reuse of second-hand electrical components, after refurbishment, as spares or for other applications.

If the remaining life of the substation structure and equipment, after refurbishment, is sufficient, the substation could be left in-situ and reused for a repowered wind farm of the same capacity.

What's in it

- Offshore substation installation [I.2]

D.5 Decommissioning port

Function

Port where equipment removed is offloaded and marshalled for next stage of processing.

What it costs

Included in decommissioning contract for each of the components.

Who supplies this

Similar to installation ports, but also including facilities with less stringent requirements and locations dedicated to decommissioning. Examples in the UK include Belfast, Great Yarmouth and Hull and specialist decommissioning facilities at Seaton. Non-UK ports include Eemshaven, Esbjerg and Vlissingen.

Ideally, decommissioning ports will have salvage and processing facilities on site and some ports may develop expertise in handling certain types of materials. In some cases, some specialisations developed as part of oil and gas decommissioning may be valuable, even if this involves additional transit time from the wind farm site.

Key facts

Facilities similar to those used for installation will be required. Large structures to be broken up are likely to be transported to facilities dedicated to such activity.

Ideally, decommissioning ports will have salvage and processing facilities on site. Some ports may develop expertise in handling certain types of materials. Some specialisations developed as part of oil and gas decommissioning may be valuable, even if this involves additional transit time from the floating offshore wind farm site..

What's in it

- Construction port [I.7]

D.6 Reuse, recycling, or disposal

Function

Once equipment is onshore, there is a motivation to extract maximum value via reuse, recycling or disposal.

What it costs

Overall, net positive value.

Who supplies this

Contractors that provide salving/recycling include Continuum Composite Transformation, Delta Marine, DUC Marine Group Plaswire, Renewable Parts, Scaldis Salvage & Marine and Wood Thilsted.

Key facts

Currently, different parts of decommissioned onshore wind turbines are reused, recycled, or disposed of, depending on age, condition and material content. There is an established second-hand market for onshore turbines known to be robust and reliable with sufficient fatigue life remaining. The turbines are refurbished and installed on new foundations for operation up to 50% beyond the design life.

Offshore costs and financing mean it is unlikely that offshore turbines will be decommissioned with sufficient fatigue life remaining to be re-installed offshore. Turbines are typically disassembled for recyclable scrap. The majority of nacelle and tower mass has residual value and only small amounts of turbine mass requires disposal. Turbines contain a range of valuable materials including steel, cast iron, copper, aluminium and in the future, permanent magnet materials.

Today, most composite blades cannot be cost-effectively recycled, however leading manufactures are developing techniques and materials that will allow recycling.

Blades are typically made from a combination of glass and carbon-fibre in epoxy- or polyester-based resin matrices, along with polyethylene terephthalate (PET) foam or balsa filler. At the root end, there are steel inserts to provide bolted connection to the blade bearing. There is also typically a copper-based lightning protection system.

So far, blades have been cut up and either sent for burning (in waste to energy or district heating plant), to landfill or for low-grade re-use. The first more easily recyclable blades are however now in use offshore.

Most turbine foundations and substation foundations have high steel content. This can be broken down and recycled as input to the manufacture of new steel components. Some substation components may be reused. Others can be recycled, again with relatively low proportion having no residual value and requiring safe disposal.

Concrete gravity based foundations can be broken down and the aggregate used in other concrete construction.

The cable conductor can be readily processed and reused in a range of sectors. XLPE insulation may be cleaned, dried and ground and recycled as filler for new power cables or as insulation in lower voltage cables or accessories.

D6.1 Blade recycling

Function

To take used offshore wind blades and allow reuse of recycling of their composite materials

What it costs

The supply chain is yet to be fully established so costs are largely unknown at this stage

Who supplies them

It is likely blade manufacturers will take responsibility for recycling of their blades, although specialist companies may emerge to undertake the processes on their behalf

Key facts

Today, most composite blades cannot be cost-effectively recycled, but significant progress is being made. Leading manufacturers and research consortia are developing new materials and processes to enable full circularity in blade lifecycles.

Blades are typically constructed from glass and carbon fibre embedded in epoxy- or polyester-based resin matrices, with polyethylene terephthalate (PET) foam or balsa wood as filler materials. Steel inserts at the root end provide bolted connections to the blade bearing, and a copper-based lightning protection system is also standard.

Historically, end-of-life blades have been cut up and either incinerated in waste-to-energy or district heating plants, sent to landfill, or repurposed for low-grade applications. However, the first generation of more easily recyclable blades is now in offshore use.

Several major initiatives are accelerating this transition. The ZEBRA project, a collaboration between Arkema, LM Wind Power, Owens Corning, SUEZ, and

ENGIE, has demonstrated a closed-loop recycling process using thermoplastic resin. This process enables the recovery and reuse of both resin and glass fibre, with a yield of over 75% for recycled resin and successful reintegration of recovered fibres into new blade materials.

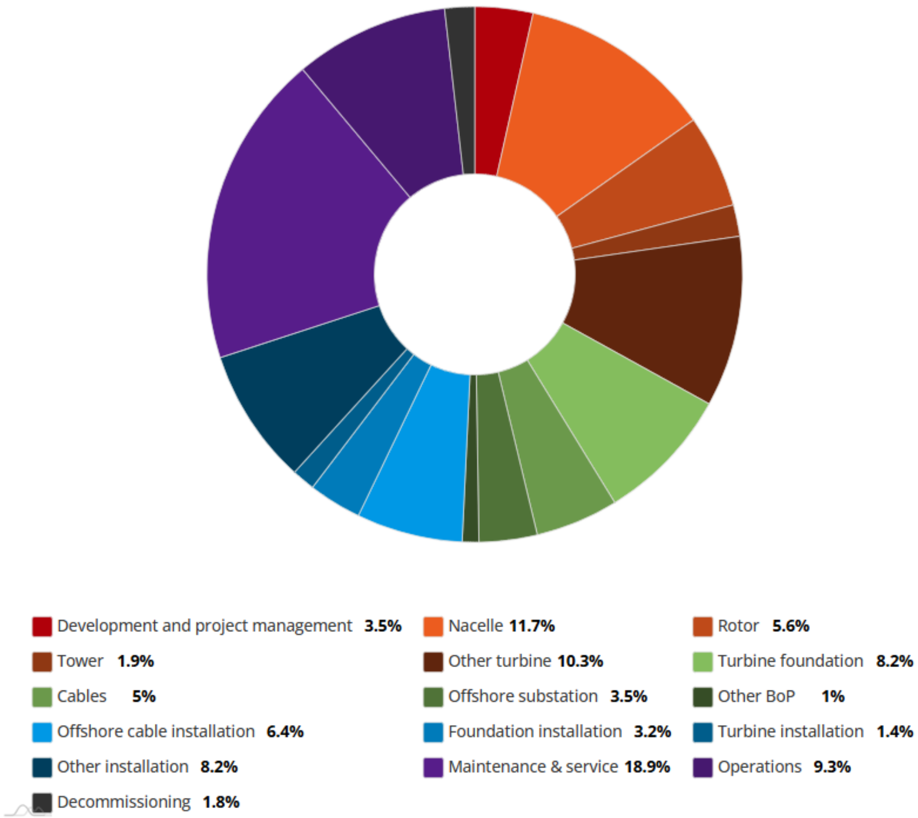
Similarly, the DecomBlades consortium, supported by partners such as Vestas, Siemens Gamesa, LM Wind Power, and Ørsted, has achieved a breakthrough by melting down glass fibre from decommissioned blades into high-quality material suitable for new blade production.

In the UK, the SusWIND programme highlights the ambition to build a domestic supply chain capable of processing all composite waste from wind turbines and other sectors. This includes co-investment in R&D and scaling up recycling infrastructure to meet the growing volume of decommissioned blades.

Many developers are recognising the importance of blade recycling and setting ambitious targets for their supply chain to meet.

These developments mark a turning point in the offshore wind sector's approach to sustainability, with blade recycling moving from experimental to commercially viable.

Wind farm costs



The pie chart shows the contribution of each major cost element to levelised cost of energy (LCOE).

The cost is comprised of:

- The capital expenditure (including development expenditure) (CAPEX)
- The cost of finance for that CAPEX
- The operational expenditure (OPEX), and
- The decommissioning expenditure (DECEX)

LCOE is defined as the revenue required (from whatever source) to earn a rate of return on investment equal to the discount rate (also referred to as the weighted average cost of capital (WACC)) over the life of the wind farm. Tax and inflation are not modelled. In other words, it is the lifetime average cost for the energy produced, quoted in today's prices.

Purpose of LCOE

LCOE is used to evaluate and compare the cost of electricity production from different technologies and at different locations. It is a good way to compare the cost of a unit of energy (say in pounds per megawatt hour of electricity (£/MWh)) produced. LCOE also does not consider costs relating to balancing supply and demand.

Lower LCOE benefits the electricity consumer (and tax payers if any subsidy is paid to generators), so decreasing LCOE is a key focus for the offshore wind industry.

LCOE combines costs and energy production into one metric, rather than comparing cost and energy production separately. It is used by technology players and industry enablers, but typically not by project investors who may be more interested in internal rate of return (IRR) or net present value (NPV) of an investment, taking into account more company-specific features like tax.

In the typical case shown in the pie chart above and table below, the LCOE is compatible with the bid prices seen in recent UK Government Contract for Difference (CfD) auctions.

CfD bid price is the revenue (£/ MWh) sought by the developer for a 15 year duration in previous auctions and 20 year durations from Allocation Round 7. Revenue after this will come from the open market. The bidder's prediction of future market prices and its approach to risk and competition will determine how it sets its CfD bid price. The CfD bid price therefore is not equal to LCOE, though there is a relationship between the two. In different markets, the scope of supply of the project developer and the terms of the competition vary, meaning that there is a different relationship between CfD bid price and LCOE.

Definition of LCOE

The technical definition of LCOE is:

$$LCOE = \frac{\sum_{t=-5}^{n+1} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=-5}^{n+1} \frac{E_t}{(1+r)^t}}$$

Where:

I_t : Investment expenditure in year t

M_t : Operation, maintenance and service expenditure in year t

E_t : Net energy generation in year t

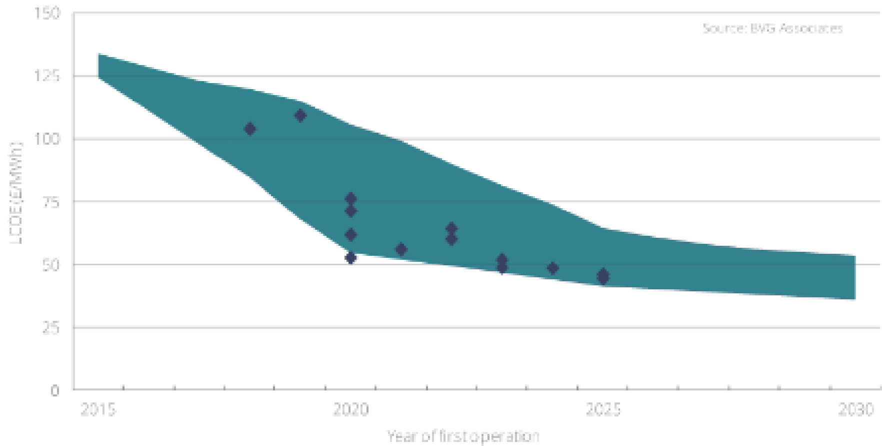
r : Discount rate (or WACC), and

n : Lifetime of project in years

Drivers of LCOE

LCOE reduction can come from reduced costs, increased energy production or changes in financing and lifetime of the project. Reduced cost can be from process or technology changes during the manufacturing, installation or operations phase. Increased energy production may be as a result of technology or by reducing lost energy via better operational processes. Reducing project risk is the main way to affect financing cost.

As shown in the chart, LCOE across Europe varies between projects (blue dots) but overall are continuing to reduce significantly over time. The LCOE has been back-calculated based on assumptions of full-life revenue & transmission costs, where applicable, as well as the auction price). The band takes into account range in site conditions and support mechanisms / local requirements that impact LCOE.



Some of the key drivers of cost are:

- **Site conditions**. Typically, projects in deeper water require more expensive foundations and have increased installation cost. Easier ground conditions such as dense sand with low gradients on homogeneous, stiff clay containing few (if any) boulders offer cost benefits as a range of piling solutions can be used and there is high confidence of long-term foundation stability. Other conditions can add significantly to cost by driving a need for alternative designs and installation methods, such as larger diameter monopiles or drilling into rock or through boulders.

Average and storm wind and wave conditions, tidal ranges and tidal flows also impact LCOE. Higher mean wind speeds increase cost, but have a net benefit for LCOE due to increased energy production. In some markets (for example in

Asia), typhoon winds drive design changes that add cost. Tidal ranges add to cost due to having to keep a minimum clearance from sea level to blade tip at all times. Tides and waves make it harder to access turbines, especially for unplanned service activities in bad weather, adding cost and reducing energy production.

Likewise, projects further from shore take longer to access, which adds cost and increases downtime, hence reducing energy production. At about 60 km, it may be most cost effective to use a service operation vessel (SOV) spending weeks at sea, rather than crew transfer vessels (CTVs) travelling to and from port daily. Projects further from shore typically also have longer grid connections, adding to transmission CAPEX and OPEX.

- Over time, there has been a move by governments from providing an agreed fixed-value market mechanism to support offshore wind to auctions where project developers bid a price for electricity they will generate. This change drives competition at project level which is passed down through the supply chain. Also, as the industry matures, what used to be highly differentiated areas of supply become commodities, driving further competition.

In some areas, such as turbines, the market is not big enough to have more than a handful of suppliers competing globally. This limits competition. In other areas, such as cables and foundations, transport costs are low enough to enable a geographically diverse supply base to bid for supply. In areas such as provision of port services, distance to the wind farm is key, which localises competition.

Vessel charter prices are a good example of the impact of pan-sector competition. Whether considering large floating installation vessels or common tugs, cyclic variations in regional wind and oil and gas activity can have a significant effect of price. Large turbine and foundation jack-up vessels are typically purpose-built for wind, so price volatility depends much more on the pipeline of offshore wind projects.

- **Supply chain evolution.** Over time, the supply chain has matured and larger players have taken on wider scopes and more risk. Wider scope within one supplier has enabled more cross-disciplinary collaboration to reduce cost. Also, larger volumes have facilitated investment in design, manufacturing and installation tooling suited to higher-volume process repetition. Large offshore wind farms may use 100 sets of identical (or similar) components, quite different from the more common practice in oil and gas of constructing one-offs.
- **Technology development**. To date, the biggest driver over time of cost of energy reduction has been the development of new technology. The most visible sign of this has been the increase in turbine rating, increasing from 2 MW turbines 20 years ago to 15 MW turbines for projects being given the go-ahead today. The rate of growth has been extraordinary and has enabled offshore wind projects in some parts of Europe to compete on cost of energy with onshore projects in other parts of Europe.

Larger turbines help drive down the per MW cost of foundations, installation and operation, whilst reaching higher into the wind field, so increasing energy production per MW installed. Larger turbines drive a need for technology development at a component level, as offshore wind turbines use the largest castings, bearings, generators and composite structures in series manufacture in any industry.

Industry incorporation of digital, autonomous, artificial intelligence and other applicable technologies is also enabling significant cost reduction, especially through improved wind farm operation and control.

Costs

Typical costs have been provided based on a project with the following parameters, typical of an upcoming UK offshore wind project.

Parameter	Data
Wind farm rating (MW)	1000

Wind turbine rating (MW)	15
Water depth at site (m)	50
Annual mean wind speed at 100 m height (m/s)	10
Distance to shore, grid, port (km)	75
Date of financial investment decision to proceed (FID)	2027
First operation date	2030

Detailed, bottom-up assessment of this typical project gives the following inputs to the LCOE equation:

- Total CAPEX = £3,470,000/MW (with spend spread realistically over years leading up to first energy production)
- Annual average OPEX = £85,000/MW
- Lifetime = 30 years
- WACC = 6.5%

Net annual average energy production = 4,200 MWh/year/ MW

As discussed above there can be quite a range in prices of any element, due to specific timing or local issues, exchange rates, competition and contracting conditions. Prices for large components include delivery to nearest port to supplier and warranty costs. Developer costs (including internal project- and construction management, insurance, typically spent contingency and overheads) are included in the highest-level boxes but are not itemised.

Cost breakdown

A more detailed breakdown of typical costs is presented in the table below. Note that figures presented are each rounded, hence totals may not equate to the sum of the sub-terms. As discussed above, there can be a large variation in costs between projects, so values stated should only be seen as indicative.

Table 1 Cost breakdown by category.

Guide categories	Costs (2024£ / MW)
Development and project management	155,000
Development and consenting services	72,300
Environmental impact assessments	10,700
Development activities and other consenting services	61,600
Environmental surveys	8,700
Animal surveys (benthic, fish, shellfish, mammals and birds)	7,500
Onshore environmental surveys	1,200
Human impact studies	770
Resource and metocean assessment	7,000
Structure	3,500
Sensors	900
Maintenance	660
Geological and hydrographical surveys	9,400
Geophysical surveys	2,500
Geotechnical surveys	5,000
Hydrographic surveys	1,900
Engineering and consultancy	9,500
Project management	48,400

Guide categories	Costs (2024£ / MW)
Wind turbine	1,200,000
Nacelle	780,000
Rotor	340,000
Tower	94,000
Balance of plant	1,100,000
Array cable	76,000
Export cable	270,000
Cable accessories	36,000
Turbine foundation	420,000
Monopile	266,000
Transition piece	124,000
Corrosion protection	28,000
Scour protection	5,400
Offshore substation	240,000
HVAC electrical system	79,800
Auxiliary systems	13,300
Topside structure	123,200
Foundation	22,000
Onshore substation	44,000
Electrical system	30,800
Buildings, access and security	13,000
Installation and commissioning	1,000,000
Inbound transport	87,000

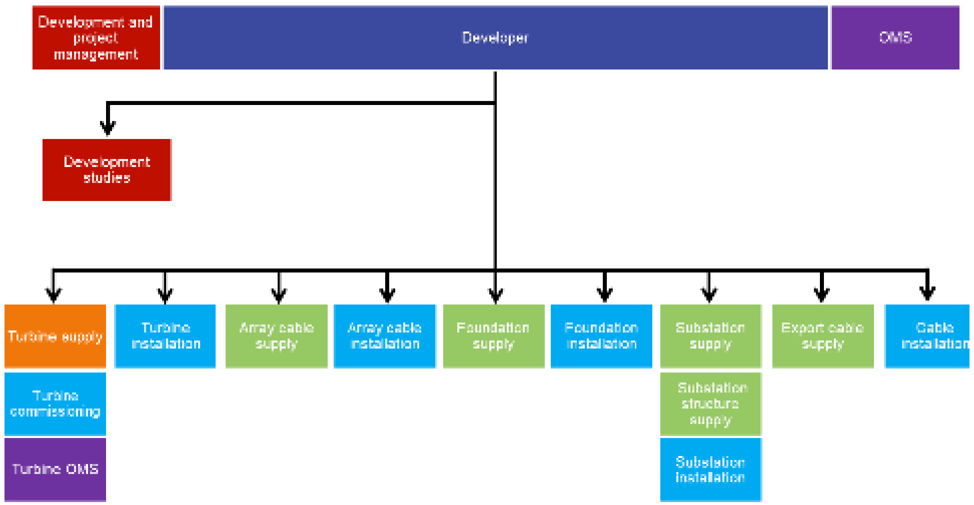
Guide categories	Costs (2024£ / MW)
Foundation installation	165,000
Monopile installation vessel	75,000
TP installation vessel	41,000
Technician services	1,000
Marshalling port	10,400
Other	37,000
Turbine installation	132,000
Turbine installation vessel	98,000
Technician services	7,000
Marshalling port	9,200
Other	17,000
Offshore cable installation	193,000
Onshore export cable installation	8,400
Offshore substation installation	43,400
Onshore substation construction	29,400
Offshore logistics	13,000
Sea-based support	6,000
Marine coordination	2,000
Weather forecasting and metocean data	600
Marine safety and rescue	4,400
Contingency and insurance	343,000
Operation, maintenance and service	85,000

Guide categories	Costs (2024£ / MW)
Operations, maintenance and service port	400
Operations	31,000
Operations control centre	1,300
Training	2,600
Onshore logistics	1,300
Technical resource (onshore and off)	6,600
Admin and support staff (onshore)	7,900
Insurance	11,220
Offshore logistics	7,200
Maintenance and service	47,000
Turbine maintenance and service	34,200
Balance of plant maintenance and service	11,600
Statutory inspections	1,000
Decommissioning	426,000
Turbine decommissioning	105,000
Foundation decommissioning	132,000
Cable decommissioning	155,000
Substation decommissioning	35,000

Procurement structures

As the industry matures, ways of procuring and managing the wide range of high value contracts required in delivering an offshore wind farm evolves. Choices depend on the risk profile of the project, the capability and financial strength of the project developer, the maturity of the technology and the supply chain, and the method of financing the project. The two main approaches are explored below. Developers will typically opt for a variant that sits somewhere between.

Multi-contracting



What is it?

- About nine main contracts are awarded covering the key elements of the wind farm
- Supply and install packages are often awarded to different companies
- Some packages can be split or combined depending on developer needs and supply chain capabilities
- Developers will typically retain flexibility during procurement to secure the best value from the supply chain

Who uses it?

- Experienced developers including Equinor, Ørsted, RWE Renewables and ScottishPower Renewables tend to multi-contract, particularly if the project is balance sheet funded
- They invest in the technical and management skills internally as they prefer to manage risk rather than pay EPCI contractors

Pros and cons

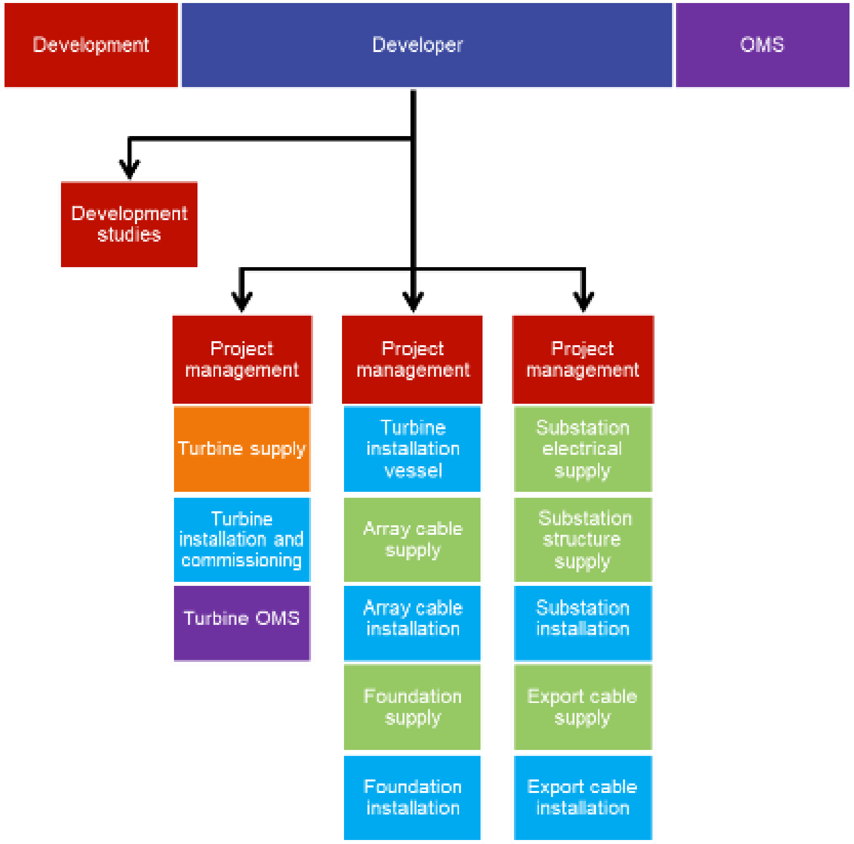
+ Offers chance of lowest outturn cost

+ Gives owner most understanding and control of their assets and the chance to best optimise

- Requires larger in-house technical and management teams

- Higher financial risk, depending on details of contracting.

EPCI



What is it?

- EPCI stands for engineer, procurement, construction and installation, where a few, large contracts are placed, each for an end-to-end scope of supply
- Usually involves three main packages, one of which will be turbine
- Involves large contracts, meaning only large, experienced contractors have the financial strength and capability to deliver

Who user it?

- Independent developers and utilities that prefer a smaller internal project team, especially when seeking to minimise own risk in order to secure project finance. Examples are SSE Renewables and Ocean Winds
- EPCI has been less common than multi-contracting in the UK

Pros and cons

+ Enables smaller development teams to deliver

+ Enables wider range of finance options

- Generally higher base cost but potentially lower cost of energy

- Optimisation generally harder to deliver across main package

UK projects

UK offshore wind farm projects in operation

Supplier list (examples only)

The list of suppliers is indicative rather than exhaustive. We have focused on suppliers with proven capability and generally have not listed suppliers with likely future capability or located distant from the UK (for example in US or China). Nevertheless, any omission does not reflect any judgement of a company's capabilities. Supply chains for other national markets are not considered.

Location is of HQ or office relevant to offshore wind (that may be a sales office in UK for business headquartered outside UK). UK subsidiaries of overseas businesses that do not have an offshore wind focus are not shown.

Table 2 Table of suppliers by supply chain category.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
P	Development and Project management		EDF Renewables, EDP Renewables, E.ON, Equinor, RWE, Ørsted, Red Rock Power, ScottishPower Renewables, SSE, Vattenfall and Flotation Energy.
P.1	Development and consenting services	Development and consenting services	ABL Group, APEM, Arup, BVG Associates, DORIS, ERM, Entrust Professional, Kinewell Energy, Lloyd's Register, Mott MacDonald, OEG Renewables, RPS, Turner & Townsend, Wood Thilsted and Xodus.
P.1.1	Development and consenting services	Environmental impact assessments	AECOM, Arcus, Cura Terrae Land & Nature, GoBe, Intertek, Land Use Consultants, Natural Power (Fred. Olsen), Royal Haskoning, RPS ,SLR, Sealand Projects, ERM and Arup.
P.2	Environmental surveys	Environmental surveys	Applied Genomics, APEM, Carcinus, ERM, Fugro, Fred. Olsen, Gardline Marine Services,RPS, RSK Environment, SLR, Natural Power, Ocean Ecology, Arup, BMT, DORIS, Global Maritime, Mott MacDonald, Ocean Infinity, Sulmara, Venterra, Wood Thilsted, Xodus, and Briggs Marine.
P.2.1	Environmental surveys	Benthic environmental surveys	ABPmer, APEM, Fugro, Gardline, Ocean Ecology and Natural Power (Fred. Olsen).
P.2.2	Environmental surveys	Fish and shellfish surveys	ABPmer, APEM, Fugro, Gardline, Natural Power (Fred. Olsen) and Precision Marine.
P.2.3	Environmental surveys	Ornithological environmental surveys	APEM, ECON, ESS Ecology, HiDef Aerial Surveying, FLI Services, Fred. Olsen and RPS.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
P.2.4	Environmental surveys	Marine mammal environmental surveys	ABPmer, APEM, Cork Ecology, ECON, ESS Ecology, Fugro, Gardline, HiDef Aerial Surveying, Jon Ford Environmental, Natural Power (Fred. Olsen), Ocean Information Services, HiDef Aerial Surveying Ltd, Seiche and RPS.
P.2.4.1	Environmental surveys	Offshore ornithological and mammal surveying vessels and craft	Vessels: Enviro-serve, Fugro, Ocean Information Services and Gardline. Aircraft (including, but not limited to): APEM, Green Rebel, and HiDef Surveying.
P.2.5	Environmental surveys	Onshore environmental surveys	Andrew McCarthy Associates, APEM, BCM Environs, ESS Ecology, Fred. Olsen, Natural Power, RSK and Thomson Ecology.
P.2.6	Environmental surveys	Human impact studies	BizGive, ERM, Hayes Mackenzie, Hoare Lea, LUC, Royal HaskoningDHV, RPS and SLR.
P.3	Resource and metocean assessment	Resource and metocean assessment	Floating lidars: AXYS Technologies, EOLOS, EOLFI, IDS Monitoring, Fraunhofer IWES, Fugro, RPS and ZX Lidars. Lidar units: Leosphere and ZX Lidars. Metocean campaigns and buoys: AXYS Technologies, Fugro, Sonardyne and Partrac. Reference data provision: The Met Office, StormGeo and Vortex. Resource campaign management and design: AXYS Technologies, DNV, Fugro, K2 Management, Natural Power, Oldbaum, ZX Measurement, RPS, Arup, BMT, DORIS, Global Maritime, HR Wallingford, Mott MacDonald, Venterra, Wood, Wood Thilsted, Xodus and Briggs Marine.
P.4	Geological and hydrographical surveys	Geological and hydrographical surveys	CMS Geoscience, EGS, Fugro, G-tec, Gardline, Horizon, MMT, ABL Group, Arup, Cathie, DORIS, Mott MacDonald, Ocean Infinity, OEG Renewables, RPS, Sulmara, Venterra, Wood Thilsted, Tekmar Group, Acteon Group, Briggs Marine, Enshore Subsea, Oceaneering, Ultrabeam and James Fisher Marine Services.
P.4.1	Geological and hydrographical surveys	Geophysical surveys	AAE Technologies, Acteon, Argeo, Fugro, Gardline, G-tec, Horizon Geosciences, Inosys,, MMT, Oceaneering, Kraken, Ternan Energy, TGS, and Sulmara.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
P.4.1.1	Geological and hydrographical surveys	Geophysical survey vessels	Fugro, Gardline, Hydrosurv, Kraken Robotics, Horizon Geosciences, MMT, Sulmara and XOCEAN.
P.4.2	Geological and hydrographical surveys	Geotechnical surveys	Fugro, G-tec, Gardline, Geoquip Marine, OWC, Rydar Geotechnical, Horizon and Sulmara.
P.4.2.1	Geological and hydrographical surveys	Geotechnical survey vessels	Fugro, G-tec, Gardline, Sulmara and Horizon.
P.4.3	Geological and hydrographical surveys	Hydrographic surveys	Specialist hydrographic survey companies such as Fugro, Gardline and MMT perform the surveys and consultants such as ABPmer and HR Wallingford undertake the impact modelling.
P.5	Autonomous survey vessels	Autonomous survey vessels	XOCEAN, Ocean Infinity, Fugro, Sea-Kit, L3Harris, Saildrone, Kongsberg Maritime, Subsea7, Sulmara and Saab Seaeye.
P.6	Engineering and consultancy	Engineering and consultancy	Arup, Apollo, Mott MacDonald, Kent, ABL Group, APEM, BMT, BVG Associates, Cathie, Chartwell Marine, DORIS, Global Maritime, ERM, HR Wallingford, Kinewell Energy, Mott MacDonald, Ocean Infinity, OEG Renewables, Offshore Solutions Group, RPS, SeaRoc, Sulmara, Turner & Townsend, Venterra, Wood, Wood Thilsted, Xodus, First Marine Solutions, First Subsea, JDR Cable Systems, Tekmar Group, Acteon group, CASC, Correll Group, Enshore Subsea, Heavy Lift Projects, Maritime Developments, Motive Offshore Group, Oceaneering, Pharos Offshore, Seaway 7, SMD, W3G Marine, Verlume, Western Isles Marine, Environment Ltd (Atlantic58), Entrust Professional and ONYX Insight.
T	Wind Turbine		GE Vernova, Siemens Gamesa Renewable Energy (SGRE) and Vestas, CSSC Haizhuang, Doosan, Dongfang Electric Corporation, Envision, Goldwind, MingYang, Shanghai Electric and Unison.
T.1	Nacelle	Nacelle	Nacelles are assembled by the wind turbine supplier, using components generally sourced from a range of external suppliers. Fasteners: Cooper & Turner

Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Polymer solutions: Nylacast
T.1.1	Nacelle	Bedplate	Bedplates are normally cast SG iron, with a steel fabricated rear section. Casting: Fonderia Vigevanese, MeuselWitz Guss, Sakana, Siempelkamp and Silbitz. Only some can manufacture the largest bedplates for offshore turbines today. Fabrications: A reasonable range of steel fabricators exist capable of bedplate manufacture.
T.1.2	Nacelle	Main bearing	Liebherr, James Walker (Lip seals only), Schaeffler, SKF, Waukesha Bearings, and thyssenkrupp.
T.1.3	Nacelle	Main shaft	Brück and thyssenkrupp.
T.1.4	Nacelle	Gearbox	Lamond and Murray, Moventas, Renk and ZF Wind Power.
T.1.5	Nacelle	Generator	ABB, Elin, GE, GreenSpur, Ingeteam, Leroy Somer, P.P.I Engineering and VEM.
T.1.6	Nacelle	Power take-off	Power converters: ABB, AVK SEG, GE Power Conversion, Ingeteam and The Switch. Transformers: ABB, CG (Pauwels), GE Power Conversion, Schneider Group, SGB and Siemens Power Transmission and Distribution. Switchgear: CG (Pauwels), GE Grid Solutions, S&C and Siemens Power Transmission and Distribution. Cabling: Draka (Prysmian), Nexans and Prysmian.
T.1.7	Nacelle	Control system	Bachmann, DEIF, KK-Electronic and Mita Teknik.
T.1.8	Nacelle	Yaw system	ABB, Bonfiglioli, Bosch Rexroth and VEM.
T.1.9	Nacelle	Yaw bearing	IMO, Liebherr, R&M Bearings International and thyssenkrupp.
T.1.10	Nacelle	Nacelle auxiliary systems	Brake: Siegerland, Stromag and Svendborg. Cooling: Hydac andWindsyn. Air conditioning: Cotes. Anemometry: FT Technologies, Gill Instruments, Kipp & Zonen, NRG Systems, Orga, Thies, Vaisala and Vector Instruments. Fire protection: Danfoss, Firetrace and Minimax.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Uninterruptible power supply (UPS): AKI Power Systems. Internal service crane: Effer, Hiab, Liftra and Palfinger Marine.
T.1.11	Nacelle	Nacelle cover	Bach Composites Industry, Eikboom and Sigmatex.
T.1.12	Nacelle	Small engineering components	Many items are off-the-shelf or can be manufactured by a range of metalworking companies.
T.1.13	Nacelle	Structural fasteners	August Friedberg, Clyde Cooper & Turner, Fuchs & Sanders, Gexpro Services and Multifix.
T.1.14	Nacelle	Condition monitoring system	Brüel & Kjær Vibro, Gram & Juhl, SecondWind and SKF.
T.2	Rotor	Rotor	Wind turbine rotors are usually designed and supplied by the wind turbine supplier as part of the complete wind turbine. Independent blade manufacturers are used by some wind turbine suppliers. Blade assemblies: GE, Siemens, and Vestas Blade moulds: DFS Composites Fasteners: Cooper & Turner Polymer solutions: Nylacast Bearings: R&M Bearings International
T.2.1	Rotor	Structural composite materials	3A Composites, Airtech, Diab, Gurit, Hexel, Owens Corning, PPG, SGL and Zoltek.
T.2.2	Rotor	Blade root	An integral element of a blade design, blade roots are designed then manufactured by the blade supplier using bought-in items.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
T.2.3	Rotor	Environmental protection	Lightning protection systems are an integral element of a blade design and the design of other turbine components in the conduction path to earth. They are manufactured by the blade and other relevant component suppliers using bought-in items. Leading edge protection: 3M. Coatings: Akzo Nobel, Bergolin and Mankiewicz.
T.2.4	Rotor	Hub casting	Fonderia Vigevanese, MeuselWitz Guss, Sakana, Siempelkamp and Silbitz. Only some can manufacture the largest hubs for offshore turbines today.
T.2.5	Rotor	Blade bearings	Dover Precision Components, IMO, Liebherr, Rollix, SKF and thyssenkrup.
T.2.6	Rotor	Pitch system	See details of hydraulic and electric systems, below.
T.2.6.1	Rotor	Hydraulic pitch system	Bosch Rexroth, Fritz Schur and Hydratech Industries.
T.2.6.2	Rotor	Electric pitch system	MOOG and SSB Wind Systems.
T.2.7	Rotor	Spinner	Bach Composites Industry, Eikboom.
T.2.8	Rotor	Rotor auxiliary systems	Automatic lubrication systems: Lincoln and SKF.
T.2.9	Rotor	Fabricated steel components	Gartsherrie, George Mcdade and Sons, Granfab, Harry Maiden, Miller Steel and Moretube Engineering.
T.3	Tower	Tower	CS Wind, Gestamp Renewable Industries, GSG Towers, Haizea Wind Group, Hutchinson, Titan Wind Energy, Global Energy Group and Welcon. Fasteners: Cooper & Turner Polymer solutions: Nylacast
T.3.1	Tower	Steel	Dillinger Hütte, Ilsenburger, Rukki, Salzgitter, Siegthaler, Severfield, CASC, Tata Steel and thyssenkrupp. Agents are also used to source and manage supply.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
T.3.2	Tower	Tower internals	Granfrab, Energy Integrity Services, Sedwell, JR Dynamics, Global Energy Group.
T.3.2.1	Tower	Personnel access and survival equipment	Elevator: Avanti, Hailo and Power Climber Wind. Fall arrest: Avanti, Latchways, Limpet Technology, Prisma Components and Uniline Safety.
T.3.2.2	Tower	Tuned damper	Tuned dampers are generally made from bought-in items.
T.3.2.3	Tower	Electrical system	These items are generally supplied by the turbine manufacturer to the tower manufacturer for fit-out.
T.3.2.4	Tower	Tower internal lighting	All parts are standard, with many suppliers, for example Chalmit.
T.3.2.5	Tower	Coatings	AkzoNobel, BASF, Hempel, NOF Metal Coatings Europe, PPG and Teknos.
B	Balance of Plant		
B.1	Cables	Cables	Cable manufacturers include Apollo, Hydro Group, Hellenic Cables, ICS2, JDR Cable Systems, LS Cable & System, Nexans, NKT, Prysmian, Sumitomo Electric and TKF.
B.1.1	Cables	Export cable	Export cable manufacturers include Hellenic Cables, LS Cable & System, Nexans, NKT, Prysmian and Sumitomo Electric.
B.1.1.1	Cables	Cable core	Cable cores are typically manufactured by the cable manufacturer such as JDR Cables. Usually, complete cable cores are manufactured and assembled at the same site to reduce the transportation costs of the different components.
B.1.1.2	Cables	Cable outer	Commodity suppliers. Fibre optic manufacturers: Hexatronic, Huber+Suhner. Fibre optic jointers and systems: Aceda and CCL UK.
B.1.1.3	Cables	Cable accessories	Interface plugs: Pfisterer, Ridderflex and TE Connectivity. Hang-off clamps: BMP, Vos Prodect and WT Henley. Cable connectors: Nexans, Pfisterer. Cable terminations: Prisma Components

Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Cable grips: Prisma Components
B.1.1.4	Cables	Cable jointing and testing	In house by cable manufacturers. Independents: Maillefer, Power CSL and WT Henley.
B.1.2	Cables	Array cable	Array cable manufacturers include Hellenic Cables, JDR Cable Systems, LS Cable & System, Nexans, NKT, Oceaneering, Prysmian, Sumitomo Electric and TKF. There are other cable manufacturers based in China and Japan, but they have yet to be used widely for UK projects.
B.1.3	Cables	Cable protection	Suppliers for cable protection include Balmoral, Subsea Protection Systems, Tekmar, Trelleborg, Protectorshell, Vos Prodect, WT Henley, CRP Subsea, First Subsea and Subsea Energy Solutions.
B.2	Turbine foundation	Turbine foundation	Design: Ramboll, COWI, Atkins, Wood Thilsted and Ballast Nedam. Monopiles: EEW, Sif, CS Wind, Dillinger Hütte, Dajin Heavy Industries, Haizea Windgroup, SeAH Wind Limited and Riggs Distler. Transition pieces: CS Wind, Smulders, Sif and EEW. Jackets: Lamprell, Smulders, Harland and Wolff, Navantia Windar, SK Oceanplant and Eni. Gravity bases: Bouygues Travaux Publics, Per Aarsleff A/S, Bilfinger, BAM Nuttall and Ballast Nedam.
B.2.1	Turbine foundation	Monopile	EEW, Sif, CS Wind, Dillinger Hütte, Dajin Heavy Industries, Haizea Windgroup, SeAH Wind Limited, Cambridge Vacuum Engineering and Riggs Distler.
B.2.2	Turbine foundation	Jacket	Jacket suppliers include Cedeco, W3G Marine, Lamprell, Smulders, Navantia Windar, SK Oceanplant and Eni.
B.2.3	Turbine foundation	Transition piece	Transition piece suppliers include CS Wind, Smulders, Sif and EEW. Fabrication suppliers include: Severfield, Hutchinson, CASC, Global Engineering and CRC Evans. Often supplied through a joint venture with the monopile supplier.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
B.2.3.1	Turbine foundation	Crew access system and work platform	The crew access system and work platform are usually supplied as part of the transition piece, see suppliers of transition pieces [B.2.3]. In practice, the steelwork for the crew access system and work platform may be subcontracted to a smaller steelwork supplier.
B.2.3.2	Turbine foundation	Internal platforms	These are usually supplied by the supplier of transition pieces [B.2.3]. In practice, the steelwork for the internal platforms may be subcontracted to a smaller steelwork supplier.
B.2.3.3	Turbine foundation	Davit crane	Suppliers of davit cranes include CraneSolutions, Demag Cranes, Granada Material Handling, Liftra, Palfinger Marine and Sparrows Group.
B.2.3.4	Turbine foundation	J-tubes, I-tube or monopile entry point	These are usually supplied by the supplier of jacket [B.2.2] or transition piece [B.2.3]. In practice, the steelwork for the J-tubes or I-tube may be subcontracted to a smaller steelwork supplier. A monopile entry point will be formed in the monopile by the monopile supplier.
B.2.4	Turbine foundation	Corrosion protection	Suppliers of corrosion protection coatings suitable for use on offshore foundations include CRC Evans, Gorilla Corrosion, Hempel, International Paint and Jotun. Suppliers of cathodic protection systems include CORROSION, Cathelco, Imenco Corrosion Technology and Impalloy.
B.2.5	Turbine foundation	Scour protection	Rock installation firms: Boskalis, Peter Madsen Rederi, DEME and Van Oord Offshore Wind. Scour mat suppliers: Exo Engineering, Naue, Norfolk Marine and SSCS. Rock bag suppliers: Ridgeway and Pipeshield.
B.3	Offshore substation	Offshore substation	Electrical system: Hitachi Energy, GE Grid Solutions and Siemens Energy. Topside structure: Aibel, CS Wind, Smulders and Seatrium. Systems integrators: Engie Fabricom, Iberdrola, Ørsted, Petrofac and Semco. Structural designers: Arup, Atkins, ISC and Ramboll.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
B.3.1	Offshore substation	Electrical system	Hitachi Energy, GE Grid Solutions and Siemens Energy.
B.3.1.1	Offshore substation	HVAC system	Acrastyle, Hornbill Engineering, Hitachi Energy, GE Grid Solutions, Linxon UK, Nucore Group and Siemens Energy.
B.3.1.2	Offshore substation	HVDC system	A&T Enclosures, Acrastyle, Hornbill Engineering, Hitachi Energy, GE Grid Solutions and Siemens Energy.
B.3.2	Offshore substation	Auxiliary Systems	Building monitoring systems (fire and gas detection, CCTV, access, security) suppliers include Communications and networking: Atos, Cisco, Cobham Wireless, Motorola and Semco Maritime Crane: Demag, Granada and Kenz Figee Diesel generator: Aggreko, Caterpillar, Iveco, Midas and Mitsubishi Fire and blast protection: Mech-Tools (steel) and Solent Composite Systems (composites) Heating, ventilation and air conditioning: Heinen & Hopman, Oteac, and Helicopter fuelling systems: Imenco Supply of general facilities is often local to assembly of the substation.
B.3.3	Offshore substation	Topside Structures	Aibel, Babcock, CS Wind, Smulders and Seatrium.
B.4	Substation foundation	Substation foundation	Dajin Heavy Industry Corporation, Eversendai, Lamprell and Smulders.
B.5	Onshore substation	Onshore substation	They are generally contracted to the same main contractor as the offshore substation electrical system [B.3.1]. Suppliers include: AJ Engineering & Construction Services, Linxon, and Morgan Marine.
B.5.1	Onshore substation	Electrical system	They are generally contracted to the same main contractor as the offshore substation electrical system [B.3.1].
B.5.2	Onshore substation	Buildings, access and security	Buildings: any provider with a suitable track record of constructing architect-designed industrial buildings can respond to a tender to construct the building and compounds.

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Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Access and security: industrial fencing, security including CCTV, access control systems, industrial LV systems, HVAC (short for heating, ventilation and air-conditioning) will be put out to tender and can be supplied by any pre-qualified supplier.
B.6	Operations base	Operations base	The wind farm owner is likely to choose a local construction company for the construction of the operations base.
I	Installation and commissioning		Installation: Suppliers listed in relevant sections below. Full engineer, procure, construct and install (EPCI) services: Boskalis, DEME Group (A2Sea, GeoSea and Tideway), Jan de Nul, MPI Offshore, Subsea 7 (Seaway Heavy Lifting, Seaway Offshore Cables) and Van Oord Offshore Wind.
I.1	Foundation installation	Foundation installation	Bauer Offshore Technologies, Boskalis, Fred. Olsen WindCarrier, GeoSea (DEME Group), Jan de Nul, Jumbo Offshore (transition pieces only), Newwaves Solutions, Foundocean (grouting only), Osbit, SAL Heavy Lift (transition pieces only), Saipem, Scaldis Salvage & Marine, SeaJacks, Seaway Heavy Lifting (Subsea 7), Swire Blue Ocean and Van Oord Offshore Wind.
I.1.1	Foundation installation	Foundation installation vessel	Operators: Boskalis, Fred. Olsen WindCarrier, GeoSea (DEME Group), Jan de Nul, Jumbo Offshore, SAL Heavy Lift, Saipem, Scaldis Salvage & Marine, SeaJacks, Seaway Heavy Lifting (Subsea 7 Group), Swire Blue Ocean and Van Oord Offshore Wind. Vessel manufacturers: as for turbine installation vessels [I.6.1].
I.1.1.1	Foundation installation	Foundation handling equipment	Suppliers include IHC IQIP, Houlder and Temporary Works Design.
I.1.1.2	Foundation installation	Foundation installation equipment	Piling equipment: Cape Holland, Fistuca, IHC IQIP, Menck and PVE. Noise mitigation: IHC IQIP and W3G Marine.
I.1.1.3	Foundation installation	Sea fastenings	Suppliers include ALE, Durham Sheet Metal, MC Construction, Semco Maritime and Temporary Works Design.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
I.2	Offshore substation installation	Offshore substation installation	The installation often forms part of the substation supply contract. Marine contractors include Boskalis, DEME, Heerema, Saipem, Scaldis Salvage & Marine, Seaway 7, Van Oord and ZPMC.
I.2.1	Offshore substation installation	Substation installation vessel	Operators include Bonn & Mees, Heerema, Huisman, Saipem, Scaldis Salvage & Marine, Seajacks, Seaway 7 and ZPMC.
I.3	Onshore substation construction	Onshore substation construction	Balfour Beatty, J Murphy and Jones Bros.
I.4	Onshore export cable installation	Onshore export cable installation	Construction companies: Balfour Beatty, J Murphy and Sons, NKT, Nexans, Powertek Utilities Group and VolkerStevin. Marine contractors: DeepOcean and Global Offshore.
I.5	Offshore cable installation	Offshore cable installation	Marine contractors: Aquatic Engineering and Construction, Boskalis, DEME, DeepOcean, Global Marine, Global Offshore, Huisman, IKM Testing, Jan de Nul, Oceanteam, Seaway 7 and Van Oord. Cable manufacturers with installation capabilities: Nexans, NKT and Prysmian.
I.5.1	Offshore cable installation	Export cable installation	Marine contractors: Boskalis, DEME, DeepOcean, Global Marine, Global Offshore, Huisman, Jan de Nul, Oceanteam, Seaway 7 and Van Oord. Cable manufacturers with installation capabilities: Nexans, NKT and Prysmian.
I.5.2	Offshore cable installation	Array cable installation	Marine contractors: Boskalis, DEME, DeepOcean, Global Marine, Global Offshore, Huisman, Jan de Nul, Oceanteam, Seaway 7 and Van Oord. Cable manufacturers with installation capabilities: Nexans, NKT and Prysmian.
I.5.3	Offshore cable installation	Cable-laying vessel	Marine contractors: Boskalis, DEME, DeepOcean, Global Marine, Global Offshore, Jan de Nul, Oceanteam, Seaway 7 and Van Oord. Cable manufacturers with installation capabilities: Nexans, NKT and Prysmian.

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Heading number	Supply chain category	Supply chain sub-category	Suppliers
I.5.3.1	Offshore cable installation	ROV	ROVs are usually provided offshore contractor. Manufacturers include Forum Energy Technologies, Louis Dreyfus Travocean, Saab Seaeye and SMD.
I.5.3.2	Offshore cable installation	Cable-handling equipment	Cable-handling equipment is usually provided by the cable installation contractor; in that case, it is either part of the vessel or must be mobilised. Manufacturers: Oceaneering, Fraser Hydraulic Power, Hulst Cable Equipment, Royal IHC, MacArtney SMD and Sparrows. Rental: Caley Ocean Systems, CWind (Global Marine Group), Demanor, Drammen Yard, Oceaneering, Osbit, RentOcean and Sparrows.
I.5.4	Offshore cable installation	Cable burial	The burial and burial tools are usually provided by the cable installation contractor. Vessel contractors: Assodivers, Boskalis, Canyon Offshore (Helix ES), Global Marine, Jan de Nul and Van Oord Offshore Wind. Manufacturers include Canyon Offshore (Helix ES), Osbit, Royal IHC and SMD.
I.5.4.1	Offshore cable installation	Cable burial vessel	Cable burial vessels are provided by a number of offshore vessel operators such as Canyon Offshore (Helix ES), Global Marine and Van Oord Offshore Wind.
I.5.4.2	Offshore cable installation	Cable plough	The cable plough is usually provided by the cable installation contractor, either as part of the vessel or mobilised specifically. Manufacturers: ETA Subsea Specialists, Osbit, Royal IHC and SMD. Rental: ETA Subsea Specialists and Pharos Offshore.
I.5.4.3	Offshore cable installation	Trenching ROV	The trenching ROV is usually provided by the cable installation contractor, either as part of the vessel or mobilised specifically. Manufacturers: Forum Energy Technology, Louis Dreyfus Travocean, Osbit, Royal IHC, SIMEC and SMD. Rental: Dockstr, Oceaneering and James Fischer Marine Services.
I.5.4.4	Offshore cable installation	Vertical injector and jetting sled	The vertical injector or jetting sled is usually provided by the cable installation contractor. Manufacturers: Miah, Royal IHC and Seatools.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Rental: ETA Subsea Specialists, Global Marine and Modus.
I.5.5	Offshore cable installation	Cable pull-in	The cable pull-in is usually provided by the cable installation contractor (see [I.5]). Horizontal Directional Drilling: Joseph Gallagher, Eco Drill and McCormack Drilling.
I.5.6	Offshore cable installation	Electrical testing and termination	The electrical testing and termination is usually provided by the cable installation contractor (see [I.5]). Manufacturers of electrical testing equipment and termination tools: 360 Wind, Axess Group, Baur, JDR, Megger, Pfisterer, Tekmar, V&SH Offshore and WT Henley.
I.6	Turbine installation	Turbine installation	A2Sea/GeoSea (DEME Group), Fred. Olsen WindCarrier, Jan de Nul, MPI Offshore, Newwaves Solutions, Seajacks, Statkraft UK, Swire Blue Ocean and Van Oord Offshore Wind.
I.6.1	Turbine installation	Turbine installation vessel	Operators: A2Sea/GeoSea (DEME Group), Fred. Olsen WindCarrier, Jan de Nul, MPI Offshore, Seajacks, Swire Blue Ocean and Van Oord Offshore Wind. Vessel manufacturers: generally in China, Korea, Singapore or the Arabian Peninsula.
I.6.1.1	Turbine installation	Turbine handling equipment and sea fastenings	Component handling tools are often provided to the offshore contractor by the turbine supplier as the tool is specific to a turbine type and installation methodology.
I.6.2	Turbine installation	Commissioning	Final commissioning is expected to be split between the EPCI contractor for the array cable installation and hook-up, and the wind turbine supplier for the wind turbine.
I.7	Construction port	Construction port	UK ports used so far include Able Seaton, Barrow, Belfast, Great Yarmouth, Harwich, Hull, Mostyn and Sheerness. Non-UK ports used for UK projects include Cuxhaven, Eemshaven, Esbjerg, Ijmuiden, Ostende and Vlissingen. Heavy lifting services: Heavy Lift Projects and Mammoet. Health and safety: CASC Support services: Boston Energy, Clarkson port services, Texo and Doyle Shipping.
I.8	Offshore logistics	Offshore logistics	High-level coordination is typically undertaken by the developer.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Construction management services: JET Engineering, Asco, DNV, Global Wind Service, LOC Renewables, Osprey, Rhenus Group, PSG Marine & Logistics, SeaRoc, Schmidbauer and Ventolines.
I.8.1	Offshore logistics	Sea-based support	Vessel manufacturers: Alicat, Arklow Marine Services, Damen, Diverse Marine, Integrated Wind Solutions, Maersk, Wagenborg and Wight Shipyard Vessel operators: Fred. Olsen, HST Marine, Mainprize Offshore, Maersk, Turner Iceni, Siem Offshore, Van Oord, Wind Energy Marine, Zelim and Windcat Workboats.
I.8.2	Offshore logistics	Marine coordination	Marine coordination is usually carried out by the developer or a subcontractor. Suppliers of marine coordination: Asco, Livelink Aerospace, James Fisher Marine Services, Royal Dirkzwager, SeaRenergy, SeaRoc, Specialist Marine Consultants, Systematic, VisSim and WindandWater.
I.8.3	Offshore logistics	Weather forecasting and metocean data	Anemometers and lidars: AXYS Technologies, EOLOS, Gill Instruments, Leosphere, ZX Lidars and Wood Group. Current and wave buoys: AXYS Technologies, OSIL Sonardyne, Partrac and RS Aqua. Weather forecast services: Fugro, Met Office, Kjeller Vindteknikk, MetoGroup, StormGeo, Clyde Space Ltd and Vento Maritime. Aerial surveys: HiDef Surveying. In addition, the vessel contractor generally provides wind measurements (for example via anemometer mounted on crane boom or lidar).
O	Operations, Maintenance and service		The wind farm owner will oversee and fulfil overall site operations activities. In terms of wind turbine planned maintenance and service in response to faults, wind turbines are typically under warranty for the first five to ten years of operations and the wind turbine suppliers offer a service level agreement during this period to provide turbine maintenance and service. After this initial warranty period, the wind farm owner may maintain and service the wind farm using an in-house team, contract to a specialist company or develop an intermediate arrangement where turbine technicians transfer to the wind farm owner at the end of the warranty period.
O.1	Operations	Operations	The owner of the wind farm typically creates a special-purpose vehicle to operate the project. This may have several shareholders, one of which is likely to take a lead role.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Operations tasks for offshore wind farms are typically provided by the majority wind farm owner. Some aspects of wind farm operations are contracted to companies such as Boston Energy, Deutsche Windtechnik, James Fisher Marine Services and 3Sun.
O.1.1	Operations	Training	Typically training occurs at a local scale through Global Wind Organisation (GWO) certified organisations including: Advanced Industrial Training, ARCH, Boston Energy, CWind (Global Marine Group), Falck Safety Services, Fleetwood Nautical Campus, Heightec, Maersk Training, MRS Training and Rescue, National Wind Farm Training Centres, Offshore Marine Academy, VRAI and ProntoPort. The GWO training standards are now widely adopted in the offshore wind industry. The GWO is a non-profit body founded by leading wind turbine suppliers and/or operators.
O.1.2	Operations	Onshore logistics	The wind farm operator will establish OMS port facilities during the installation process, as many support vessels active during the operational phase will operate from local ports. The wind farm owner will typically occupy quayside facilities, operating on a long-term lease with the owner of the port infrastructure.
O.1.3	Operations	Offshore logistics	The wind farm owner will setup and manage a marine operations centre at the main OMS port. Third party suppliers of marine coordination services and software include ONYX Insight, SeaRoc (Fred. Olsen), Vissim, and Windandwater.dk.
O.1.3.1	Operations	Crew transfer vessels	Vessel operators: Acta Marine Wind Services, MJ Power, BA Technologies, Mainstay Marine Solutions, MPI Workboats, Njord Offshore, Northern Offshore Services, North Sea Logistics, OEG Renewables, Seacat Services, Turbine Transfers and Windcat Workboats. Manufacturers: Alicat, Fjellstrand, Fred. Olsen WindCarrier, Manor Renewables, South Boats and Umoe.
O.1.3.2	Operations	Service operation vessels	Vessel operators: Acta Marine, Bernard Schulte, Bibby Marine, Esvagt, Louis Dreyfus Travocean, Østensjø Rederi and Vroon. Manufacturers: Astilleros Gondanm Cemre, Damen, North Star, Royal IHC and Ulstein.
O.1.3.3	Operations	Turbine access systems	Suppliers include Ampelmann, Fjellstrand, Houlder, Osbit, Uptime, Pict Offshore and Windcat.
O.1.3.4	Operations	Helicopters	Operators: Babcock, Bond Aviation Group, Heli Service International and Northern Helicopter.

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Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Manufacturers: Airbus, Leonardo and Sikorsky.
O.1.4	Operations	Health and safety inspections	Suppliers include Bureau Veritas, Sennen Tech, DNV-GL, SGS and TÜV SÜD.
O.1.4.1	Operations	Health and safety equipment	Aspli, Trauma Resus, Viking Life Saving Equipment, Fennex, Zelim, Pict Offshore and WFE Safety.
O.2	Maintenance and service	Maintenance and service	Maintenance and service activities are provided by a combination of the owner's in-house resources, wind turbine suppliers and third party service providers. These are further defined under the sub-headings below. Suppliers include: James Fisher Marine Services, Boston Energy, ONYX Insight, Pict Offshore, Cognitive Business and Swire Renewable Energy.
O.2.1	Maintenance and service	Turbine maintenance and service	The wind turbine supplier, during the defect notification period (DNP) and for the duration of any agreed contract beyond the DNP. The wind farm owner may seek to bring service capability in-house or to engage an independent service provider (ISP), which involves seeking agreement with the manufacturer for the supply of spares, software systems and specialist expertise. ISPs include Aquaterra, JR Dynamics, Sedwell, EchoBolt, Boston Energy,Deutsche Windtechnik, James Fischer Marine Services, Pict Offshore, ONYX Insight, Swire Renewable Energy and 3Sun.
O.2.1.1	Maintenance and service	Blade inspection and repair	Service suppliers include Bladefence, Cyberhawk, Deutche Windtechnik, DNV-GL, FORCE Technology, GEV, Global Wind Service, James Fisher Marine Services, Mistras, Natural Power (Fred. Olsen), Swire Renewable Energy and 3Sun. Inspection technology suppliers include ABJ, BladeBug, Anakata Wind Power, Cornis, Scoptico, SkySpecs and TSR Wind.
O.2.1.1.1	Maintenance and service	Unmanned aerial vehicle	Manufacturers: Aerial Vision, Anakata Wind Power, ASV Global, DJI and SkyFront. Operators: Cyvberhawk, Esvagt, Force Technology, Perceptual Robotics and SkySpecs.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
O.2.1.1.2	Maintenance and service	Autonomous vessels	Suppliers include Fugro, Sulmara, Unmanned Survey Solutions, and Xocean.
O.2.1.2	Maintenance and service	Main component refurbishment, replacement and repair	Suppliers include Boston Energy, James Fisher Marine Services, Seajacks, Fred. Olsen WindCarrier and Ziton.
O.2.1.2.1	Maintenance and service	Large component repair vessel	See turbine installation vessels [I.6.1].
O.2.2	Maintenance and service	Balance of plant maintenance and service	CWind (Global Marine Group), Fred. Olsen WindCarrier, James Fisher Marine Services, DORIS, Ocean Infinity, OEG Renewables, Sulmara, Venterra, First Marine Solutions, JDR Cable Systems, Synaptec, Acteon Group, Briggs Marine, Correll Group, Maritime Developments, Oceaneering, Pharos Offshore, Rotech Subsea, SMD, W3G Marine, Boston Energy, Pict Offshore and 3Sun.
O.2.2.1	Maintenance and service	Foundation inspection and repair	Suppliers include CWind (Global Marine Group), Deutsche Windtechnik, Fugro, Global Wind Service, Mistras, Offtech Wind and Strainstall (James Fisher).
O.2.2.1.1	Maintenance and service	Remotely operated vehicle	Manufacturers: ECA Hytec, Saab Seaeye and Seatronics. Operators: Fugro, James Fisher Marine Services, Verlume HonuWorx and BEAM.
O.2.2.1.2	Maintenance and service	Autonomous underwater vehicle	Manufactures: ECA Hytec, General Dynamics, Teledyne Marine Gavia and Woods Hole Oceanographic Institution. Operators: Fugro, Modus, Verlume and UTEC.
O.2.2.2	Maintenance and service	Cable inspection and repair	Offshore works: Boskalis, Briggs Marine, CWind (Global Marine Group), Offshore Marine Management, Oceaneering, Power CSL, Flexlife, Pharos Offshore, Leask Marine and Seatech Commercial Diving. Electrical works: Boskalis, Power Cable Services.
O.2.2.3	Maintenance and service	Scour monitoring and management	Inspection: CodaOctopus, DHI. Management: HR Wallingford, Norfolk Marine and Subsea Protection Systems.

Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Cable monitoring: Proserv and Synaptec.
O.2.2.4	Maintenance and service	Substation maintenance and service	High voltage electrical contractors such as ABB, Alstom, GE, Schneider Group and Siemens Power Transmission and Distribution. Offshore contractors such as Deutsche Windtechnik, Petrofac
D	Decommissioning		Contractors will be similar to those used for installation. Likely also other offshore operators will enter the space, including players with offshore oil and gas decommissioning experience who will not get involved with new product installation.
D.1	Turbine decommissioning	Turbine decommissioning	Turbine installation contractors such as A2Sea/GeoSea (DEME Group), Seajacks and Van Oord Offshore Wind can provide turbine decommissioning. Likely also other offshore operators will enter the space, including players with offshore oil and gas decommissioning experience.
D.2	Foundation decommissioning	Foundation decommissioning	Foundation installation contractors such as Boskalis, Decom Engineering, Ashtead, Geosea (DEME Group) and Jan de Nul can provide foundation decommissioning. Likely also other offshore operators will enter the space, including players with offshore oil and gas decommissioning experience.
D.3	Cable decommissioning	Cable decommissioning	Cable installation contractors such as Boskalis, Global Marine and Subsea 7 can provide cable decommissioning. In addition, companies such as CRS Holland, Pharos Offshore, Rotech Subsea and Subsea Environmental Services can carry out subsea cable recovery.
D.4	Offshore Substation decommissioning	Offshore Substation decommissioning	Substation installation contractors such as Boskalis, Saipem and Seaway Heavy Lifting (Subsea 7) can provide substation decommissioning.
D.5	Decommissioning port	Decommissioning port	Similar to installation ports, but also including facilities with less stringent requirements and locations dedicated to decommissioning. Examples in the UK include Belfast, Great Yarmouth and Hull and specialist decommissioning facilities at Seaton. Non-UK ports include Eemshaven, Esbjerg and Vlissingen.

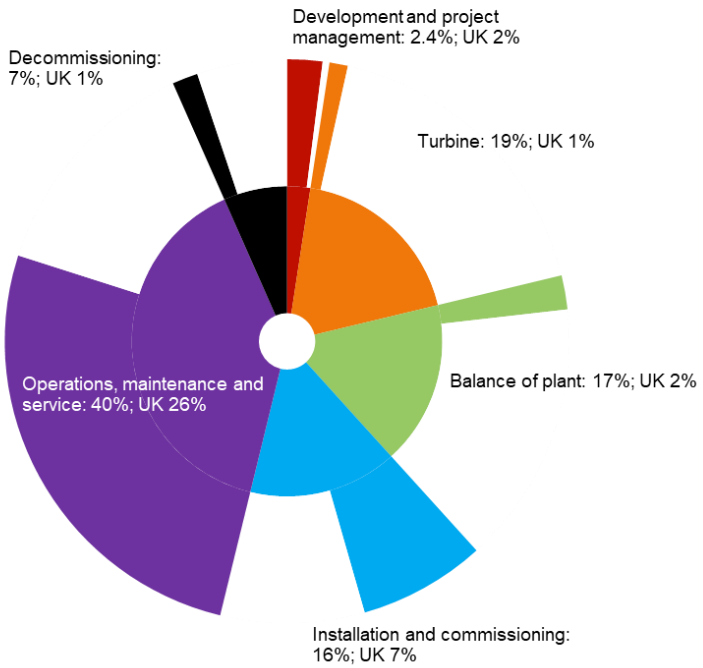
Heading number	Supply chain category	Supply chain sub-category	Suppliers
			Ideally, decommissioning ports will have salvage and processing facilities on site and some ports may develop expertise in handling certain types of materials. In some cases, some specialisations developed as part of oil and gas decommissioning may be valuable, even if this involves additional transit time from the wind farm site.
D.6	Reuse, recycling or disposal	Reuse, recycling or disposal	Contractors that provide salving/recycling include Wood Thilsted, Continuum Composite Transformation, Plaswire, Renewable Parts, Delta Marine, DUC Marine Group and Scaldis Salvage & Marine.

UK Content

Alongside its contribution to UK energy needs, the UK's offshore wind sector is also bringing local economic benefits, in terms of investment and local job creation. To help track progress, the industry tracks UK content.

UK content is defined in *Methodology for measuring the UK content of UK offshore wind farms* (BVG Associates for Department of Energy and Climate Change, The Crown Estate and RenewableUK, May 2015, available online at https://bvgassociates.com/publications/).

Source: BVG Associates



This chart shows a breakdown of UK content for a typical recent UK offshore wind farm. The overall UK content is 40% of undiscounted lifetime spend. The key contributions typically are:

- Operations, maintenance and service, where much of the activity is close to the wind farm site,
- Installation and commissioning, where the UK has several leading marine contractors and equipment suppliers, and
- Turbine, where most blades and some towers are supplied from the UK.

UK offshore wind history

2000: First offshore project

The UK's first demonstration offshore wind farm was installed in December 2000 off the Northumberland coast. It consists of two 2 MW Vestas wind turbines with a rotor diameter of 66 m, on monopile foundations in about 10 m water, less than 2 km from shore.

At the time, these were the largest turbines installed offshore in the world. At the same time, the first applications (Round 1) for sea bed leases were presented to The Crown Estate, the landlord for the sea bed within UK waters.

Figure 85 Blyth offshore wind farm, courtesy of E.ON.

2003: First commercial project

North Hoyle, the UK's first commercial wind farm was installed off the North Wales coast. It consists of thirty 2 MW Vestas turbines with a rotor diameter of 80 m, on monopile foundations in about 12 m water, about 8 km from shore.

Other Round 1 projects followed soon after, though the last of 12 projects were only installed in 2013, bringing the total Round 1 capacity to 1.2 GW. Five projects were withdrawn based on environmental grounds.

In 2003, Narec (now part of the Offshore Renewable Energy (ORE) Catapult), was set up in Blyth to support the development of renewable energy by providing world-class test and other technical services.

At the end of 2003, the results of Round 2 of sea bed leasing were announced, with 15 projects awarded a total of 7.2 GW capacity.

Figure 86 Aerial view of the North Hoyle offshore wind farm. Creative Commons (CC BY-SA 3.0), photo by Tom Jeffs.

2007: First 100 m diameter rotors, first 5 MW turbines installed offshore and first use of jacket foundations

Burbo Bank was the first UK offshore wind farm where 100 m rotor diameter turbines were installed. It consists of 25 3.6 MW Siemens turbines with a rotor diameter of 107 m, installed off Liverpool.

At the same time, two 5 MW Senvion turbines with a rotor diameter of 126 m were installed in the Moray Firth, Scotland, on the first jacket foundations installed in offshore wind, globally.

In 2007, the Government announced a strategic environmental assessment as an early step to Round 3 of sea bed leasing by The Crown Estate. The third sea bed leasing round was subsequently launched by The Crown Estate in 2008, offering nine large zones with a capacity of around 30 GW.

Figure 87 Aerial view of the Burbo Bank offshore wind farm, courtesy of Ørsted.

2009: First 100 MW project

In 2009, the first 100 MW project started operation off the Lincolnshire coast, when the twin projects Lynn and Inner Dowsing were commissioned. The single construction project consists of 54 3.6 MW Siemens turbines, totalling 194 MW.

UK installations pushed the UK past Denmark to take over as the global lead for offshore wind installed capacity.

Figure 88 Lynn and Inner Dowsing Wind Farm under construction. Creative Commons (CC BY-2.0), photo by Chris.

2010: First 100 turbine project

Thanet, in the Southern North Sea, became the world's largest offshore wind project and the first to have 100 turbines. It consists of 100 3 MW Vestas turbines, located in water depths up to 23 m, about 12 km from shore.

At the same time, the winners of The Crown Estate's Round 3 leasing competition were announced, the largest with capacity up to 10 GW. Thanet, in the Southern North Sea, became the world's largest offshore wind project and the first to have 100 turbines. It consists of 100 3 MW Vestas turbines, located in water depths up to 23 m, about 12 km from shore.

At the same time, the winners of The Crown Estate's Round 3 leasing competition were announced, the largest with capacity up to 10 GW.

Figure 89 Thanet offshore wind farm, courtesy of Vattenfall.

2012: First 500 MW project

Greater Gabbard, the UK's first 500 MW project started operation. It consists of 140 3.6 MW Siemens turbines and became the world's largest offshore wind farm.

In 2012, The Crown Estate also published its flagship industry report on the potential for cost of energy reduction in offshore wind to 2020. Coupled with the output the Offshore Wind Cost Reduction Task Force, this set the direction of Government-industry collaboration in offshore wind for the next six years.

It was also the year that the ORE Catapult was established in Glasgow to lead technology innovation and research centre for offshore wind, wave and tidal energy.

Figure 90 Greater Gabbard offshore wind farm, courtesy of Greater Gabbard Offshore Wind Farm.

2013: First 6 MW and 7 MW turbines installed

The first 7 MW turbine was constructed offshore in the Firth of Forth, Scotland. The prototype turbine, developed by Samsung, has a rotor diameter 171 m. This turbine is now operated by ORE Catapult.

At the same time, the first 6 MW direct-drive (gearless) Siemens offshore wind turbines were installed at Gunfleet Sands in the Thames Estuary. Historically, gearboxes have been a source of unreliability and OPEX for wind turbines, but removing them drives a significant increase in size and cost of the generator. Some other suppliers, such as MHI Vestas, have opted for a mid-speed generator with a simplified gearbox as a solution.

London Array, at 630 MW, took over as the world's largest wind farm, consisting of 175 3.6 MW Siemens turbines.

The Government also announced an intermediate step to a new auction market mechanism for offshore wind, Contracts for Difference (CfD) as part of Electricity Market Reform. This step, known as Final Investment Decision (FID) Enabling for Renewables, led eventually to a range of offshore wind projects obtaining strike prices of £140 to £155/ MWh for projects delivered up to 2019.

Figure 91 Levenmouth turbine, courtesy of Offshore Renewable Energy Catapult.

2015: First UK Contracts for Difference auction

The first CfD auction results for UK offshore wind were announced, with strike prices of £114 to £120/ MWh (2012 prices) for projects to be delivered by 2019.

In 2014, Mitsubishi Heavy Industries, Ltd. the Japanese multinational engineering, electrical equipment and electronics company and wind turbine supplier Vestas established a 50:50 joint venture for supply to the offshore wind industry, MHI Vestas Offshore Wind.

Figure 92 Gwynt y Môr offshore wind farm, (c) RWE.

2017: First Round 3 project operating

Seven years after obtaining an agreement for lease, the first wind farm from the UK leasing Round 3 started operation (although it was not fully commissioned until 2018). Rampion, in the English Channel, consists of 130 3.45 MW turbines from MHI Vestas Offshore Wind.

At the same time, the world's first commercial floating offshore wind farm Hywind Scotland started operation. The five 6 MW Siemens turbines were installed on spar-buoy foundations in water about 100 m deep off Peterhead in Grampian, Scotland.

The second CfD auction results for UK offshore wind were announced, with strike prices of £57 to £75/ MWh (2012 prices) for projects to be delivered by 2023, showing a substantial cost of energy reduction since the previous auction.

German conglomerate, Siemens, the largest industrial manufacturing company in Europe, merged its wind division with Spanish turbine supplier Gamesa to form Siemens Gamesa Renewable Energy. GE Renewable Energy acquired leading wind turbine blade manufacturer LM Wind Power.

Figure 93 Rampion offshore wind farm, courtesy of Rampion Offshore Wind.

2018: First 9.5 MW turbines

The first contracts were placed for MHI Vestas Offshore Wind 9.5 MW turbines, which will be installed in 2021 and 2022 at the Triton Knoll and Moray East wind farms. Both MHI Vestas Offshore Wind and Siemens Gamesa Renewable Energy have 10 MW+ turbines and GE Renewable Energy announced its 12 MW+ turbine with a 220 m diameter rotor.

At the same time, the record for the largest offshore wind farm was broken, with the 659 MW Walney Extension project in Morecambe Bay, consisting of 40 MHI Vestas Offshore Wind 8.25 MW turbines and 47 Siemens Gamesa Renewable Energy 7 MW turbines.

Figure 94 Siemens SG 10.0-193 DD, (c) Siemens Gamesa Renewable Energy.

2019: First 1 GW offshore wind farm

The 1,218 MW Hornsea One wind farm began operation becoming the world's largest offshore wind farm. It consists of 174 Siemens Gamesa Renewable Energy 7 MW turbines and is almost double the capacity of the previous largest offshore wind farm.

The 588 MW Beatrice Offshore Wind Farm, Scotland's first commercial-scale offshore wind project developed through the Scottish Territorial Waters leasing round, entered operation. Located in the Moray Firth, Beatrice features 84 Siemens Gamesa 7 MW turbines and marked a major milestone for Scotland's offshore wind industry.

The third CfD auction resulted in record low prices for offshore wind, awarding strike prices (at 2012 prices) of £39.65/ MWh and £41.61/ MWh for projects commissioned in 2023/2024 and 2024/2025 respectively. Projects in what was the Dogger Bank Round 3 Zone were awarded CfDs for a total of 4.8 GW.

Following the CfD auction results, it was announced that two projects would be built without a CfD.

These were the East Anglia THREE project (that will now be built alongside East Anglia ONE North and TWO projects as one large project called the East Anglia Hub) and an additional part of the Seagreen Phase 1 project.

The first offshore wind project in the UK was decommissioned. The 4 MW Blyth Offshore Wind farm had been commissioned in 2000.

In 2019 the UK Government and the Offshore Wind Industry Council signed a Sector Deal for offshore wind in the UK. The deal included a number of targets for the industry including a target of 30 GW of installed capacity by 2030, which has since been increased to 40 GW.

Figure 95 Hornsea Project One wind farm. Creative commons (CC BY-SA 4.0) photo by The joy of all things.

2020: First 13 MW turbine contracted

There was only one offshore wind project installed in the UK during 2020, the 714 MW East Anglia ONE project which was fully commissioned in July 2020.

Offshore construction began for the Triton Knoll and Neart na Gaoithe projects. Onshore construction started for the Dogger Bank A and B projects, which also reached FID. The projects will have a combined installed capacity of 2.4 GW. Dogger Bank A and B will also use GE Renewable Energy's 13 MW Haliade-X turbine, the first time turbines of this size have been contracted.

New lease competitions run by The Crown Estate and Crown Estate Scotland were delayed, including by COVID-19.

SGRE also announced its latest offshore turbine rated at 14 MW with a rotor diameter of 222 m. The turbine will first be installed on commercial projects in 2024.

Figure 96 East Anglia ONE under construction, Wikimedia Commons (CC BY-SA 4.0) photo by Trommens

2021: Leases awarded for a further 8 GW of capacity

The Crown Estate allocated areas for nearly 8 GW of offshore wind capacity in the Offshore Wind Leasing Round 4 in 2021. The six winning bids will pay a combined £879 million every year throughout the development phase in option fees. The Crown Estate also announced its plans to lease up to 4 GW floating offshore wind in the Celtic Sea.

The first round of offshore wind leasing in Scottish waters for over a decade, ScotWind, was launched in July 2021, with water depths suitable for bottom-fixed and floating offshore wind.

The UK Government also launched the fourth CfD allocation round with a pot of £200 million allocated for offshore wind, and an additional £24 million ringfenced specifically for floating offshore wind. It also announced that CfD auctions will be conducted annually from 2023 onwards to increase the rate of installations.

The largest floating offshore windfarm to date, Kincardine Offshore Windfarm, was fully commissioned in October 2021 with an installed capacity of 50 MW.

The Hornsea 2 project generated its first power in December 2021. Once completed, the 1.3 GW windfarm will overtake Hornsea 1 as the largest offshore wind farm in the world. It is expected to become fully operational in 2022.

Figure 97 Prototype of the Principle Power floating foundations used in the Kincardine project. Creative Commons (CC BY-SA 3.0) photo by Untrakdrover.

2022: World's Largest Offshore Wind Farm and ScotWind Leasing Round

The Hornsea Two offshore wind farm became fully operational, surpassing Hornsea One to become the world's largest offshore wind farm with a capacity of 1.3 GW. The project consists of 165 Siemens Gamesa 8 MW turbines and is located off the Yorkshire coast in the North Sea.

ScotWind, the largest leasing round for Scottish offshore wind to date, concluded with 20 projects awarded seabed rights. The ScotWind projects consist of a combination of floating and fixed installations, collectively representing a potential capacity of 27.625 GW. This marked a significant step towards Scotland's renewable energy ambitions of 11 GW of Offshore wind capacity by 2030 and the deployment of large-scale floating offshore wind technology.

The UK Government confirmed its 50 GW offshore wind target for 2030, including 5 GW of floating wind. The results of the fourth Contracts for Difference (CfD) auction were announced, awarding record-low strike prices of as little as £37.35/ MWh (2012 prices) for offshore wind projects, highlighting the continued cost reductions in the sector.

2023: First 15 MW Turbines and Floating Wind Expansion

The UK Government held the fifth CfD auction, but for the first time, no major offshore wind projects were awarded due to strike price concerns. The failure of the auction raised concerns about investment in the sector and prompted the government to reassess its approach to offshore wind pricing mechanisms.

Dogger Bank Wind Farm Phase A began installing its first turbines, making it the first project globally to use GE Renewable Energy's 13 MW Haliade-X turbines, with a rotor diameter of 220 m. The project, set to be the world's largest upon full completion, is expected to reach 3.6 GW across three phases.

The first commercial-scale 15 MW wind turbines were contracted for UK projects, with manufacturers such as Siemens Gamesa and GE announcing plans to deploy their latest high-capacity models. These turbines will be installed at future phases of Dogger Bank and other projects scheduled for the mid-2020s.

Seagreen Wind Farm was fully commissioned in 2023, becoming Scotland's largest wind farm and the world's deepest fixed-bottom farm, with maximum turbine depth of 58.7m.

Floating wind continued to gain traction with the result of the INTOG (Innovation and Targeted Oil & Gas) leasing round from Crown Estate Scotland, aimed at integrating offshore wind with oil and gas decarbonisation. Thirteen projects were offered seabed rights, representing 5.5GW of capacity. The first of these projects, Green Volt, was allocated a CfD in 2024, becoming one of the first commercial scale floating wind project to be granted funding.

The Crown Estate also progressed plans for Celtic Sea floating wind development, targeting 4 GW by 2035.

2024: Record UK Offshore Wind Auction and Supply Chain Expansion

Despite the previous year's CfD setback, major investment in the UK offshore wind supply chain was announced, including expansions in turbine blade manufacturing, subsea cables, and port infrastructure to support the increasing scale of offshore wind projects. The UK continued its leadership in offshore wind innovation, with the deployment of next-generation floating wind platforms and new HVDC transmission technologies for more efficient energy transport.

The first turbines for the Moray West project were installed, with the wind farm expected to contribute an additional 882 MW to Scotland's renewable energy portfolio by 2025.

2025: UK Offshore Wind Capacity Exceeds 20 GW

The UK surpassed 20 GW of installed offshore wind capacity, reinforcing its position as a global leader in the sector. The milestone was achieved with the commissioning of major projects such as Dogger Bank B and Moray West, as well as the expansion of floating offshore wind installations.

The UK Government confirmed plans for a sixth CfD auction, with further emphasis on supply chain investment, grid upgrades, and floating wind deployment. Offshore wind's contribution to UK electricity generation continued to grow, helping to drive progress towards net zero emissions by 2050.

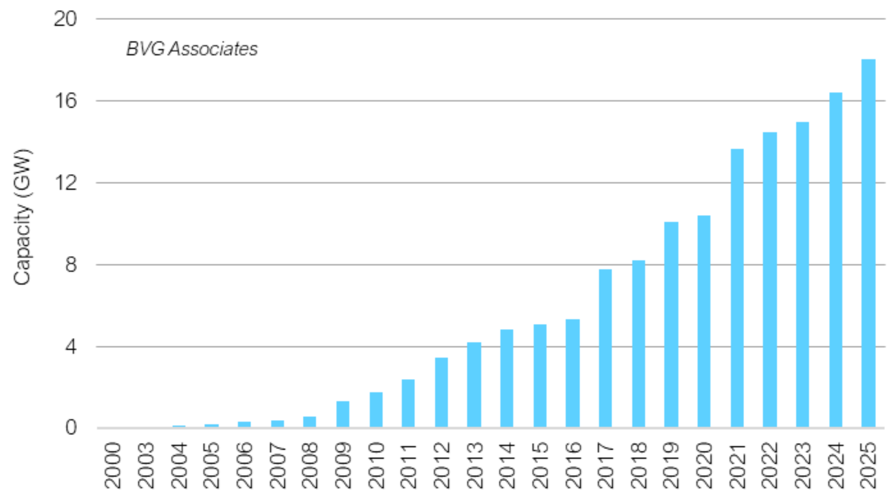


Figure 98 Capacity installed by end of year for UK offshore wind projects.

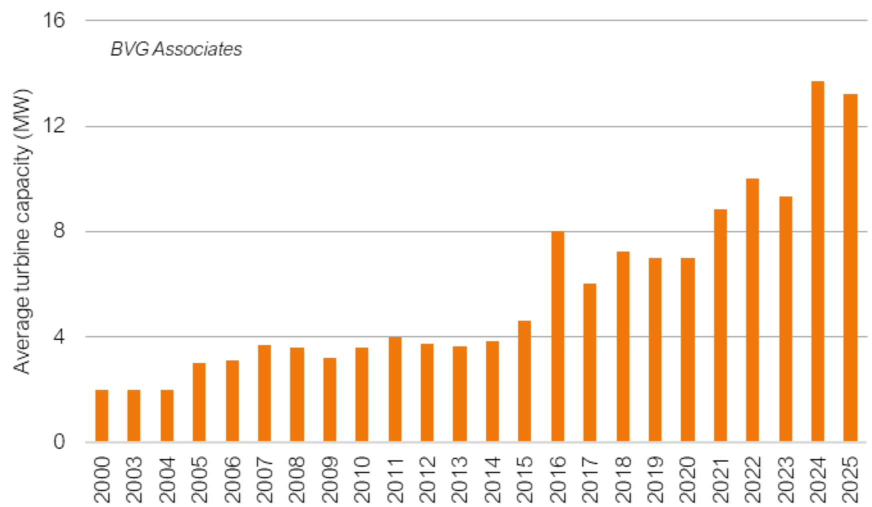


Figure 99 Average turbine size installed in each year.

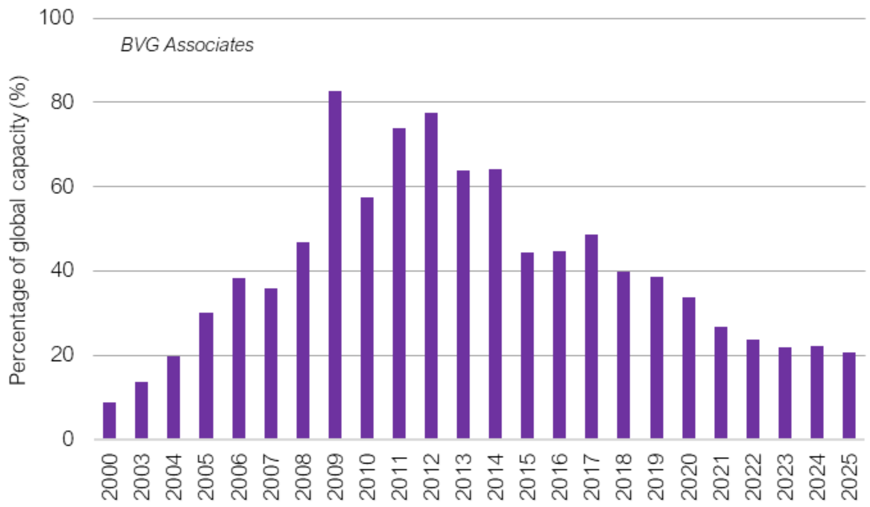


Figure 100 Percentage of global capacity in the UK.

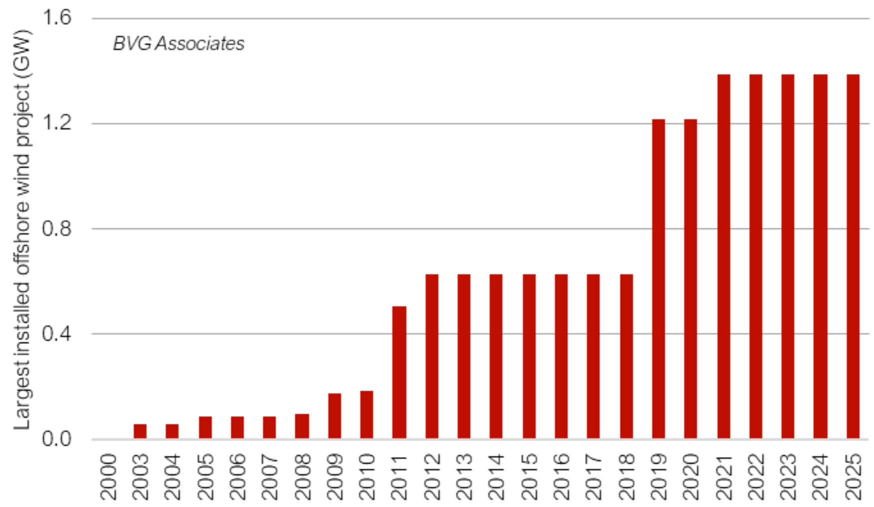


Figure 102 Largest offshore project installed to date.

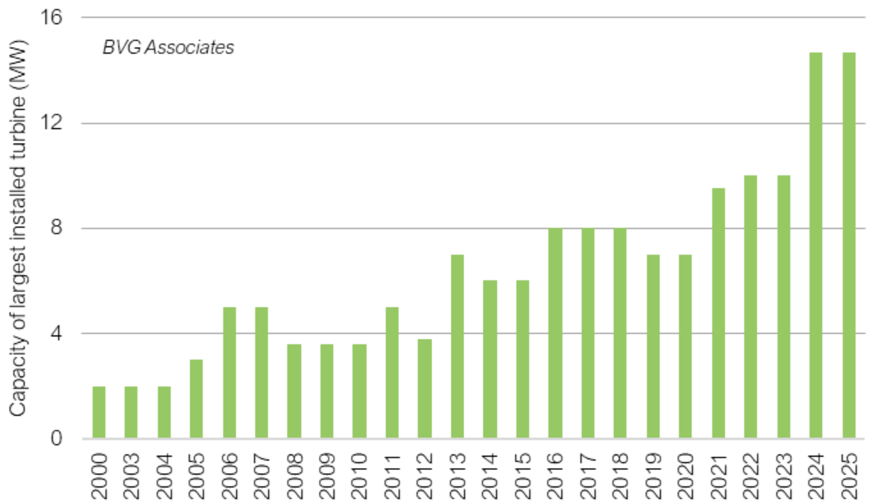


Figure 101 Largest turbine installed offshore to date.

Glossary

	Definition
Annual energy production (AEP)	The amount of energy generated in a year. Gross AEP is the predicted annual energy production based on the turbine power curve, excluding losses. Net AEP is the metered annual energy production at the offshore substation, so includes wind farm downtime, wake, electrical and other losses.
Array cable	Electrical cable that connects the turbines to each other and the offshore substation.
Availability	The percentage of time the assets are available to produce / transfer power if the wind speed is within the operational range of the turbine.
Balance of plant (BoP)	Includes all the components of the wind farm except the turbines, including transmission assets built as a direct result of the wind farm.
The Department for Energy Security and Net Zero (DESNZ)	DESNZ is the UK Government department responsible for facilitating the deployment of offshore wind and delivering the UK's wider energy and net zero policies.
Consent	Planning permission.
Cable protection system (CPS)	Cable protection systems protect the subsea cable against various external aggressions. Systems include bend restrictors and bend stiffeners where the cable may be subject to increased loading.
Capacity factor	Ratio of annual energy production to maximum energy production if the turbine / wind farm ran at rated power all year.
Capital expenditure (CAPEX)	Spend on all activities up until works completion date.
Contract for difference (CfD)	Contract where government agrees to pay the wind farm owner the difference between an agreed strike price and the average market price of electricity (reference price). If the difference is negative the wind farm owner pays the difference to the government.
Crew transfer vessel (CTV)	A vessel used to transport wind farm technicians and other personnel to the offshore wind farm turbines either from port or from a fixed or floating base. Vessels operating today are typically specially designed catamarans that accommodate around 12 passengers.

	Definition
Cross-linked polyethylene (XLPE)	A thermoset material widely used as electrical insulation in power cables.
Doubly-fed induction generator (DFIG)	An electrical arrangement where part of the wind turbine generator power passes via slip rings and convertors to enable a limited variable speed operating range whilst minimising the cost of power electronics.
Decommissioning expenditure (DECEX)	Spend on removal or making safe of offshore infrastructure at the end of its useful life, plus disposal of equipment.
Environmental impact assessment (EIA)	Assessment of the potential impact of the proposed development on the physical, biological and human environment during construction, operation and decommissioning.
Engineer, procure, construct and install (EPCI)	A common form of contracting for offshore construction. The contractor takes responsibility for a wide scope and delivers via own and subcontract resources.
Export cable	Electrical cable that connects the onshore and offshore substations, or between an AC offshore substation and a DC converter substation.
Front end engineering and design (FEED)	Front-end engineering and design (FEED) studies address areas of wind farm system design and develop the concept of the wind farm in advance of procurement, contracting and construction.
Final investment decision (FID)	The point at which a developer has in place all the consents, agreements and major contracts required to commence project construction (or these are near execution form) and there is a firm commitment from equity holders and debt funders to provide funding to cover the majority of construction costs.
Floating foundation	A buoyant foundation structure anchored to the sea bed via mooring lines. The term includes several foundation types including spar buoys, tension leg platforms and semi-submersibles.
Gas insulated switchgear (GIS)	Gas-insulated switchgear is often chosen for its compactness and increased reliability over than air insulated switchgear, but has higher cost.
Gigawatt (GW) and Gigawatt hour (GWh)	Unit of power and unit of energy.
Gravity base foundation	A type of foundation designed to be transported offshore as a (normally concrete) hollow structure that is later fixed to the sea bed with the addition of ballast.

	Definition
High voltage alternating current (HVAC)	An electric power transmission system that uses alternating current for the bulk transmission of electrical power. Alternating current is the form in which electric power is generated by wind turbines and delivered to an end user.
High voltage direct current (HVDC)	An electric power transmission system that uses direct current for the bulk transmission of electrical power. For long-distance transmission, HVDC systems may offer lifetime cost advantages over HVAC systems over long transmission distances. They are currently only used for point-to-point connections.
Highest astronomical tide (HAT)	The highest tidal height predicted to occur under average meteorological conditions and any combination of astronomical conditions.
Horizontal directional drilling (HDD)	Horizontal directional drilling is a low impact (trenchless) method of installing underground cables using a surface-launched drilling rig.
Jacket foundation	See Non-monopile steel foundation.
Levelised cost of energy (LCOE)	Levelised cost of energy is a commonly used measure of the cost of electricity production. It is defined as the revenue required (from whatever source) to earn a rate of return on investment equal to the WACC over the life of the wind farm. Tax and inflation are not modelled.
Mean high water springs (MHWS)	The average tidal height throughout the year of two successive high waters during those periods of 24 hours when the range of the tide is at its greatest.
Mean sea level (MSL)	The average tidal height over a long period of time.
Megawatt (MW) and Megawatt hour (MWh)	Unit of power and unit of energy.
Monopile foundation	A type of foundation with a cylindrical tube (normally steel) that is normally driven tens of metres into the sea bed, although it can also be inserted into pre-drilled holes.
Non-monopile steel foundation	Collective term used to describe all steel foundations other than monopiles. Includes braced, welded, space-frame structures (collectively called 'jackets'), tripods and tripiles.
Offshore substation (OSS)	The structure used to transform and transfer the energy collected by the wind turbines to land in the most efficient manner. It may involve increasing the voltage, providing reactive compensation and converting the current from AC to DC. Some wind farms may have more than one offshore substation and equipment may be located on a number of smaller structures and potentially on one or more turbine transition pieces.

	Definition
Offshore Transmission Owner (OFTO)	An OFTO, appointed in UK by Ofgem (Office of Gas and Electricity Markets), has ownership and responsibility for the transmission assets of an offshore wind farm.
Operational expenditure (OPEX)	Spend on all activities from works completion date until decommissioning.
Operations, maintenance and service (OMS)	OMS comprises wind farm OMS and onshore transmission OMS. Definitions of O, M and S are as follows: Operation: day-to-day management including all the work not covered under maintenance and service. For wind farm OMS, this includes cost for port facilities, buildings, management personnel, environmental monitoring and community engagement. Maintenance of assets: scheduled (that is, planned a long time in advance) maintenance, that may be based on suppliers' recommendations or owner's experience. It includes condition-based or time-based maintenance programmes and planned health and safety inspections. Typical maintenance includes inspection, checking of bolted joints and replacement of wear parts (with design life less than the design life of the project). Service of assets: unscheduled interventions in response to events or failures. Interventions may be proactive (before failure occurs, for example responding to inspections or condition monitoring (CM) or reactive (after failure that affects generation has occurred). Also included are interventions due to major components not lasting the full turbine design life, even if intervention was planned prior to construction. Service operations include both on site repair and replacement of large and small components.
Remotely operated vehicle (ROV)	ROVs are remotely guided subsea mobile devices. They are usually deployed from a vessel. ROVs can be used for inspections or to carry out handling and repair.
Service operation vessel (SOV)	A vessel that provides accommodation, workshops and equipment for the transfer of personnel to turbine during OMS. Vessels in service today are typically up to 85 m long with accommodation for about 60 people.
Significant wave height (Hs)	The wave height (trough to crest) of the highest third of the waves over a given period.

	Definition
Supervisory Control and Data Acquisition (SCADA) system	Data acquisition, transmission and storage system covering all wind farm assets. The SCADA system enable individual wind turbines, the wind farm substations and associated wind farm equipment to communicate operational status including faults. This allows operators to remotely diagnose faults and issue commands to stop, start and reset turbines and other equipment. The SCADA system keeps a full operating history of the wind farm.
Transition piece	A part of the foundation that provides the connection between the foundation and the wind turbine tower. For monopiles, it is usually installed after piling. For non-monopile steel or gravity base foundations, the transition is connected to the main structure before installation.
Turbine rated power	The nominal maximum power output from a wind turbine. Sometimes this is referred to as capacity. The wind turbine is limited to this power output, which typically applies when the wind speed at the hub height exceeds about 12 m/s and continues until about 25-30 m/s when the wind turbine stops generating to avoid excessive loading. In more benign operating conditions characterised by ambient temperature, main component temperatures, wind speed, turbulence level and grid voltage levels, the output may be allowed to exceed the rated power by about 5%.
Unexploded ordnance (UXO)	Explosive weapons that did not explode when they were released and remain a risk to sea bed users.
Weighted average cost of capital (WACC)	The weighted average rate of return a wind farm owner expects to compensate itself and its internal and external investors over the life of a project.
Wind shear	The degree to which wind speed changes with height.
Works completion date (WCD)	Date at which construction works are deemed to be complete and the wind farm is handed to the operations team. In reality, this may take place over a period of time.

More information

Organisations active in supporting fixed offshore wind

Several organisations provide useful resources to learn more about the floating offshore wind industry, including the following research organisations, trade associations and government departments:

UK

Offshore Renewable Energy Catapult (ORE Catapult)

The ORE Catapult is playing a leading role in stimulating innovation in offshore wind. It established the Floating Offshore Wind Centre of Excellence, a collaborative programme with industry and academic partners that aims to accelerate the development of floating offshore wind in the UK.

The ORE Catapult and the Floating Offshore Wind Centre of Excellence produce reports on floating offshore wind technology, supply chain and markets.

For more information visit https://ore.catapult.org.uk.

ORE Catapult, together with the Crown Estate, published a related document to this one called "A Guide to an Offshore Wind Farm" for fixed offshore projects. For more information visit https://guidetoanoffshorewindfarm.com/.

The Crown Estate

The Crown Estate manages the sea bed around England, Wales and Northern Ireland. It coordinates the offshore wind sea bed leasing rounds in these areas.

For more information visit www.thecrownestate.co.uk.

Crown Estate Scotland

Crown Estate Scotland manages the sea bed around Scotland. It coordinates the offshore wind sea bed leasing rounds in Scotland.

For more information visit www.crownestatescotland.com.

RenewableUK

RenewableUK is the leading trade association representing offshore wind energy companies in the UK. Among its wide-ranging activities is its work on helping the industry meet its requirements for a skilled workforce.

For more information visit www.renewableuk.com.

Scottish Renewables

Scottish Renewables is the trade association that represents the renewable energy industries in Scotland.

For more information visit www.scottishrenewables.com/.

Offshore Wind Growth Partnership

The Offshore Wind Growth Partnership is the UK's flagship supply chain growth funding and business support organisation dedicated to offshore wind.

Its mission is to accelerate development of the UK's offshore wind supply chain.

OWGP has been set up as an independent, not-for-profit organisation to support development of the offshore wind supply chain, helping to generate know-how, economic value, highly skilled jobs, and export income for UK businesses.

In December 2024, it was announced that OWGP is expanding its activities to take on the role of the Offshore Wind Industrial Growth Plan Delivery Body ("IGP Delivery Body").

The IGP Delivery Body's role and objectives are described in the Industrial Growth Plan (published in April 2024), available on the Offshore Wind Industry Council (OWIC) website.

For more information, visit: https://owgp.org.uk/

The Department for Energy Security and Net Zero (DESNZ)

DESNZ is the UK Government department responsible for facilitating the deployment of offshore wind and delivering the UK's wider energy and net zero policies. Further information is available at: www.gov.uk/government/organisations/department-for-energy-security-and-net-zero

Carbon Trust

The Carbon Trust is an organisation that advises businesses, governments and other organisations on sustainable technologies and issues. It runs the Floating Wind Joint Industry Project (Floating Wind JIP), a collaborative research and development initiative between leading offshore wind stakeholders to accelerate the development of floating offshore wind.

The Floating Wind JIP deliver projects and reports that aim to facilitate technology development and advance commercialisation of the floating offshore wind industry.

For more information visit www.carbontrust.com/our-projects/floating-wind-joint-industry-programme-jip.

Scottish Enterprise

Scottish Enterprise (SE) is Scotland's national economic development agency and provides a range of services to businesses, entrepreneurs, and organizations looking to grow, innovate, or invest in Scotland.

For more information visit: https://www.scottish-enterprise.com/

Highlands and Islands Enterprise

Highlands and Islands Enterprise (HIE) work with businesses, communities and social enterprises across the Highlands and Islands. HIE support businesses looking to locate into the region, and their support can include specialist advice across a range of key topics including innovation, R&D and improving productivity, as well as access to property, and funding.

South of Scotland Enterprise

South of Scotland Enterprise (SOSE) is the economic and community development agency for the South of Scotland. SOSE help businesses and enterprising communities throughout Dumfries and Galloway and the Scottish Borders to thrive, grow, and fulfil their best potential.

World Forum Offshore Wind (WFO)

The WFO is a collaborative organisation that represents the offshore wind industry. It consists of a range of different stakeholders.

For more information visit https://wfo-global.org/.

InnoEnergy

InnoEnergy provides reports on innovation and future cost reduction, including in offshore wind.

For more information visit https://www.innoenergy.com/

The UK's devolved administrations and a range of national and regional bodies are also active in stimulating the growth of the offshore wind industry.

G+

G+ is the global health and safety organisation for offshore wind. https://www.gplusoffshorewind.com/

BVG Associates

BVG Associates wrote the Guide to an offshore wind farm on behalf of the Offshore Renewable Energy Catapult and The Crown Estate. BVG Associates is an independent strategy consultancy in offshore wind, helping organisations, large and small, newcomers and highly experienced, to succeed in a rapidly growing, dynamic market.

For more information visit www.bvgassociates.com

International

International Renewable Energy Agency (IRENA)

An intergovernmental organisation that supports countries on renewable energy transition. It focuses on advising on renewable energy policy, technology innovation, investment frameworks, and capacity building. IRENA produces reports, scenarios, and roadmaps, such as the World Energy Transitions Outlook and specific technology outlooks (including offshore wind). It also facilitates international cooperation and hosts platforms like the Collaborative Framework on Offshore Renewables.

Global Wind Energy Council (GWEC)

An international trade association representing the global wind energy sector. GWEC works on advocacy, policy engagement, market intelligence, and industry partnerships, aiming to promote wind power development globally. It produces annual reports (like the Global Offshore Wind Report), and plays a key role in connecting industry players, governments, and finance communities, especially in emerging markets.

World Bank Group (via ESMAP Offshore Wind Program)

A multilateral development institution that supports offshore wind through the Energy Sector Management Assistance Program (ESMAP). The program provides early-stage technical assistance, regulatory and policy support, market assessments, and financial planning to help de-risk offshore wind investment in developing countries. It has delivered detailed roadmaps and strategic planning for countries such as Vietnam, Brazil, Romania, South Africa, Sri Lanka, Colombia, and the Philippines. It also works to mobilise private investment and supports capacity development.

International Energy Agency (IEA)

An intergovernmental organisation providing policy advice, data, and analysis on global energy systems. It conducts in-depth energy technology and policy reviews, including on offshore wind, and runs Technology Collaboration Programmes (TCPs) that bring together experts to share best practices and advance innovation. IEA publishes reports such as the Offshore Wind Outlook and tracks market trends, system integration challenges, and cost trajectories. It has also emphasised the role of offshore wind in achieving net-zero emissions goals.

Scottish Development International (SDI)

Scottish Development International promotes Scotland as a place for investment and trade by providing information, partnering with businesses and investors that want to set up or invest in Scotland, and helping businesses find the connections they need.

Further assistance and information

Information on the role of The Crown Estate is available at www.thecrownestate.co.uk.

The Offshore Renewable Energy Catapult is playing a leading role in stimulating innovation in offshore wind. ore.catapult.org.uk

RenewableUK is the leading trade association representing offshore wind energy companies. Among its wide-ranging activities is its work on helping the industry meet its requirements for a skilled workforce. www.renewableuk.com

The Department for Business, Energy and Industry Strategy is the leading UK Government Department facilitating the deployment of offshore wind. www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy

InnoEnergy provides reports on innovation and future cost reduction, including in offshore wind. http://www.innoenergy.com/news-list/tag/offshore-wind/

The UK's devolved administrations and a range of national and regional bodies are also active in stimulating the growth of the offshore wind industry.