EUROPEAN UNION

FACILITATING OFFSHORE WIND IN INDIA

SUPPLY CHAIN, PORT INFRASTRUCTURE AND LOGISTICS STUDY

for offshore wind farm development in Gujarat and Tamil Nadu

June 2016

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LIST OF ACRONYMS AND ABBREVIATIONS

Air gap	Distance between water level and top of vessel and safe clearance
AMSL	Above mean sea level
Beam	The maximum width of a vessel or other floating body
Bollard Pull	The force which a tug can exert upon its load when towing
CGS	Concrete gravity structure
CSI	Container security initiative
CTV	Crew transfer vessel
Draft	Depth of the keel of a vessel
GBF	Gravity based foundation
GBS	Gravity based structure
GRP	Glass reinforced polypropylene
H&S	Health and safety
HLV	Heavy lift vessel
HLCV	Heavy lift cargo vessel, often called a geared vessel as it has its own lift gear
HSE	Health, safety and environment
IAC	Inter-array cables
ISPS	IMO International ship and port facility security code
LAT	Lowest astronomical tide
LOA	Length overall, of a vessel
MPs	Monopiles
MSL	Mean sea level
NM	Nautical miles
O&M	Operation and maintenance
OWA	The offshore wind accelerator project, hosted by The Carbon Trust
OWF/OWP	Offshore wind farm (called offshore wind parks in Germany)
OSS/OSP	Offshore substation or offshore substation platform
PPE	Personal protection equipment
ROV	Remotely operated vehicles
Scour	Erosion of material adjacent to the structure due to water movement
SHLV	Sheerleg heavy lift vessel
SPMT	Self-propelled modular transportation
Spring tide	The highest tides of the lunar tidal cycle
Storm surge	Increase in mean sea level due to atmospheric pressure variations
T&I	Transport and installation
TEU	Twenty-foot equivalent units, a measure of container vessel size
TIB	Transport and installation Barge
WFSV	Wind farm support vessel

FOREWORD

On behalf of the project consortium, we are pleased to present the Supply chain, Port infrastructure and Logistics Study for the states of Gujarat and Tamil Nadu, which is an important outcome of the Facilitating Offshore Wind in India project's second year. The four-year project aims to put together a roadmap for developing a sustainable and commercially viable offshore wind industry in India.

This report first provides an overview of the key supply chain elements required for offshore wind and undertakes an initial review of the potential for Indian companies to enter the market. Following on from the supply chain assessment a port infrastructure and logistics assessment is provided, identifying key component specifications, vessel requirements, installation strategies and port infrastructure required from manufacturing to installation and through to the operation and maintenance of an offshore wind farm. The report culminates with an offshore wind port readiness assessment for Gujarat and Tamil Nadu and provides an insight into project decommissioning.

India, already a key global player in the field of installed onshore wind capacity, is under increasing pressure to meet its energy deficit – a growing concern due to a booming population – using indigenous and low carbon sources. While costs of offshore wind projects are still high, there are clear indications that they can be brought down substantially through experience and economies of scale. The rewards in India have the potential to be great: a strong, steady resource that can play a major role in supplying clean energy to the major load centres in coastal cities and industrial areas within Gujarat and Tamil Nadu.

With the recent approval of India's Offshore Wind Policy by the Union Cabinet in October 2015, the impetus and added incentive for offshore wind development remains very positive. This is indeed an exciting time to explore the future of offshore wind in India and we hope you find this Supply chain, Port infrastructure and Logistics assessment for Offshore Wind Farm Development in Gujarat and Tamil Nadu a useful resource.


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ABOUT FOWIND

The consortium led by the Global Wind Energy Council (GWEC) is implementing the Facilitating Offshore Wind in India (FOWIND) project. Other consortium partners include the Centre for Study of Science, Technology and Policy (CSTEP), DNV GL, the Gujarat Power Corporation Limited (GPCL), and the World Institute of Sustainable Energy (WISE). The National Institute of Wind Energy (NIWE), an autonomous R&D institution under the Indian Ministry of New and Renewable Energy, is a knowledge partner to the project since June 2015.

The project seeks to establish structural collaboration and knowledge sharing between the EU and India on offshore wind technology, policy and regulation and serve as a platform for promoting offshore wind research and development activities. The project focuses on the states of Gujarat and Tamil Nadu for identification of potential zones for development through preliminary resource and feasibility assessments for future offshore wind developments, as well as through techno-commercial analysis and preliminary resource assessment. The project consists of a total of seven work packages.

This Supply chain, Port infrastructure and Logistics study has been developed as part of Work Package 3. A separate study covering the grid infrastructure for Gujarat and Tamil Nadu is also being completed as part of Work Package 3. The aim of the Grid Infrastructure study is to evaluate the amount of grid integrated renewable energy sources that can be reliably incorporated into the grid in regional transmission and distributions networks, and consider the associated costs.

EXECUTIVE SUMMARY

This Supply Chain, Port Infrastructure and Logistics Study has been developed as part of FOWIND's Work Package 3. The overarching objective is to develop further understanding of typical ports, vessels, infrastructure and supply chain requirements for offshore wind project development. Specifically the report delivers:

- an overview of key supply chain elements required for offshore wind;
- a high-level appraisal regarding the feasibility of local supply for key components in the medium and long term;
- an overview of key infrastructure and logistical requirements for an offshore wind project during development, fabrication, transportation, installation, operations and maintenance and decommissioning;
- an appraisal of suitability and readiness of India's existing port infrastructure for offshore wind development.

The supply chain assessment identifies the extensive procurement list that would be required to develop a typical offshore wind farm. The specific supply chain requirements and considerations for major offshore wind project phases/packages (e.g. development, turbines, support structures, electrical elements, construction and O&M) are further defined. The remainder of the assessment focuses on identifying key global players and providing a commentary on current and potential Indian suppliers that might have capability to enter the local market. Given the relative immaturity of the Indian market and the supply chain the local assessment is conducted at high-level and would need to be re-visited when specific projects are identified.

The port infrastructure and logistics assessment commences with an initial preparation phase where; estimated Indian project specifications (from the FOWIND Pre-feasibility reports), component specifications, vessel requirements and possible installation strategies are defined. Following this initial preparation phase the port screening phase is executed, which provides a desk-based study, considering the suitability of offshore wind ports in Gujarat and Tamil Nadu to supply the potential offshore wind project demand for construction and O&M operations. The final stage provides a more detailed port readiness assessment which includes reports from site visits conducted at the most promising ports.

Key findings formulated during the course of this Supply Chain, Port Infrastructure and Logistics Study can be summarised as follows:

Supply chain assessment

There are a number of areas where there is good potential for Indian companies to move into the offshore wind sector, in particular, aspects of the development process, the fabrication of support structures and offshore substation topsides.

Due to the complexities of developing offshore wind and lessons from other emerging markets it is anticipated local companies will require some collaboration and capacity building with experienced organisations, particularly during the local market's embryonic development years.

If a large project pipeline, combined with attractive incentives, develops in India then the local supply chain will almost certainly grow in parallel and indeed attract both local and overseas OEMs to develop their business within the region.





Port infrastructure and logistics

The report provides extensive details and commentary regarding typical offshore wind component specifications, the range and suitability of construction vessels, different installation strategies and explanations for the suitability of common port infrastructure for offshore wind.

Following the port readiness assessments it can be concluded that no single port estate in India is currently suitable to facilitate all offshore wind construction activities without some level of adaptation or with the strategic use of multiple port estates.

Early consultations should be made, during the development process, with port authorities to establish any current and future conflicts of interest with regards to spatial planning and their appetite to facilitate offshore wind.

Gujarat – the most promising port estates appear to be Hazira (marshalling, manufacturing and O&M) and Pipavav (marshalling, OSS manufacturing and O&M).

Tamil Nadu – the most promising port estate in close proximity to the proposed development zones appears to be Tuticorin (marshalling and O&M). Kattupalli could have some potential for substructure and offshore substationto manufacture, but has significant access restrictions to the most favoured development zones.
Zones A to G[4] are effectively land-locked by the very shallow Palk Strait, and should Kattupalli or Chennai ports be mobilised, it would require any components to be circumnavigated large distances around the island of Sri Lanka.
In both Gujarat and Tamil Nadu it is also likely a number of smaller ports would be suitable for O&M support and could play a strategic role during the operation of specific projects.

[4] http://www.fowind.in/publications/report

1 INTRODUCTION TO THE FOWIND INFRASTRUCTURE STUDY

In February 2015, the Indian government announced its plans to almost quadruple its renewable power capacity to 175 GW by 2022 as part of the plan to supply electricity to every household in the country[1]. This includes 60 GW from wind energy. India already has a strong track record in onshore wind, with an installed capacity of 26743.61 MW or 26.74 GW according to the MNRE (world's fifth largest wind energy producer) at the end of March 2016[2].The sector has faced several challenges including national policy instability and state-specific issues linked to land acquisition and grid integration. However, both onshore and offshore wind energy are anticipated to play a vital future role in moving the country into a low carbon economy.

During 2013, the Ministry of New and Renewable Energy (MNRE) in India launched consultations on its policy for Offshore Wind under the previous government[3].
It is heartening to see that the new government in Delhi is even more committed to vastly increasing the exploitation of India's not inconsiderable renewable energy sources, and building a strong and increasingly equitable economy on the basis of clean, indigenous and increasingly competitive renewable energy sources.

The offshore policy and various guidelines on resource assessment, clearances, for setting up of offshore wind projects was approved by the Union Cabinet in October 2015. The objective of the policy is to promote development of offshore wind farms. The nodal ministry for overall monitoring of offshore wind development in the country will be the Ministry of New and Renewable Energy.

The FOWIND project consortium is working closely with the Ministry of New and Renewable Energy, the National Institute of Wind Energy, key centres and state based agencies to develop a roadmap for offshore wind development in India, with a focus on the states of Gujarat and Tamil Nadu. The on-going discussions on developing offshore wind in India are encouraging and the FOWIND project is providing technical support through its preliminary assessments and feasibility analysis while increasing stakeholder awareness and involvement.

The FOWIND consortium's Supply Chain, Port Infrastructure and Logistics Study for both Gujarat and Tamil Nadu, is a key deliverable from the project's second year and follows on from the FOWIND Pre-feasibility Study Reports issued in mid 2015[4].

This report aims to support key offshore wind stakeholders in India, including local developers, operators, government bodies, R&D institutions, fabricators, vessels owners, port operators and wind turbine OEMs. The overarching objective is to develop further understanding of typical ports, vessels, infrastructure and supply chain requirements for offshore wind projects. Specifically the core objectives of this report can be summarised as follows, to provide:

- an overview of key supply chain elements required for offshore wind;
- an appraisal regarding the feasibility of the local supply for key components in the medium and long term;
- an overview of key infrastructure and logistical requirements for an offshore wind project during development, fabrication, transportation, installation, operations and maintenance and decommissioning;
- an appraisal of suitability and readiness of India's existing port infrastructure for offshore wind development.

This study will form an important input into future offshore wind feasibility investigations. The study is based on a comprehensive review of existing literature available in the public domain, and on applied experience and knowledge gained in over 10 years of commercial European offshore wind projects.

Section 2 - ***The Supply Chain Assessment*** provides an overview of the key supply chain elements required for offshore wind farms and undertakes an initial review of the potential for Indian companies to enter the market.

Section 3 - ***The Port Infrastructure and Logistics Assessment*** details the port infrastructure and logistics required from manufacturing (i.e. wind turbine and foundation, etc) to installation and the subsequent operation and maintenance (O&M) phase of an offshore wind farm. A port screening and port readiness study is conducted for Gujarat and Tamil Nadu.

Section 4 - ***Decommissioning*** provides a high-level introduction to the processes and operations likely to be implemented when decommissioning an offshore wind farm at the end of its 20 to 25 year design life.

[1] http://www.makeinindia.com/sector/renewable-energy
[2] NMRE - http://mnre.gov.in/mission-and-vision-2/achievements/
[3] http://mnre.gov.in/file-manager/UserFiles/National-Offshore-Wind-Energy-Policy.pdf
[4] http://www.fowind.in/publications/report

2 SUPPLY CHAIN ASSESSMENT

The development of an offshore wind farm from design to fabrication to installation and through to operation is a complex puzzle with an extensive supply chain containing multiple interfaces (see Figure 1).

Interfaces can range from large primary interfaces such as the wind turbine to foundation connection, to interfaces as small as a fire detection device fitted within an offshore substation; requiring consideration of mounting points, connection into the station's low voltage system and HSE requirements.

In order to better illustrate the diversity and magnitude of a typical project's supply chain an offshore wind procurement list has been formulated to document some of the important ingredients required to realise an offshore wind farm from fabrication through to operation (see Table 1 and Table 2). This list is illustrative rather than comprehensive and aims to give the reader a background level understanding. The procurement list focuses on the physical materials and component requirements rather than specific specialist consultants, contractors or man-power that is required during all the key project development stages. Each item on this list comes with a whole host of complex interfacing, risk, health & safety and environmental considerations. Their implications and interactions must be carefully evaluated during project development.

The importance of procuring specialist contractors with their experience should not be underestimated (e.g. design-houses, fabrication contractors, transportation and installation contractors etc).

A skilled workforce will be required for design development, project management, fabrication, transportation, installation, commissioning, operations & maintenance and decommissioning.

In Europe, offshore wind projects have a Europe wide and indeed global supply chain. The procurement process is driven by various factors, but primarily cost (commercial factors) and quality (technical factors). Quality and hence risk reduction is particularly important with regards to the selection of suppliers with a solid and proven track record in offshore wind. This is seen across the European markets and now also in emerging markets such as China, where for example in a number of projects we are seeing developers reducing project risk profiles by selecting offshore wind turbines from the limited number of suppliers with proven track records rather than selecting less-proven local WTG OEMs. Local content is of course important in many markets but this can often be driven by political incentives and/or directives rather than a pure cost versus quality decision.

It is anticipated that the supply chain in India would develop in a similar fashion to other emerging Asia-Pacific markets (e.g. China, Taiwan, Japan and South Korea). During the early stages of development it is probable that skill and equipment gaps will exist within the supply chain and global procurement strategies will be required. As the local supply chain develops, gaps will gradually be closed by the emerging local suppliers. However, due to the diversity, complexity and specialisation in the offshore wind supply chain, in the medium and long term a global supply chain will likely still play a significant role for offshore wind in India.

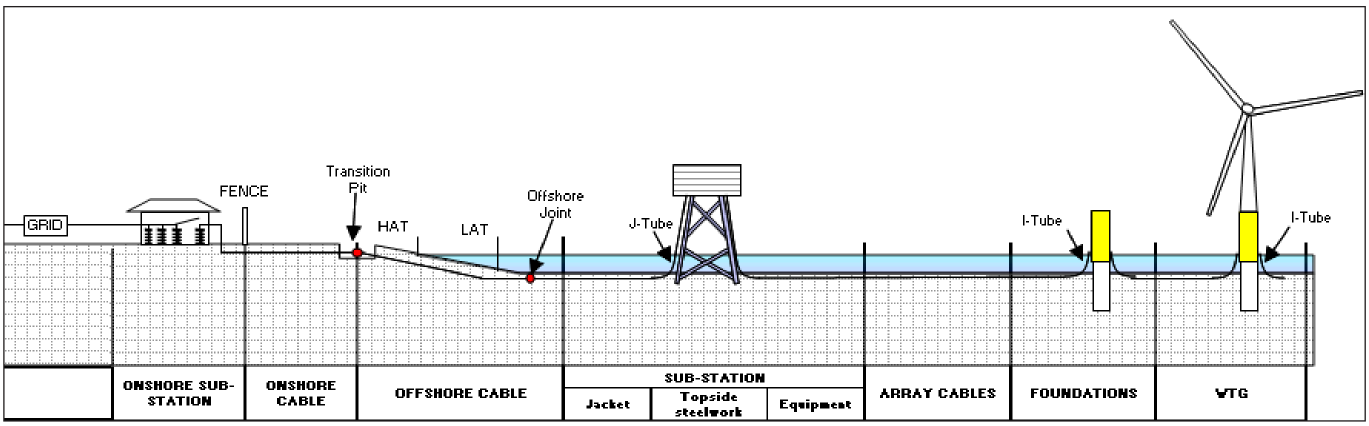


Figure 1 - Primary offshore wind interfaces

Offshore wind procurement list

Key materials, equipment and components*

WTG Supply	**Foundations** (WTG/OSS)	**Offshore substation topside** (electrical/structural/others)	**Offshore electrical network** (export/array cables & others)
■ Generator ■ Gearbox ■ Main shaft ■ Control system ■ Blade ■ Nacelle cover ■ Spinner ■ Personnel access ■ Drive train components ■ Tower ■ Davit cranes ■ SCADA system ■ Flanges ■ Coatings ■ Nacelle bedplate ■ Main bearing ■ Power take-off ■ Yaw system ■ Yaw bearing ■ Nacelle auxiliary systems ■ Small engineering components ■ Fasteners ■ Conditioning monitoring system ■ Structural composite materials ■ Lighting protection ■ Pitch system ■ Hydraulic system ■ Earthing system ■ Etc.	■ Steel of suitable grade (or concrete & reinforcement if GBS) ■ Interface flanges ■ Castings ■ Standard tubulars (jacket) ■ Bolts ■ Coatings ■ Grout ■ Grout seals ■ Grout lines ■ Fall arrest yo-yo ■ Navigation lights ■ Fog horn ■ Lighting ■ Signage ■ Transition piece ■ Vessel docking interface ■ Platforms (incl. GRP grating) ■ Handrails ■ Davit or similar light crane ■ Crew access system (ladders) ■ J-tube ■ Scour protection ■ Sacrificial anode ■ Temporary covers ■ Earthing system ■ Condition monitoring system ■ Shims (for levelling) ■ Scour protection material ■ Etc.	■ Transformers (if AC) ■ Converters (if HVDC) ■ Reactors ■ Switchgear ■ Crane ■ Backup generator ■ Plate girders ■ Universal beams ■ Cable laydown deck ■ Fire walls ■ Cooling system ■ Oil sump ■ Bunds ■ Helipad ■ Platform access ■ Hatches ■ Stairways ■ Water tanks ■ Accommodation ■ Control room ■ Cable supports ■ Earthing materials ■ Panels, cable trays, tracks, clamps and supports ■ Fire and blast protection systems ■ Low voltage supplies ■ Navigation aids ■ Fuel tanks ■ Safety system ■ Life raft ■ Etc.	■ Array cables ■ Export cables ■ Cables hangers ■ Cable protection systems - J-tube seals - Bend restrictors (e.g. Techmar) - Stiffeners - Cable mats ■ Pulling engines ■ Conductor ■ Insulator ■ Mechanical and chemical protection ■ Etc.

* This list is illustrative rather than comprehensive and aims to provide background level understanding. The procurement list focuses on the physical materials, equipment and component requirements rather than specific specialist companies, contractor or manpower.

Table 1 - Offshore wind procurement list (part 1)

Offshore wind procurement list Key materials, equipment and components*			
Onshore electrical and civil works	**Fabrication equipment**	**Transport and installation equipment**	**Operations and maintenance equipment**
■ Similar electrical systems to offshore substation ■ Buildings and other facilities are simplified compared with offshore ■ Metering equipment ■ Etc.	■ Welding equipment (manual & automated) ■ Welding consumables ■ Welding enclosures ■ Plate rolling (bending) machine ■ Cutting equipment ■ Milling machines ■ Drilling machines ■ Grinding equipment ■ Forging equipment (e.g. furnace/ hammer) ■ Casting equipment ■ Coating equipment ■ Blasting equipment ■ Mechanical handling systems ■ Gantry cranes ■ SPMTs ■ Ringer cranes ■ Temporary supports ■ Non-destructive testing (NDT) equipment ■ Surveying equipment (as built records) ■ Scaffolding ■ HSE equipment (e.g. PPE) ■ Etc.	■ WTIVs ■ Barges ■ Jack-ups vessels ■ Heavy lift vessels ■ Cable laying vessels ■ Seabed cable plough ■ Cable jetting tool ■ Rock cutting/trenching tool ■ Pile hammers ■ Pile guides and followers ■ Pile lifting frames (hydraulic) ■ Seabed piling template (tripods/ jackets) ■ Grout mixing systems ■ Grouting lines/connections ■ Grout testing equipment ■ Sea lashings/temp supports ■ Pile plugs (buoyant MPs) ■ Lifting slings and spreader bars ■ Specialist handling toolds (e.g. WTG blades) ■ Access systems ■ Drilling rings ■ Pile cleaners ■ Cable lifting frames ■ ROV (inspections) ■ Surveying equipment ■ HSE equipment (e.g. PPE) ■ Etc.	■ Crew transfer vessels ■ Helicopters (if considered) ■ Jack-up vessel (major repairs) ■ Onshore control room ■ SCADA system ■ Condition monitoring system ■ Spare parts (key spares stored at O&M base\0 ■ Inspection equipment ■ ROV (inspections) ■ Marine growth removal equipment ■ Cable repair equipment ■ Access equipment ■ HSE equipment e.g. PPE) ■ Other equipment used during installation may be required for specific unscheduled major O&M activities e.g. WTG serial defect replacements, scour material replenishment ■ Etc.
* This list is illustrative rather than comprehensive and aims to provide background level understanding. The procurement list focuses on the physical materials, equipment and component requirements rather than specific specialist companies, contractor or manpower.			

Table 2 - Offshore wind procurement list (part 2)

The remainder of section 2 provides an overview of the various aspects of the supply chain that are required to construct and operate an offshore wind farm. Given the relative lack of maturity of the Indian offshore wind market and the supply chain, most of the focus is on global suppliers, but commentary on current and potential Indian suppliers is provided where appropriate.

The section is structured to follow the main work packages involved with offshore wind, namely:

- development
- wind turbines
- support structure/foundations
- electrical elements
- installation and commissioning
- operations and maintenance

2.1 Development

Once a site has been allocated and the developer has a lease, the developer will undertake all the early stage activities needed to see the project successfully developed to construction and operation.

There are a large number of tasks which are required (see figure 3) but broadly they can be summarised into four main areas:

1. Understanding the site through site surveys and desk based research (including wind resource, wave and current assessments; and birds, marine mammals, fish, benthos, coastal, geotechnical & geophysical surveys
2. Consenting and planning work (including undertaking the Environmental Impact Assessment, engaging with stakeholders and applying for planning permission)
3. Design and engineering work (including initial feasibility studies, concept and detailed design)
4. Commercial and legal work (developing the business case, obtaining land agreements, obtaining financing, grid connection agreements, etc.)

Each of these elements is discussed further.
The developer will typically manage this process, contracting a large number of external consultants. Supply chain capacity in this element is mainly focused around people, with a wide range of skill sets required.

2.1.1 Site surveys

Site surveys are required to help the developer understand and characterise the site, in turn allowing the optimum wind farm design. Surveys will need to be completed across the entirety of the offshore site, cable route and onshore site. Both onshore and offshore contractors are therefore used.

Personnel, in the form of trained surveyors, engineers, ornithologists, geophysicists, etc. are crucial at this stage.

Capital equipment is also required, mainly in vessels undertaking the various surveys. Different surveys have different requirements. Some light aircraft have even been used in the UK, utilising high definition cameras to rapidly scan large areas of seabed for marine mammals or birds.

Publically funded institutions could offer some support in the early scoping phase e.g. the National Institute of Oceanography (NIO), National Institute of Ocean Technology (NIOT) and labs of the Council of Scientific and Industrial Research.

Leading marine surveyors include: Fugro, Intertek and Gardline (many of whom are already active in India).

Those organisations currently undertaking marine surveys in India or have vessels that could be converted should be well placed to obtain work in the sector. There is an emerging body of guidance for vessels in the UK and EU markets that could be reviewed to better understand specific requirements.

2.1.1.1 Wind resource assessment

Wind is the fuel for wind farms and so a crucial element of the development and design process is undertaking a robust assessment of the wind resource. This is typically achieved through the erection of a meteorological mast (met mast) at the site, but other remote sensing techniques (such as LiDAR) can also be used. These devices seek to measure wind at proposed turbine hub heights (for example 100 m above sea level) and can therefore be quite large structures comprising a foundation, platform, steel lattice met mast, access facilities as well as the measuring sensors. Meteorological sensors track wind speed (with instruments at a number of heights or via LiDAR, measuring over a range of heights with one sensor), wind direction, temperature, pressure, humidity, solar radiation and visibility. A full met mast EPCI contract in European deeper water typically costs around 11 to 14 million EUROS.

Figure 2 - Offshore met mast installation, UK

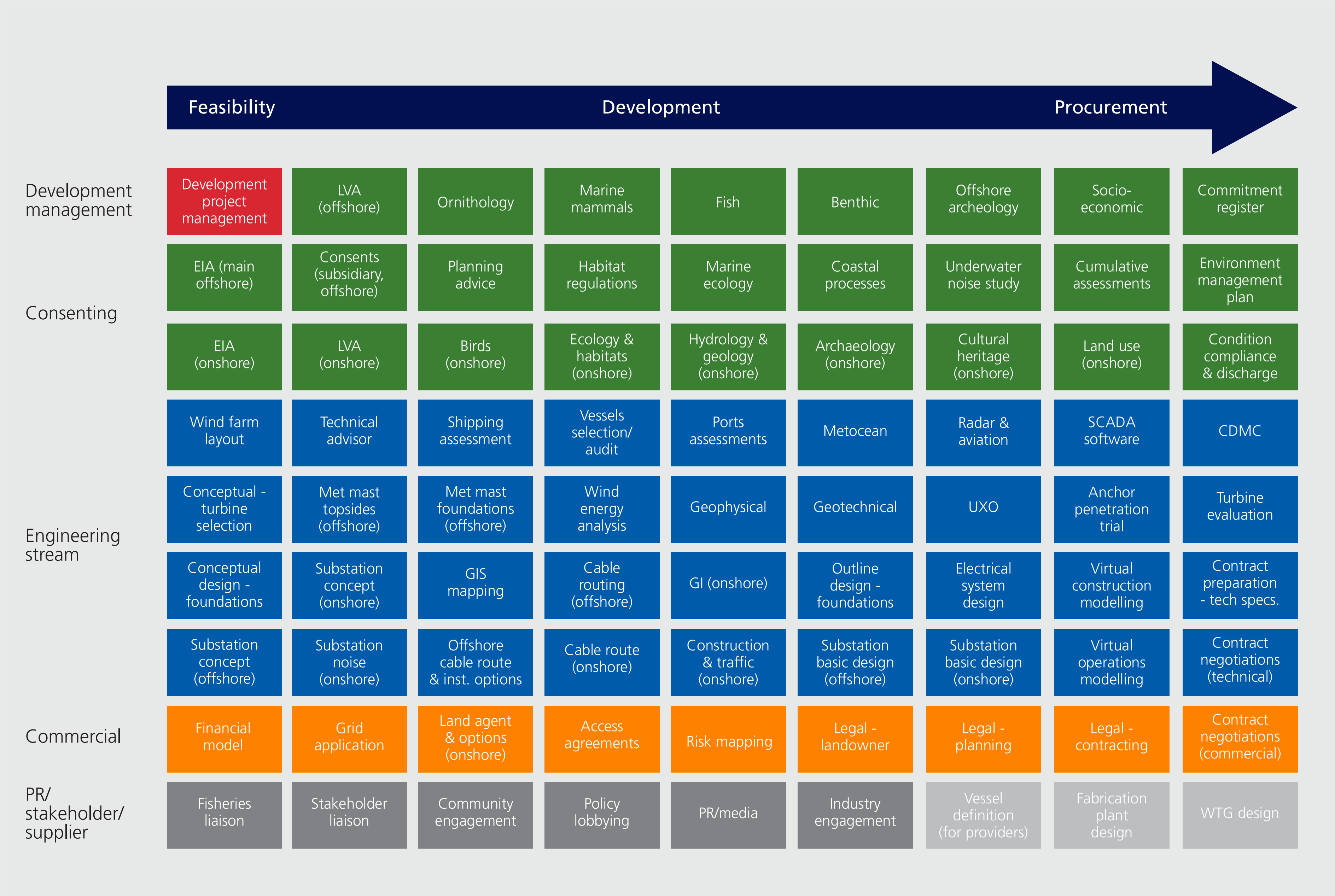


Figure 3 - Development activities

Some of the key players in the EU include:

- Foundation and Platform: BiFab, Bladt, MT Højgaard and SIF-Smulder
- Masts: Carl C and Francis & Lewis
- Meteorological sensors: FT Technologies, NRG Systems, Thies and Vector Instruments
- Metocean sensors: Nortek, Planet Ocean

Key existing onshore met mast suppliers in India may be positioned to enter offshore sector, based on a preliminary market assessment, some of these include:

- Shah Infra Tower, Aditya Enterprises and RK Windmast

Fabrication of the met mast support structure could be a useful way for Indian fabricators to gain an early foothold in the market. Existing Indian suppliers of meteorological sensors for the onshore wind industry will also be well positioned to move into the offshore sector.

In Europe, some early projects directly deployed onshore met masts offshore, but with limited consideration of the additional dynamic loading from waves which then resulted in additional fatigue loading causing early failure or structural concerns for some of these masts (especially when masts are deployed on slender and flexible monopile foundations).

2.1.1.2 Oceanographic surveys

A detailed oceanographic model of the wind farm site will be required to inform various design, construction and operational aspects of the project. These validated models are used to predict for example wave and current parameters across the site. Models are validated against existing data points and also data gathered from on-site oceanographic surveys.

Oceanographic surveys shall typically include measurement of the intensity of current, tidal variations, wave pattern and heights of waves. Normally it can be carried out by ADCP (Acoustic Current Doppler Profiler) which can be seabed mounted (see Figure 4, left) or ship bottom mounted. Seabed mounted systems are always preferred over the ship bottom mounted; however there is a risk of theft or sand wave movement. Periodic acquisition of data shall reduce the risk. Wave buoys (see figure 4, right) are also used and measure sea surface displacements from inferred motions of the buoy. Various fixed instruments can also be attached to offshore platforms (e.g. vertically oriented radar and laser altimeters).

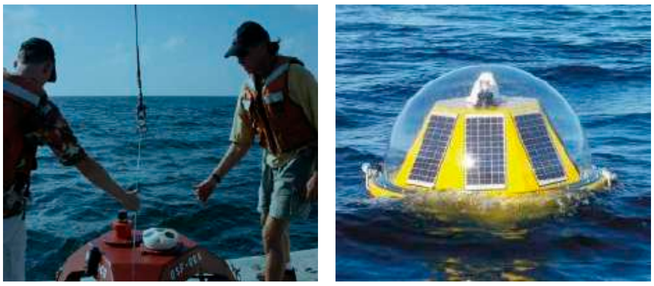


Figure 4 - ADCP (left) and wave buoy (right)

The duration of survey campaign depends on the accuracy of data desired. Minimum measurement period of one month is recommended for currents/water levels in order to cover a complete lunar cycle and its effect.

For waves a minimum of 6-12 months onsite measurement would be required. ADCPs can be deployed at a specific location by lowering it from a survey vessel and then anchoring using heavy weights. In many cases sea divers are used to accurately place the ADCP on position. The fleet of engineers/technicians includes but is not limited to oceanographer, skipper/crew and sea divers.

Some of the key players in India based on a preliminary market assessment include:
National Institute of Oceanography (NIO), Geological Survey of India (GSI), Ocean Science & Surveying (formally known as Egs Survey), Fugro Survey (India), Indomer, CGG, and Petroleum Geo-Services.

2.1.1.3 Geophysical and geotechnical surveys

Geophysical surveys for offshore wind farm development will typically include but not limited to bathymetry surveys in order to capture the water depth variations within a specified area, side-scan sonar survey to map the seabed profile, sub-bottom profile survey (see Figure 5, top) in order to understand stratigraphy of soil below seabed up to a limited depth, magnetometer survey to locate any existing buried metallic substances. Also, grab sampling is recommended to have a better geological understanding of seabed soil. Grab samples can be subjected to visual geological inspection, soil particle and classification analysis.

Normally specialist survey vessels are available or other vessel types can be converted for this operation by carefully retro-fitting surveying equipment. The selection of vessels based on the anticipated sea condition is the prime factor in order to have vessel stability within the desired range. Survey equipment must capture the data with minimal disturbances.

The fleet of engineers/technicians shall include but not limited to oceanographer, marine geologist, electronics & communication engineer, hydrographic surveyor, and geophysicist. High-end equipment like a multi-beam echo sounder for bathymetry, dual frequency side scan solar, sub bottom profilers (such as boomer/sparker) are available in prevailing markets. The capacity and accuracy of survey equipment shall be carefully selected based on the extent of data required.

Some of the key players based on a preliminary market assessment in India include: Ocean Science & Surveying (formally known as Egs Survey), Fugro Survey (India), Indomer and Petroleum Geo-Services.

Geotechnical investigation ideally shall follow the geophysical survey. It includes drilling of boreholes at pre-defined coordinates, collecting in-situ disturbed and undisturbed soil samples, in-situ tests like cone penetrometer test (CPT), standard penetration test (SPT), dynamic cone penetration test (DCPT), seismic resonance and etc. For more representative in-situ test data CPTs are favoured over others such as SPT and DCPT (see Figure 5, bottom).

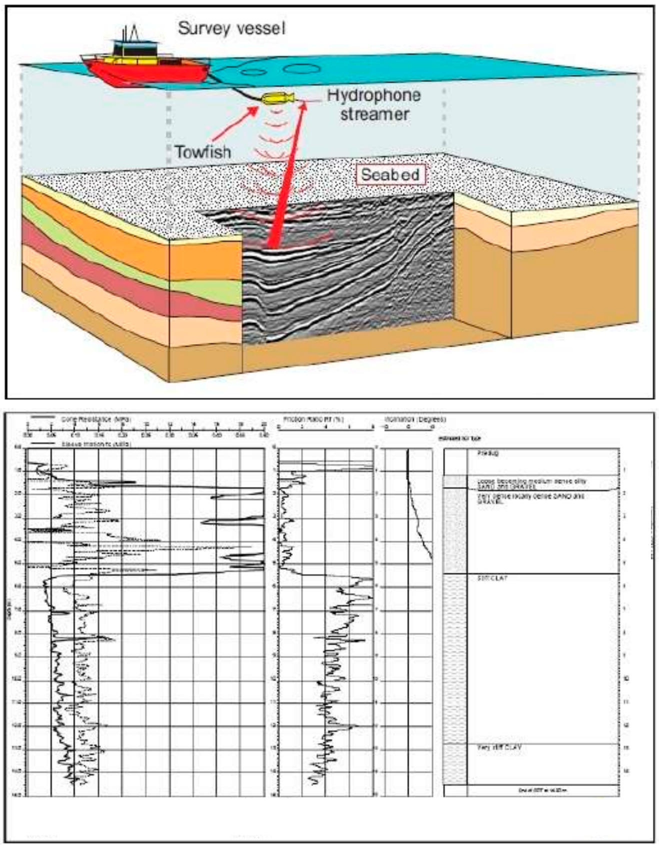


Figure 5 - Sub-bottom profiler (top) and CPT data (bottom)

Geophysical surveys help to define the extent and location of geotechnical investigation. The depth of borehole may vary from 30 to 80 m depending on foundation design requirements. A range of laboratory tests are then performed on collected soil samples to establish the engineering properties of the soil/rock.

Jack-up vessels are available which can be mounted with drilling rigs and other in-situ test equipment in order to perform the desired investigation program. Jack-ups can be towed to location via tugboats and fixed on defined co-ordinates using their in-built hydraulic legs.
The minimum length of legs and spud-can bearing capability in the seabed shall be carefully studied in order to have safe and efficient operations. Towing of jack-ups in a rough sea condition is not recommended. Many companies have also successfully operated drilling ships mounted with high efficiency dampers for geotechnical drilling. The fleet of engineers/technicians shall include but not limited to geotechnical engineer, geologist, Jack-up operator, towing expert and skipper/crew.

Some of the key players based on a preliminary market assessment in India could include: Fugro Geotech (India), DBM Geotechnics & Construction, Comacoe, and Oceanking Survey Services.

2.1.2 Consent and planning

A crucial element in the development stage is obtaining planning consent or approval for the project.
Each country will have their own unique planning process, although all require an environmental impact assessment. This will cover both human and natural receptors, and therefore requires engagement with a huge range of stakeholders.

Relatively little capital equipment is required for this stage compared with the construction phase (over and above the requirements for site surveys). Instead, specific expertise in undertaking environmental assessments, engaging and reaching agreement with stakeholders and understanding the planning process will be required. Offshore wind experience is important, particularly for assessing environmental impacts, as the risk profile is different from an oil and gas platform (except oil in offshore substation transformers and a limited amount of gearbox oil) and greater focus is required on elements such as bird flight paths and aviation radar. Large multinationals with offshore wind experience in the EU will be well positioned. Other environmental and planning consultancies could also enter the market, particularly those already active in large infrastructure projects (particularly in the marine environment).

Some of the leading environmental consultancies in the EU include: ERM, Natural Power, NIRAS and Royal Haskoning.

Some of the key players based on a preliminary market assessment in India could include: AECOM, Chilworth Technology, ERM, Engineers India Limited and Royal Haskoning.

2.1.3 Design and engineering

In addition to the environmental elements, there is a huge amount of engineering and design work that is required to install such large structures in the hostile marine environment. Offshore wind experience here is vital, although could at a stretch be transferred over time from onshore wind or offshore oil and gas. The blue sections in Figure 3 show the various engineering elements that need to be completed.

Some of the leading engineering consultancies in the EU include: Atkins, COWI, DNV GL, LIC Energy, OWEC, Ramboll, and Sgurr . It should also be noted that a number of these have local offices in India.

Some of the key players in India include companies with existing wind and large infrastructure engineering experience such as; Aker Solution, Arup, Engineers India Limited, L&T Construction and Saipem India Projects. Lessons learnt from other emerging markets such as China have shown that there is steep and challenging learning curve at the beginning of the offshore wind industry. A number of leading local engineering consultancies have subsequently teamed-up or formed joint ventures with leading and experienced European engineering consultancies.

2.1.3.1 General Consultant and Owner's Engineer

It is unlikely that owners/developers will have sufficient internal human resources to conduct all of the vast number of the project management and technical/ commercial development tasks (see Figure 3). In this situation it is common for a developer to contract an experienced General Consultant and/or Owner's Engineer.

In Europe only developers with a large project portfolio (e.g. Dong Energy) have developed extensive internal project development teams – smaller developers and those in emerging markets will tend to augment project teams with external consultants.

In general the purpose of an external consultant would be to:

- Provide experienced advice to the owner/developer
- Help reduce the project risk profile
- Help optimise the project for cost of energy

General Consultants or Owner's Engineer can assist with the following:

- Delivery of Engineering, Environmental and Commercial tasks
- Supporting the Project Management Office
- 3rd party independent reviews

2.1.3.2 Third party review and certification

In some markets (such as Germany) project certification is mandatory, while other developers may choose to obtain project certification to help minimise risk. This is where an independent third party reviews the approach taken by the developer against a predefined standard. This then gives comfort to the regulatory authorities and/or investors that the project is fit for purpose. It is not yet clear whether the Indian market will mandate project certification.

In addition, turbine manufacturers typically need to obtain type certification. This is to reduce the technology risk of the project and give confidence to developers and investors.

2.1.4 Commercial and legal work

There is a significant amount of legal and commercial work required to reach investment decisions involving millions and potentially billions of Indian rupees. Typically the developer would manage the business case in house but may employ external advisors to support. Legal firms support all elements of the process.

2.2 Wind turbines

Historically, offshore wind turbines have been versions of onshore turbines adapted for the marine environment, yet over the past ten years offshore specific designs have emerged. The principle difference is that they are much larger, but also have a greater focus on reliability and durability in a hostile environment (given the challenges of getting to site in case of downtime).

There are a much smaller number of Wind Turbine Original Equipment Manufacturers (OEMs) in offshore wind compared with onshore wind. There are five major EU OEMs; the leading player is Siemens, followed by MHI Vestas, Senvion (formerly of Suzlon), ALSTOM and Areva Gamesa. In addition there are a number of Chinese players (including Goldwind, Ming Yang, XEMC, Sinovel and others) and Japanese manufacturers (Hitachi). In India, Suzlon has rights to license and build the Senvion 6.XM series machine[5].

Table 3 shows the latest offering to the market for a selection of leading manufacturers. Beyond this, plans are developing for 10 MW turbines by the end of the decade.

Wind turbine OEMs design the wind turbine but are then effectively 'assemblers' bringing together parts from a range of sub-suppliers.

The main elements of the supply chain are:

- Turbine assembly
- Blades
- Castings and forgings
- Drive train (gearboxes and generators)
- Towers

Each element has further sub-components not covered in this report.

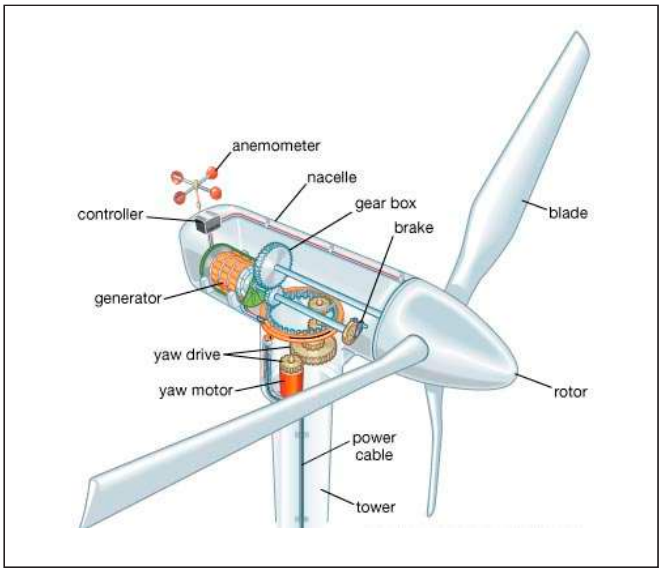


Figure 6 - Fundamental WTG components

2.2.1 Turbine assembly

Before transport to site for installation, the major components of the wind turbine generators (WTG) must be finished and assembled into the final product at specialist coastal facilities by the OEM.
These are hugely important sites, both in terms of investment (~1000 Crores Indian Rupees) but also through the development of supply chain hubs in the nearby area. Investment on this scale is primarily driven by market size and a strong order book and would therefore be linked to the expected market demand in India.

[5] http://www.windpowermonthly.com/article/1331506/analysis-divorce-suzion-senvion

Manufacturer	Current offering to market (end of 2015)
Siemens	6 MW (commercially installed), 7 MW commercial contract signed
MHI Vestas	8 MW (commercial contract signed)
ALSTOM (GE)	6 MW (demo site under construction)
Senvion	6.16 MW (commercial installation underway)
Adwen	5 MW (commercial deployment)
Ming Yang	6.5 MW 2-bladed downwind (one prototype contracted in EU)
Hitachi	5 MW downwind - prototype installed

Table 3 - Offshore wind turbine models currently in the market

Entry into the offshore market is extremely challenging, requiring huge financial and technical resources. A track record is vital, yet very expensive and time consuming to obtain. Major players including Samsung and GE have all initially entered but then exited the market due to these challenges. Any existing Indian OEMs supplying the onshore market must be aware of these challenges, and will need to be supported almost entirely by the domestic Indian market. The hurdle of offshore track record (risk) is an important factor but could be partially mitigated by local content requirements, cost advantages and O&M advantages from local OEM suppliers. Similar to the Chinese market, it is likely that many of the early projects will use both European and local OEMs.

2.2.2 Blades

The function of the blade is to convert the energy in the airstream into rotational torque on the main shaft, which drives the generator. 2 to 5 MW class turbines have blades around 50 to 60 m in length while new 6 MW+ turbine models demand blades in the 70 m+ range. The largest blade deployed to date is 83.5 m for the Samsung 7 MW turbine. The sheer scale of these blades means very high technical design and manufacturing capability is required. Increasing blade length results in increased loads on the WTG, bearings, tower and foundations. This demands advances in materials technology to keep blade mass down together with a robust WTG and foundation design to allow for family turbines, which share key components, but are focused on different IEC class sites. This reduces design costs somewhat and reduces the certification effort, increasing speed to market and competiveness. Due to the high cost of transportation and factory costs modular blade design (in both chord and length wise) may emerge, which allows them to be shipped in containers and assembled on site.

Most rotor blades are made from glass fibre reinforced plastics (FRP), i.e. glass fibre reinforced polyester or epoxy. However carbon fibres have recently began augmenting the glass fibres for their comparatively light weight, higher rigidity and superior strength properties. Apart from being expensive, carbon fibres are difficult to work with and they conduct electricity, which makes blades potentially more vulnerable to lightning strikes. A number of manufacturers use carbon fibres for the supporting laminates of their offshore blades (large size) to keep the mass within a limit. Using extruded carbon in blades is quicker and has a higher degree of control in the manufacturing process than infusion. Epoxy resins have higher material performance properties than the polyester resins, but epoxy resins are comparatively expensive. LM Wind Power uses polyester resins in almost all its blades to keep the costs down whereas Vestas and Suzlon prefer epoxy over polyester for better material quality.

Major OEMs with in-house capability include Siemens, MHI Vestas and Senvion. ALSTOM has a partnership with LM Blades while Euros and SSP have also supplied blades to the sector.

Suzlon began its first blade manufacturing facility at Daman (UT), India in 2002. They have since added four more blade manufacturing facilities in Pondicherry (UT), Dhule (Maharashtra), Bhuj (Gujarat) and Padubidri Udupi (Karnataka). It is understood that should the offshore wind market develop with a sufficient pipeline Suzlon could consider development of a purpose built offshore wind turbine manufacturing facility within a suitable port estate.

LM Wind Power (established in 1940 in Denmark) has rotor blade facilities located in Taluka-Halol, Vadodra (Gujarat) and Dabaspet (Karnataka).

Other Indian OEMs also have in-house rotor blade manufacturing facilities, e.g. Suzlon and Inox.


Source: Business green

Figure 7 - 8 MW Offshore WTG blade

2.2.3 Casting and forgings

Offshore wind turbine manufacture requires heavy duty metal work for several components. Castings are needed for items such as the rotor hub, nacelle bedplate, bearing housing and gearbox housing and steel forgings are needed for bearings, shafts, gear wheels and flanges. The size of the steel castings needed by very large offshore wind turbines (in excess of 20 tonnes) limits the number of foundries in the EU and the demands of very large offshore wind turbines (large items and reasonably high volume) sets it apart from other sources of business.

Castings and forgings have been supplied to offshore wind by suppliers such as Brück, Euskal, Felguera Melt, Fonderia Vigevanese, Metso, Siempelkamp, Torgelow and VTC.

Based on a preliminary market assessment in India forges such as Bharat Forge, L&T Special Steel, Kalyani Forge, SE Forge and Heavy Forgings may be able to move into the sector.

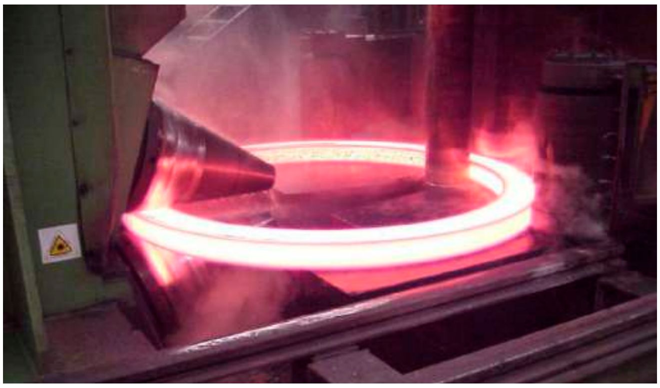


Figure 8 - Forging a WTG ring flange

2.2.4 Gearbox and generators

The major components in the drive train of offshore wind turbines are the generator unit and (for non-direct drive models) the gearbox. Larger turbines and the demands of maintenance at sea mean that there is a general diversification from the 3-speed gearbox drive trains that have dominated the wind industry (on- and offshore) to date and a range of increasingly product-specific solutions such as mid-speed, direct drive or even hydraulic power transmission emerge.
Some of the key suppliers of gearboxes are Bosch Rexroth, ZF Wind, and Winergy. Leading manufacturers of converters include ABB.

2.2.5 Towers

Towers are rolled, tapered steel tubes, which are flanged and bolted together in sections. Towers are the same for on- and offshore wind – albeit on a larger scale offshore. As turbines get bigger, the tower will also need to increase in size and number of sections.
Most technical development is likely to occur in the area of structural load optimisation through an integrated design approach for turbine, tower and foundation. A good example of such a project is a recent offshore wind integrated design study focused on cost reduction, called FORCE[6].
Major EU tower suppliers include Ambau, Welcon and CS Wind. Existing manufacturers of towers in the Indian sector may be able to scale up to deliver into the offshore market (including Windar and DN Wind).

[6] FORCE - https://www.dnvgl.com/energy/feature-articles/project-force.html

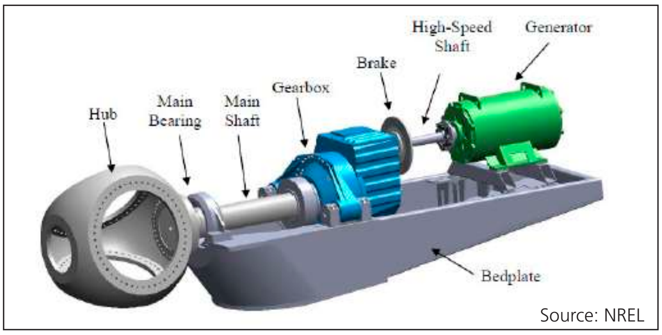


Figure 9 - WTG modular drivetrain configuration

2.3 Support structure/foundations

The wind turbine is supported by a foundation that is typically fixed to the seabed, although some floating designs are starting to emerge.

Monopile foundations have dominated the market to date, but a range of other concepts exists. These include jackets, tripods, gravity based concrete solutions (GBS) and suction bucket foundations. A wide range of site-specific factors including depth of water, ground conditions, turbine size and wave loading dictates the choice of foundation. The capability of the local fabrication and installation supply chain will also impact foundation choice and the design process. In addition to the primary structure, the foundation design includes secondary and tertiary elements such as; crew access systems, cable protection systems (e.g. I or J-tubes), davit cranes, grouted connection systems (e.g. high-strength grout, grout lines, grout seals) and corrosion protection systems (coatings and cathodic protection). I or J-tubes are steel tubes that allow the installation of cables by providing a conduit through which the cables can be pulled. Scour protection is often required at the foundation/seabed interface, particularly in areas of high current flows.

Broadly speaking monopiles are the simplest (and to date cheapest) technology, yet begin to struggle with water depth above 40 m, particularly for the largest wind turbines (6 to 8 MW). Ground conditions can also preclude the use of monopiles (e.g. where rock head exists at depth or large boulders are present in the soil profile). Jackets are used for deeper sites with larger turbines, given their versatility and inherent strength. GBSs have been used in the Baltic where ground conditions make piling difficult but have struggled to break into the North Sea market. Suction bucket jackets potentially offer a quicker, quieter means of installation (than piling) but are only suitable in certain ground conditions and have yet to be used on a commercial scale project.

Figure 10 - WTG Tower fabrication

Regarding the key supply chain risks for steel foundations the following should be carefully considered:

- **Steel grade**
  Offshore wind structures are subjected to high levels of dynamic loading and subsequent fatigue damage. Wall thicknesses can be large (e.g. >100mm in large monopiles) and design temperatures are low. To resist this fatigue loading and prevent brittle fracture special high-grade tough offshore steels are required. These are only available from a limited number of suppliers (e.g. Dillinger, Tata, JFE and Nippon). Furthermore the thickness of the material for jacket nodes must be tested and typically even higher grades are required for similar thicknesses in other structural parts (e.g. legs and brace members).

- **Welding qualifications and automation**
  All welds within an offshore wind structure must be completed to specific Welding Procedure Specifications (WPS) and these procedures must be qualified with suitable Procedure Qualification Records (PQRs). Fabricators have a significant advantage if they already hold suitable weld PQRs. The ability for a fabricator to produce double sided full penetration welds would also be advantageous due to the significant fatigue benefits. All welders must be suitably qualified.

- **Coating supply**
  The marine environment contains all the components required to corrode carbon steel (water, oxygen and dissolved Chlorides). The severe corrosion takes place in the splash zone where the structure is constantly exposed to air and water. Corrosion is mitigated through a combination of: 1. Sacrificial thickness, 2. Cathodic protection (anodes), 3. Coating systems.

  Offshore paint coatings are highly specialised and are typically Epoxy based (sometimes glass-flake reinforced to extend the lifetime). Suitable coating systems are only available from a limited number of suppliers with extensive track record, e.g. Jotun, International and Hempel.

- **Flange supply**
  Similar to the wind turbine the foundation to WTG interface flange is a specialist item that must be manufactured to precise tolerances. See Section 2.2.1.

- **Cast nodes**
  Jacket structures that are heavily loaded may push the design limits of fabricated nodes (X and K joints). Cast joints enable a superior fatigue detail classification due to the smoother construction and subsequent reduced stress concentrations. If cast nodes are required this will add significant cost and specialist suppliers would need to be identified. See Section 2.2.1.

- **Anode supply**
  Anodes or cathodic protection is an effective method of protecting steel in the zones where it is permanently submerged. It is widely used in the maritime and oil and gas industries. Hence multiple suppliers exist.

- **Grout material**
  Grouted connections are commonly used in both monopiles and jackets to connect structures underwater (e.g. monopile/transition piece and jacket/pin pile). For monopiles specialist high-strength grouts are used. For jackets different projects have used both high-strength and lower strength Ordinary Portland Cement (OPC) grouts. High-strength grouts

typically result in a shorter connection and are often required for heavily loaded connections. The specialist nature of high-strength grouts limits suitable suppliers e.g. Found Ocean and Densit.

- **Grout seals**
  These contain the grout at the base connection and their integrity is a high risk during installation. As seen on a number of early projects, failure of gout seals can severely cost projects financially, due to vastly expensive vessels waiting on-site while remedial repairs are completed. There are two main types: 1. Passive seals – thick rubber wiper seals held in place by the pressure head of grout, 2. Active seals – inflatable bags that once activated underwater fill the annulus. Due to the high risk nature, grout seal design and supply is typically left to a hand-full of specialist companies e.g. Crux and Trelleborg.

- **Fabrication tolerances and dimensional limitations**
  Offshore wind foundations need to be fabricated to tight tolerances (especially large diameter monopiles) and the foundations designed must be within the handling capability of fabricators (e.g. crane under hook heights, load-out quays, storage etc). This of course limits the number of fabricators with capabilities to deliver offshore structures. Promoting competitive tendering by not excluding too many fabricators is also a key consideration during design. The majority of fabricators with offshore wind track records are located in Europe but capability does exist within India and surrounding regions such as in China and the Middle East, albeit with very limited offshore wind track records.

- **Installation limitations**
  Vessel availability and handling capabilities will have a significant impact during foundation design. See Section 2.5. In addition specialist installation equipment availability can impact foundation choice and design, for example hammer driving limits can impact monopile design and feasible pile diameters.

In Gujarat the mean depth varies from 15 m to 43 m and in Tamil Nadu to depth varies between 11 m and 53 m within the identified development zones in each State. This suggests that a range of foundation concepts could be used, subject to further consideration of site specific factors. Reference can be made to Table 1 and Table 2 to further understand the procurement complexities that India may face with regards to the foundation supply chain.

Figure 11 - Jacket fabrication (top) and monopile fabrication (bottom)

2.3.1 Monopiles

Steel tubular structures, between 40 m and 80 m in length, embedded in the ground using large hammers and if necessary drills. Tubular sections are rolled from steel plate then welded together. A transition piece, consisting of more complex welded steel sections, usually acts as the interface between the monopile and the turbine, although designs have emerged without the transition piece. To date 7.5 m has been the maximum diameter with a wall thickness of ~100 mm but Sif Smulders recently committed to a factory with capability of rolling 11 m diameter tubes.

The leading suppliers in Europe include Bladt, Bilfinger, EEW, Steelwind, SIF and Smulders.

Smaller monopiles are relatively easy to manufacture and existing Indian suppliers of rolled tubes should be able to enter the market. Larger fabricators in India, such as Larsen and Toubro (L&T) and Essar Projects, may already have capability to roll the larger diameter/thickness tubulars required for XL monopiles. However, the largest monopiles currently being designed in the EU may exceed the capability that many existing fabricators in the Indian market have at present. As a result to boost local content more conservative designs (using smaller turbines in shallower water) may be preferred for earlier sites.

2.3.2 Jacket foundations

Jackets most commonly have three or four legs, and are affixed to the seabed using piles of around 1.5 to 3 m diameter. These can be pre-piled, and the jacket lowered on subsequently, or post-piled, through the sleeves at the base of the positioned jacket. They are similar in design to the jackets used in the offshore oil and gas industry, although the manufacturing requirements are very different (many units at low cost) to that taken to oil and gas projects (one or two units, at much higher budget). As a result, the main R&D focus in offshore wind is through standardisation and process optimisation.
The fabricator Bilfinger have developed an automated jacket facility in Poland that uses robotic welding of nodes and utilisation of standard off-the-shelf tubular members – it is suggested automation cuts welding time by more than 70% compared with traditional O&G point-to-point jacket fabrication using manual welding. This optimisation is stated as having potential to reduce costs by 30%.

Jackets have been used on various projects around Europe, including Ormonde, Thornton Bank, Baltic 2, Wikinger and Nordsee Ost, with further installation expected at East Anglia 1, Beatrice and Neart Na Gaoithe. Like monopiles, jackets are considered proven.

Typical size of a jacket for a 6 MW turbine is around 600 - 800 tonne.

Leading manufactures include Bladt, EEW, Smulders, Bifab and Navantia. In India large-scale fabricators and shipyards active in the oil and gas industry are well placed to transfer across. For example Larsen and Toubro (L&T)'s Head of Business Development in Europe has previously stated that: 'they can make jackets for the offshore wind market'[7]. Other potential Indian players might include; Essar Projects, Bharati Shipyard, Cochin Shipyard and EEW. There also exist fabricators with offshore capability in China (e.g. ZPMC and Blue Island Offshore) and in the Middle East (e.g. Lamprell in U.A.E.).

2.3.3 Gravity base concrete foundations

Gravity base foundations (GBS) are large structures made from reinforced concrete that use sheer weight, including ballast, to provide stability to the turbines.
These structures can be over 3,000 tonne and have a footprint of 30 m or more.

GBSs can be broadly categorised into:

- 'lifted' concepts - where the structure is installed, often with the turbine pre-installed, using a specialist installation vessel, and
- 'floating' concepts - where the GBS is floated out and then installed by sinking the structure to the seafloor

Strabag - Boskalis and GBF are leading developers of lifted concepts, while BAM – Van Oord and Gravitas are progressing floated concepts.

GBS concepts have already been used in offshore wind in the Baltic, most recently at the 48 MW Karehamn site in Sweden, yet the technology has largely failed to break into the North Sea market. For the more novel concepts, this lack of progress is likely to reflect the risk associated with delivering an efficient end to end process of manufacture and installation for a large number of units (alongside all the other tasks) that are required for a commercial scale wind farm. It is not clear whether GBSs are likely to be a widely attractive concept in the Indian market, but in areas where there is high rock-head, like Tamil Nadu, they are likely to be amongst the favoured options to be evaluated at Front End Engineering Design stage (FEED). This is particularly true if the port infrastructure necessary to facilitate manufacture and launch of these very large reinforced concrete structures is already locally available (e.g. Kattupalli).

2.4 Electrical

The typical electrical layout is a High Voltage Alternative Current (HVAC) system, with strings of 6 to 8 turbines connected by an inter-array cable (IAC), ~up to 50 km, to the offshore substation. The offshore substation steps up the power and then transmits to shore along an export cable.
An onshore substation cleans and steps up the power and connects it to the transmission network. This is

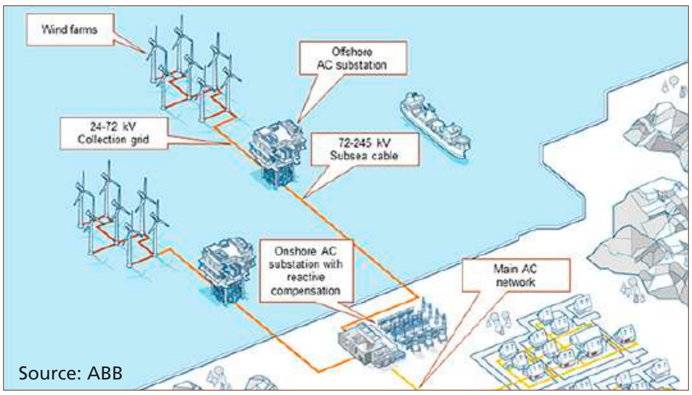


Figure 12 - High voltage AC electrical layout

[7] http://www.theengineer.co.uk/channels/policy-and-business/in-depth/indian-oil-and-gas-giant-eyes-uk-renewables-move/1016637.article

However, the electrical layout for the wind farm will vary primarily on the size of the wind farm and the distance to shore. For smaller projects, closer to shore (~ <10 km) it may be possible to remove the offshore substation, using an array cable(s) to transmit the power directly to an onshore substation. For projects further offshore (~ > 50-100 km) and hub arrangements (where multiple wind farms connect into one offshore connection), High Voltage Direct Current (HVDC) systems are used. These have higher capacities and reduce losses over distance but are more expensive to install. Only Germany has to date installed HVDC systems offshore.
The following sections focus on HVAC as this is the technology that will be expected to be used in Indian offshore wind for the foreseeable future.

2.4.1 HVAC cables

Electrical cables are typically made up of three copper cores set into an XLPE (cross linked polyethylene) base, surrounded by steel wire armouring. Fibre optic cables provide a communication channel for the wind farm.

For array cables, 33 kV array cables have been used to date, although there is significant R&D, qualification work and future projects using larger capacity WTGs that will utilise 66 kV cables.

Export cables typically operate at 132 kV but increasingly 220 kV is being used. Typical requirements for a 132 kV (AC) three core 800 mm² cable include:

- Capacity: approximately 175 MVA
- Diameter: 214 mm
- Weight: 87 kg/m

Technological improvements being considered include higher ratings, more dynamic ratings and greater condition and vibration monitoring.

The HVAC cable market has traditionally been tight (particularly for higher voltages) and is dominated by a few very well established players such as Nexans, Prysmian, JDR cable, Van Oord, ABB and NKT. High barriers to entry exist including significant technical and manufacturing capability and high investment costs. Yet existing Indian manufacturers of cable (including Polycabs and Universal Cables) are likely to be able to enter the market.

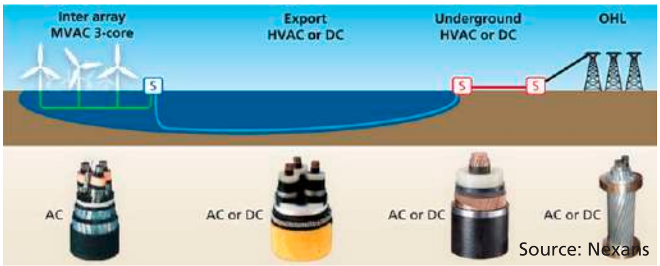


Figure 13 - Offshore wind export and array cable types

2.4.2 Offshore substation

The offshore substation steps the voltage up from the array cable operating voltage to the export system operating voltage, provides switching devices to connect or disconnect equipment and protection equipment to respond to faults. This plant includes transformers, reactors, switchgear, control, fire protection systems and low voltage auxiliary systems. All this equipment is contained in a large fabricated topside structure which usually includes two or more stories and is installed upon a support structure (usually a jacket). Topsides are around 30 m x 30 m x 15 m (LxWxH) and can weigh over 1,000 tonnes. Depending on the size of the project, there may be more than one offshore substation.

Technology risk is considered relatively low. The supply for AC plant globally is not solely related to the demand in the offshore wind market. This has the advantage of providing a deep pool of design and manufacturing resource but also puts offshore wind in competition for supply at times of high demand from other sectors. Instead the size and mass of the topside (see Figure 14) is a major manufacturing, logistical and installation challenge. To date almost all substations have been bespoke designs. Designers must carefully consider the durability of electrical equipment installed offshore.
To mitigate damage and risks from the harsh offshore environment, equipment is typically housed inside multiple containers or the topside is fabricated as a single fully sealed unit. Offshore substations contain more interfaces and equipment than any other part of the offshore wind farm, hence careful management of the complex and typically global supply chain is required.

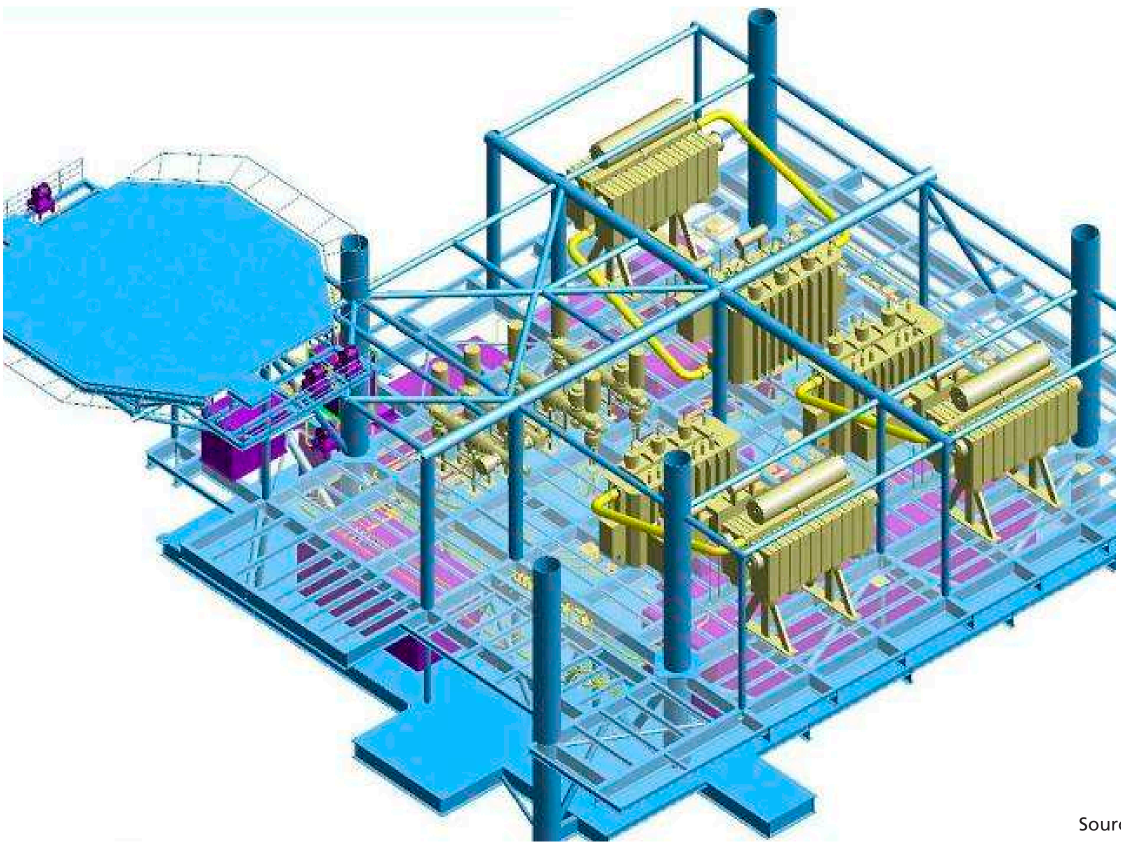
The support structure is fabricated by large yards including Heerema, Bladt, Bilfinger, Harlan and Wolff and Semco Maritime.

Yards manufacturing topsides for oil and gas in India and the Middle East may be well placed to manufacture topsides for offshore wind. Larsen and Toubro (L&T), Essar Projects, Dolphin Offshore Enterprises and possibly other fabrication yards/shipyards in India may be able to enter this segment. For jacket substructure fabrication see Section 2.3.2.

A recent concept design from Siemens is the development of a 'distributed transformer concept'[8]. This would remove the need for an offshore substation through attaching an offshore transformer module directly to the foundation of a wind turbine. Some of the main suppliers of electrical equipment are Siemens, ABB, ALSTOM and CG Power (also active in India).

2.4.3 Onshore substation

The onshore substation receives power from the export cable(s), steps the power up to the transmission voltage and connects the wind farm to the onshore transmission (high voltage) network. Switching devices allow connection or disconnection of equipment and protection equipment helps respond to faults. Reactive power and other grid code issues are dealt with. Onshore substations for offshore wind farms are almost identical to substations for other power generating technologies and so existing suppliers in India should be able to move into the market.



Source: HFG

Figure 14 - Greater Gabbard substation topside, 480 MW

[8] http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2015/energymanagement/pr2015030151emenhtm&content[]=EM

Towed ‘dumb’ barge with crane

Shearleg crane-barge

Semi-submersible/heavy-lift vessel

DP2 Heavy-lift cargo vessel

Leg-stabilised crane vessel

Self-propelled jack-up

Figure 15 - Installation vessels

2.5 Installations vessels and infrastructure

There are four distinct major installation processes required for an offshore wind farm: turbines, foundations, cables, and the offshore substation. Each has unique technical challenges, therefore requiring specialised vessels. Installation activity is coordinated from an installation port.

Each of these elements is now discussed in turn. For more information on the specific process see Section 3.

2.5.1 Turbine installation vessels

Turbine installation requires a large number of heavy nacelles (120 to 400 tonne) and blades to be lifted to a significant height (typically ~100 m), with great precision and in challenging weather conditions. Typically the installation vessel also collects the turbine parts from shore and transports them to site. This fairly unique set of challenges means that specialist Wind Turbine Installation Vessels (WTIVs) are used.

Historically installation vessels have been a major bottleneck for the sector with few purpose built vessels and demand from a buoyant oil and gas market driving up prices and reducing capacity for offshore wind developers. However, over the past few years around 20 purpose built vessels have been ordered, most of which are now coming on stream. Examples include: A2Sea's Sea Challenger and Sea Installer, Van Oord's Aeolus, Seajacks's Scylla and Swire Blue Ocean's Pacific Orca.

It is worth noting that for smaller turbines there is a surplus of suitable jack-ups and installation vessels, due to the move in Europe towards larger turbines.

As a result over-supply in the market is likely, at least for the next couple of years, although Asian demand could potentially reduce this. This can be seen by the recent announcement that Seafox 5, a state of the art installation vessel, will move to the oil and gas market for a year or so. Looking longer term, specifications may need boosting for more challenging sites in deeper water and next generation wind turbines.

2.5.2 Foundation installation vessels

Three different types of vessel have been used to install foundations. These include:

- Wind turbine installation vessels (see above)
- Floating heavy lift vessels with advanced position holding capability (e.g. Seaway Heavy Lifting's Oleg Strashnov and Stanislav Yudin, Van Oord and there are several others with potential like Saipem 3000, and OSA's Samson & Goliath)
- Sheer leg crane vessels (e.g. Taklift 7)

There appears to be sufficient supply of capacity for standard monopile installation while the supply of the lifting capability needed to install monopiles with diameters greater than 7.5 metres will need to be invested in to meet projected demand if semi-buoyant installation methods are not adopted.
Jacket installation vessels with adequate deck capacity to carry more than three foundations are very limited in supply and will constrain deployment at deep water sites without investment in more vessels.

India has an established Oil and Gas industry, and there are several similarities between the vessel specifications necessary for lifting offshore wind turbine foundations, and the installation of O&G jacket foundations and topsides. Suitable vessels may also be available more widely in Asia (e.g. China/South Korea) and the Middle East.

2.5.3 Cable installation vessels

Installation of power cables for offshore wind is similar to installation of telecoms cables and umbilical's in oil and gas. Yet despite this cable installation has and continues to remain a significant issue for the sector with an often-cited statistic that 80 % of insurance claims to date have been from cable faults.

A range of vessels has been used in the market including vessels and barges. Recently commissioned vessels include SIEM Offshore (Installer) and Aimery and the CLV Ndurance.

In India, cable installation vessel operators currently active in the telecoms or oil and gas sectors would be well placed to move into the offshore wind market.

2.5.4 Offshore substation installation vessels

The sheer size and mass of the offshore topside requires that specialist heavy lift crane vessels are used (unless a float-over method or self-installing topside design can be utilised). There is widespread experience of installing oil and gas topsides in India, and substation topsides are very similar in dimensions and weights to smaller oil rigs. The vessels used in the Indian marketplace to fulfil this role should be suitable to be used for offshore wind as well.

2.5.5 Ports

It is not essential for offshore wind development to have numerous ports to work from, and provided there is at least one large facility, which meets the specific technical criteria to support the anticipated development strategies in its region, and then this will be adequate.

The two areas identified as being promising for early offshore wind development in India are the Gulf of Khambhat in Gujarat, and the Gulf of Mannar off Tamil Nadu. This is discussed in far greater depth in Section 3.

2.6 Operations and maintenance

A large range of activities is required in the O&M phase of a wind farm (see Figure 16). These include onshore and offshore logistics, day-to-day maintenance of the offshore assets (turbines, foundations, electrical elements) and operation and back office administration in keeping with the running of a large (wind) power plant.

The majority of the work is focused on addressing the scheduled and unscheduled maintenance requirements of the wind turbines. Meanwhile foundations generally require infrequent inspections and remedial works, virtually all of which can be undertaken in a scheduled fashion, since foundation failures of sufficient severity to cause turbine stoppages are very rare. The majority of foundation maintenance is typically focused around periodic statutory inspections, marine growth and guano removal, paint coatings and cathodic protection inspections and small remedial tasks such as painting and repairs of secondary steelwork and auxiliary devices (e.g. davit cranes, ID signs etc.). Occasionally more substantial works are required on the foundations, such as scour pit inspections or remediation, but again these can typically be scheduled without incurring significant production losses.

Unlike foundations, failures in sub-sea cables can lead to substantial periods of lost production, and therefore, albeit rare, unscheduled outages of cables are treated with considerable urgency. Periodic seabed surveys will usually be undertaken every few years to monitor the burial status of the cables and assess the risks due to external aggravation, such as anchor strikes or trawling activities etc.

The primary supply chain activities are around crew transfer vessels, portside infrastructure and offshore technicians. Spares are often required but usually provided by the original OEM, with a limited market to date for third party providers, and which is therefore not discussed further. Much of the turbine-related work is monopolised by the turbine OEM's who have the turbine-specific skills and expertise to undertake the work and an existing supply chain set up to provide the parts and other services as required. However, works associated with balance of plant items, such as foundations and cables, are sufficiently diverse that specialist contractors are often used for these works, opening up opportunities for local business.

The key logistical challenge is getting technicians to site, with the distance to shore driving different strategies (see Figure 16). Close to the O&M port (less than ~40 Nm) crew transfer vessels are used to ferry technicians to the site every day. These are typically catamarans in the range of 15 to 24 m length, classed to transport up to 12 technicians and associated parts and equipment, with cruising speeds in the order of 20 knots. Crew vessels are primarily limited by sea state, often preventing access to offshore assets in rough weather. At more exposed sites helicopters are sometimes used to support crew transfer vessels for works requiring rapid response and relatively small parts or equipment during periods of more onerous weather. For large wind farms further offshore (typically more than about 40 nm from the O&M port), offshore-based concepts are starting to emerge with accommodation provided near the wind farm and technicians working for extended periods offshore (akin to the oil and gas sector). The rest of the section assumes the first strategy is used.

2.6.1 Crew transfer vessels

The sector has seen rapid development in vessel design. First generation vessels were 18 to 24 m fishing or guard vessels, which had the minimum of modifications. Second generation vessels were those that were specially designed workboats conforming to MCA category 2 of MGN 280, and ISO 12217 for offshore wind. More radical third generation designs have been proposed through the Offshore Wind Accelerator competition including SWATHs (small-waterplane-area twin hull) and, SES (surface effect ships) and these are slowly starting to enter the market.

There is a thriving and competitive industry in the manufacture of personnel transfer vessels. Leading EU suppliers include Alnmaritec, Alicat, CWind and Damen. In India, existing yards and manufacturers should be able to transition to build offshore wind transfer boats, although it may be sensible to utilise the existing vessel design experience from the EU in the short term.

2.6.2 Ports

O&M ports are much smaller than those required for construction and are situated as close to the site as reasonably possible to minimise day to day transit time. Shore-side services are vital to support offshore logistics and all offshore wind farm O&M activity needs access to port facilities such as load-out and work boat mooring. See Section 3 for more details.

2.6.3 Technicians

Suitably qualified and experienced personnel are crucial to undertaking effective O&M. Technicians typically travel out to site every day by boat, transfer across to the turbine, climb the turbine, undertake the maintenance work and then repeat as appropriate.

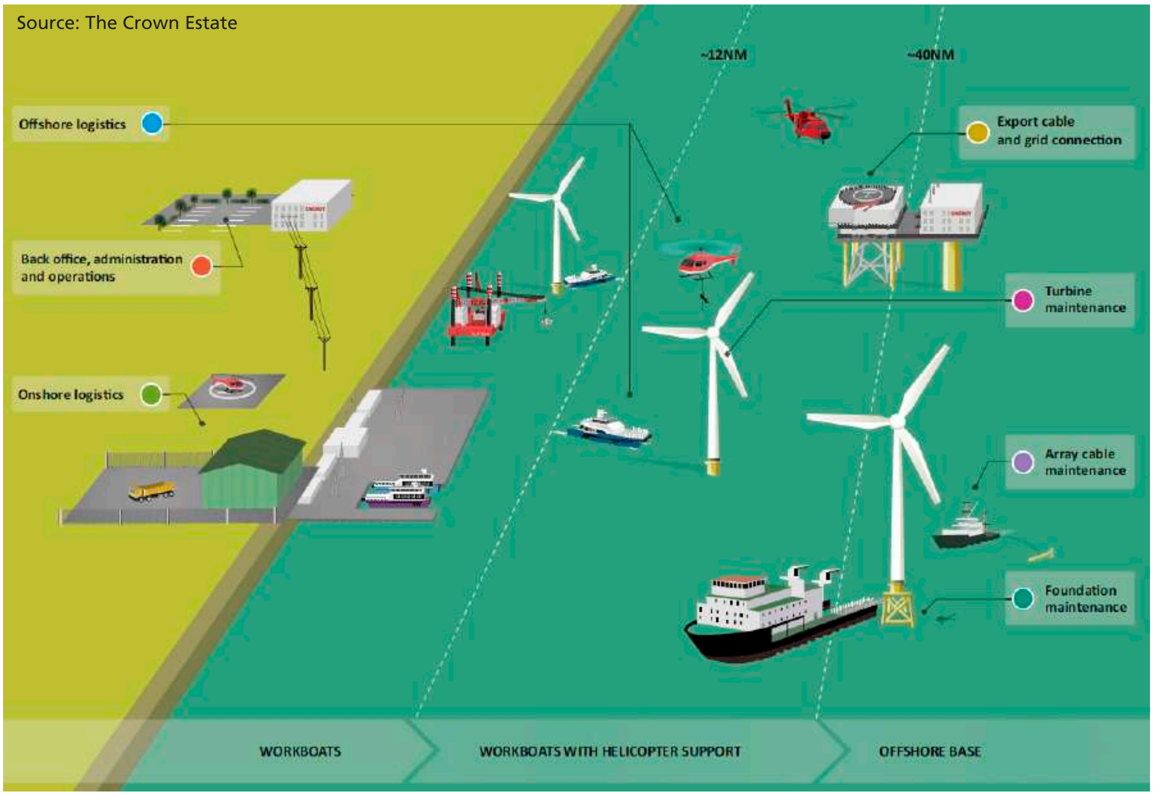


Figure 16 - Overview of key offshore wind O&M activities

It is quite physical work in a hostile environment and there are various certificates and accreditations that are required. A large number of training providers have opened up to meet the demand and now include courses provided by manufacturers (such as Siemens), higher education courses and commercial training providers. Roughly, the sector needs between 0.5 and 1.5 full time equivalent jobs per operational turbine.

Turbines typically come with a five year warranty from the manufacturer and during this period, the OEM will typically employ the majority of technicians on site. After the warranty period is over, the owner operator can opt to extend the OEM warranty agreement or takes over responsibility for the plant and directly employ the technicians. Some more 'hands-on' owners are taking responsibility earlier and/or having jointly employed technicians working on the wind farm during the warranty period.

2.7 Supply chain conclusions

There are a number of areas where there is good potential for Indian companies to move into the offshore wind sector, in particular, aspects of the development process, the fabrication of support structures and offshore substation topsides. Due to the complexities of developing offshore wind and lessons from other emerging markets it is anticipated local companies will require some collaboration and capacity building with experienced organisations, particularly during the local market's embryonic development years.

To some degree the size of the local project pipeline will dictate the level of localisation. If a large project pipeline, combined with attractive incentives, develops in India then the local supply chain will almost certainly grow in parallel and indeed attract both local and overseas OEMs to develop their business within the region.

In Europe the offshore wind supply chain is now becoming large and highly specialised. This has involved moving beyond what can be manufactured in existing facilities and led to the development of purpose built ports and optimised manufacturing facilities. The need for cost reduction has for example seen the recent development of serial production facilities for jacket foundations, XL monopiles (6 to 10 m diameter) and purpose built installation vessels. Doing so requires a huge amount of investment and therefore confidence in the market, but these new developments present an excellent opportunity for India to accelerate learning-curves as their local offshore wind market develops. Table 4 on the next page summarises the findings from this supply chain study.

Element	Some of the leading companies in EU	Some of the potential companies who could enter market in India based on preliminary market assessment
Site surveys	Fugro, Gardline and Intertek (many of whom are already active in India)	The National Institute of Oceanography (NIO), National Institute of Ocean Technology (NIOT) and labs of the Council of Scientific and Industrial Research. Publically funded institutions could initially offer some support. CGG, DBM Geotechnicians, EGS Survey, Fugro Survey (India), Indomer and Petroleum Geo-Services.
Wind resource assessment - Met mast foundation & platform	BiFab, Bladt, MT Højgaard and SIF-Smulder	Essar and L&T. Other fabricators/shipyards e.g. Bharati Shipyard and Cochin Shipyard will likely have capability for these structures.
Wind resource assessment - Met masts	Carl C and Francis & Lewis	Current onshore suppliers with possible potential to enter offshore wind market: Aditya Enterprises, RK Windmast, and Shah Infra Tower.
Wind resource assessment - Meteorological sensors	FT Technologies, NRG Systems, Riso, Thies and Vector Instruments	Current onshore suppliers: SGS Weather and Environmental Systems, NRG Systems.
Oceanographic assessment - sensors	Nortek and Planet Ocean	Nortek are active in Asia. Other suppliers exist offering equipment on lease terms or purchasing terms.
Consenting and planning	ERM, Natural Power and NIRAS and Royal Haskoning	AECOM, Chilworth Technology, ERM, Engineers India Limited and Royal Haskoning.
Design and engineering	Arup, Atkins, COWI, DNV GL, LIC energy, Mott MacDonald, OWEC, Ramboll and Sgurr	Aker Solution, Arup, Saipem India Projects, Engineers India, L&T Construction.
Wind turbines	As of late 2015, the leading player is Siemens, followed by MHI Vestas, Senvion (formerly of Suzlon), ALSTOM and Areva Gamesa. In addition there are a number of Chinese players (including Goldwind, Ming Yang, Sinovel and others) and Japanese manufacturers (Hitachi).	If a sufficient market develops leading OEM suppliers might consider investing in a local offshore wind base in India. Most of the major OEM's operating in India have multi-megawatt offshore turbine platforms operating globally. Areva Gamesa, MHI Vestas and GE Energy India through its acquisition of ALSTOM Power in 2015. Suzlon Energy has rights to license and build the Senvion 6.XM series machine.
Blades for offshore wind turbines	LM Blades, Euros and SSP	Suzlon, INOX rotor blade, LM Wind Power and Vestas.
Casting & forgings	Brück, Euskal Felguera Melt, Fonderia Vigevanese, Metso, Siempelkamp, Torgelow and VTC	Bharat Forge, Heavy Forgings, L&T Special Steel, Kalyani forge, SE Forge, and Synergy Green Industries may be able to move into the sector.
Gearbox and generators	Key suppliers of gearboxes are: Bosch Rexroth, ZF Wind, and Winergy. Leading manufacturers of generators include ABB.	ZF Coimbatore, Winergy are prominent gearbox suppliers in India. ABB-India is the leading supplier of generators in India.
Towers	Ambau, Welcon and CS Wind	Typically in India local OEMs manufacture towers. Windar, Anand, Batliboi, and DN Wind Systems, L&T, GWPL may be able to scale up to cater for the offshore market.

Element	Some of the leading companies in EU	Some of the potential companies who could enter market in India based on preliminary market assessment
Monopiles	Bladt, EEW, Steelwind, Bilfinger, SIF, and Smulders	Smaller monopiles are relatively easy to manufacture and existing Indian suppliers of rolled tubes should be able to enter the market. Larsen and Toubro (L&T) and Essar Projects may be well positioned to enter this segment with some knowledge transfer. Other local fabricators/ shipyards may have capability for at least smaller diameter MPs.
Jacket foundations	Bladt, EEW, Smulders, Bifab, and Navantia	In India large-scale fabricators/shipyards active in the oil and gas industry are well placed to transfer across. Larsen and Toubro (L&T), Essar Projects, Bharati Shipyard, Cochin Shipyard, and EEW may be able to enter this segment.
Gravity base concrete\ foundations	GBS Concepts: Strabag - Boskalis and GBF are leading developers of lifted concepts, while BAM – Van Oord and Gravitas Offshore are progressing floated concepts GBS Fabricators: MBG, Monberg & Thorsen – (Now MT Højgaard), Skanska, Ballast Nedam, Bilfinger Berger, Aarsleff, Pihl – Foundations and Jan De Nul.	High barriers to entry exist including high investment costs in manufacturing facilities. L&T have a long history in construction of reinforced concrete structures and a facility in Kattupalli which is suitable for their manufacture and launching.
HVAC cables	Nexans, Prysmian, JDR cable, Van Oord, ABB and NKT	High barriers to entry exist including significant technical and manufacturing capability and high investment costs. Yet existing Indian manufacturers of cable, including Polycabs and Universal Cables, are likely to be able to enter the market. Amongst the Indian suppliers, Polycab has exposure towards onshore inter-array cables for export markets.
Offshore substation	Main suppliers of electrical equipment are Siemens, ABB, Alstom and CG Power. The support structure is fabricated by large yards including Heerema, Bladt, Bilfinger, Harlan and Wolff and Semco Maritime.	High barriers to entry exist including significant technical and manufacturing capability and high investment costs. Yards manufacturing topsides for oil and gas in India and the Middle East may be well placed to manufacture topsides for offshore wind. Larsen and Toubro (L&T), Essar Projects, Dolphin Offshore Enterprises and other fabrication yards/ shipyards in India may be able to enter this segment. ABB, Siemens, Alstom are reasonably active in electrical components, systems and services including the wind power industry and established sectors such as Oil & Gas, Marine and Power generation.
Onshore substation		Onshore substations for offshore wind farms are almost identical to substations for other power generating technologies and so any existing suppliers in India should be able to move into the market.

Table 4 - Supply chain conclusions

Specific recommendations with respect to the readiness of local companies in the offshore supply chain can be undertaken in future studies. In European experience these detailed reports are confidential in nature and respond to specific commercial and technical queries from the contracting party or company.

3 PORT INFRASTRUCTURE AND LOGISTICS

3.1 Study objective

Ports are strategic hubs in the offshore wind farm supply chain, since all components, plant and transport operations must transit through these facilities. Therefore, they must provide suitable infrastructure in order to meet the specific requirements of the offshore wind industry.

The characteristics of available ports and vessels are critical for defining and optimising Offshore Wind Installation Strategies and Logistical Operations. This Port Infrastructure and Logistics study details the port infrastructure and logistics required from manufacturing (i.e. wind turbine and foundation, etc) to installation and the subsequent operation and maintenance (O&M) phase of an offshore wind farm.

The study expands upon the previous FOWIND Pre-feasibility study reports for Gujarat and Tamil Nadu, and focuses on defining and investigating the following key areas:

- offshore wind port types (Section 3.2)
- anticipated offshore wind project specifications for India (Section 3.4)
- anticipated offshore wind component specifications (Section 3.5
- definition of available vessel types for offshore wind (Section 3.6
- possible installation strategies (Section 3.7)
- typical port infrastructure descriptions (Section 3.8)
- port screening and port readiness in Gujarat and Tamil Nadu (Section 3.9)

The primary objective of this study is to develop an understanding of the existing port infrastructure capabilities available to support offshore wind energy projects in the Indian states of Gujarat and Tamil Nadu. The port infrastructure and logistics assessment methodology is described in Section 3.3.

3.2 Offshore wind ports

3.2.1 Introduction

This study considers the primary operations for which port facilities are required when constructing and operating an offshore wind project, namely: manufacturing, marshalling (or staging), and O&M. This section aims to provide definitions for the five main types of offshore wind port, specifically ports for:

- wind turbine (WTG) manufacturing (see Section 3.2.2)
- WTG foundation manufacturing (see Section 3.2.3)
- offshore substation manufacturing (see Section 3.2.4)
- operations and maintenance (see Section 3.2.5)
- marshalling (or staging) (see Section 3.2.6)

It should be noted that an individual port estate may have the capability to handle more than one or even all of the above port operations. Nevertheless different operations and components have different handling and storage requirements and as such ports must be considered on a case by case basis. For example different stages of the manufacturing and installation process are likely to require different crane specifications, quayside loadings and quayside water depths. Hence when selecting offshore wind ports it is critical to work backwards from the anticipated envelope of offshore wind components to be handled during each stage of the offshore wind project(s).

Clearly the location of the port facilities with respect to the offshore wind farm site(s) has a big impact when selecting suitable port estates. Therefore before assessing the ability of port infrastructure for handling offshore wind farm components, it is necessary to have a thorough appreciation of the most common logistical methods by which wind farm components are handled.

Large wind farm components are generally manufactured in proximity to port facilities, given the difficulties of handling such large components and the need to reduce the large transit distances to the offshore project site.

There are a number of methods for the delivery of wind farm components from the original equipment manufacturers' (OEM) premises to the offshore wind farm site. The generally applicable options include:

1. Loading and off-loading of components onto quayside storage areas in ports, at the manufacturer's and marshalling (or staging) site respectively;
2. Loading of components onto a transport vessel or barge at the manufacturer's premises and off-loading onto a floating barge in a sheltered harbour near the offshore wind farm site, to be stored, awaiting transfer to the installation vessel;
3. Loading of the components onto a transport vessel or barge at the manufacturer's premises, and off-loading onto the installation vessel at the offshore wind farm site – known as feeder vessel duties; or
4. Loading of the components directly onto the installation vessel at the manufacturer's premises, and installation at the offshore wind farm site (see Figure 17).

In this ideal scenario (option 4), all manufacturing facilities are located on the coast, in the nearest port to the offshore wind farm. In this configuration the foundation or turbine installation vessel would cycle directly between the manufacturer's port and the offshore wind farm, and all necessary storage, to accommodate fluctuations in installation rate, would be accommodated within the manufacturers' premises.

For the purposes of assessing port facilities, the assumption is that option 1 is the preferred option for transportation of wind turbine (WTG) components from a manufacturer's facility to a developer's marshalling (or staging) harbour.

Options 2 to 4 become relevant when considering staging of foundation and array cable installation and mobilisation from the developer's marshalling (or staging) harbour.

3.2.2 Wind turbine manufacturing port

Given the large size of offshore wind turbines (currently 3.0 to 8.0 MW) compared with their smaller onshore relatives, wind turbine manufacturers need to locate their fabrication facilities within a port estate with a suitable quay side for both receipt of the raw manufacturing materials/components and load-out of the fully fabricated WTG components ready for project supply

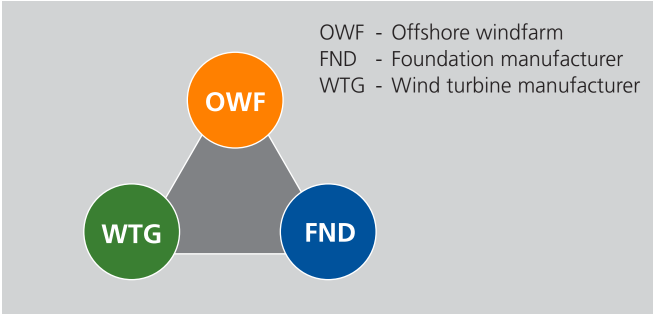


Figure 17 - Spatial distribution of 3 key port facilities for offshore wind farm construction

As a result in regions with a high offshore wind development density (e.g. >5 GW within 100 NM & within 10 years), the large WTG OEMs have established purpose built wind turbine manufacturing port facilities. Figure 18 shows Siemens Wind Power's proposed new fabrication facility in Hull, UK.
Key features of a wind turbine manufacturing port facility would include:

- Workshops – large inside facilities for blade, tower and nacelle fabrication/assembly
- Storage areas – with sufficient bearing capacities and area to meet supply chain
- Quayside – with suitable access and depth for vessels
- Road/rail links – to facilitate land based supply of smaller materials/components
- Cranage – sufficient for fabrication and load-out of components
- Workforce – a large number of specialist employees are required, e.g. skilled welders, coating specialists and machinery operators
- Location – close proximity to supply chain preferable to reduce transits

Figure 18 - Port of Hull (UK), Siemens wind power WTG fabrication facility (under development)

3.2.3 Wind turbine foundation manufacturing port

In Europe there are now a significant number of well-established and experienced foundation fabricators. Again given the large size and mass of offshore wind foundations manufacturers need to locate their fabrication facilities within a port estate with a suitable quay side for both receipt of the raw materials and load-out of the fully fabricated foundations ready for project supply. Unlike WTG OEMs, whose facilities tend to be more offshore wind market centric, foundation fabricator's primary historical business tends to be oil and gas platform or maritime vessel fabrication. As a result a number of existing foundation manufacturing port facilities exist but are not always in very close proximity to the offshore wind market. As a result it is common to implement an installation strategy involving an intermediate marshalling port, see Section 3.2.6.
Figure 19 shows a wind turbine fabrication quayside at the Port of Bremerhaven in Germany. Key features of a foundation manufacturing port facility would include:

- Fabrication shops – very large internal workshops for fabricating foundation components, providing controlled environments for cutting, rolling and welding
- Coating shops – large internal environments for blasting and painting offshore structures
- Storage areas – with sufficient bearing capacities and area to meet supply chain
- Quayside – with suitable bearing capacities, access and depth for vessels
- Cranage – sufficient for fabrication and load-out of foundations (load-out typically done using over-head gantry crane or large crawler cranes or possibly SPMTs
- Road/rail links – to facilitate land based supply of smaller materials/components
- Raw material supply chain – in the case of steel structures, a suitable supply chain for high grade offshore steels is critical
- Workforce – a large number of specialist employees are required, e.g. skilled welders, coating specialists and machinery operators
- Location – close proximity to supply chain preferable but not critical if combined with a marshalling port

Figure 19 - Port of Bremerhaven (Germany) - WTG foundation fabrication

3.2.4 Offshore substation manufacturing port

Like offshore wind turbine foundations, offshore substation manufacturing facilities' historic business tends to be oil and gas platforms. Depending on the capability of different fabricators and also the project's contractual arrangements it is not uncommon for the substructure and the topside to be fabricated at different locations. In terms of offshore substation manufacturing port facility requirements these will be very similar to foundation manufacturing ports, but with larger bearing capacity and load-out requirements given the significant mass of these structures.
Figure 20 shows an OSS topside under construction at Heerema's fabrication facility, located in the Port of Zwijndrecht in the Netherlands.

Figure 20 - Port of Zwijndrecht (the Netherlands) - Heerema OSS fabrication

3.2.5 Operations & maintenance port

Offshore wind projects require a designated port facility including an onshore office and storage warehouse to act as the hub for all the operational and maintenance activities required during the wind farm's 20 to 25 year operational life. These are termed operations and maintenance (O&M) ports and it is possible for one port to operate and maintain multiple wind farms. Figure 21 shows the Port of Ramsgate which is the O&M port for the following UK projects; Thanet (300 MW), Kentish Flats (90 MW), Kentish Flats Extension (49.5 MW) and London Array (630 MW). The Port of Ramsgate was also used as a marshalling port during construction for the Thanet project's transition pieces (barge storage was used due to limited quayside bearing capacities).

The O&M port and vessels should be based as close as possible to the project site so as to reduce transportation time for service technicians. The port is used as a base for scheduled maintenance and minor intervention needs to be able to accommodate small service vessels. These are typically catamarans with 750-1,500 kW propulsion power, capable of cruising at 20-25 knots or more (15 to 25 m LOA, 2 m draft, and 10 m beam maximum). It is important that the O&M port can be accessed close to 100% of the time under all weather conditions and is not significantly restricted by tidal constraints or lock gate limitations.

Vessels of this size require minimal water depths and quayside equipment and in general can operate from any waterway suitable for small fishing vessels. Hence any port with capability to accommodate even the smallest cargo vessels will likely have the capability to accommodate wind farm support vessels.

Furthermore, if a helicopter is to be employed within the access strategy, the infrastructure to support this may be best positioned adjacent to the port-base where possible, although helicopter ports further inland may also be considered.

The port required for major intervention operations, typically involving a jack-up rig, does not need to be so close to the site. As an example in Europe, a gearbox can be loaded onto a jack-up barge in a Danish harbour and then installed in a turbine located in the UK.

After the exchange, the faulty gearbox could stay on the jack-up barge until it is back in Denmark or Germany and then sent for repair. A similar approach could be applied locally in India. Port facilities used for major intervention must be able to accommodate the jack-up barges used in the industry (130 m LOA, 12 m draft).

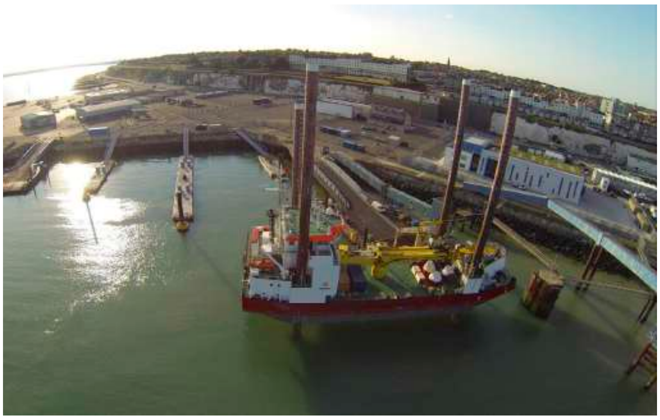


Figure 21 - Port of Ramsgate (UK) - Thanet, Kentish Flats and London Array O&M base

3.2.6 Marshalling (or staging) port

A marshalling or staging port is an intermediate port facility located in close proximity to the offshore project(s) which it serves. This concept becomes increasingly valuable when manufacturers/fabricators are located long distances from the wind farm installation site.
Figure 22 shows a WTG component marshalling port in Eemshaven which serves offshore projects in Germany.

It is vital to address the fundamental question of what benefit a marshalling (staging) port may be to offshore wind farm development, during both the construction and O&M phases, considering the four general methods for delivery as discussed in Section 3.2.1.

In reality, with most offshore wind farms which have been built to date in Northern Europe, the manufacturing premises and the offshore wind farms have been located at considerable distances from each other, and indeed in most cases these facilities have been located in other countries.

Figure 22 - Port of Eemshaven, WTG component marshalling

In general, the specialised offshore wind farm installation vessels have charter rates of several times those of cargo vessels, so to minimise overall installation and O&M costs, it is vital that voyage durations for the main installation vessels are kept to a minimum.

Offshore windfarm installation vessels have been optimised primarily to install components, whereas modern cargo vessel designs are ideally suited for transporting large and heavy components over long distances. By using a combination of (1) cargo vessels for the long distance logistics from manufacturers to marshalling ports, and (2) wind turbine installation vessels (WTIVs) for shorter installation cycles, an optimal solution for offshore windfarm logistics and transport and installation (T&I) and potentially O&M has evolved, see Figure 23.

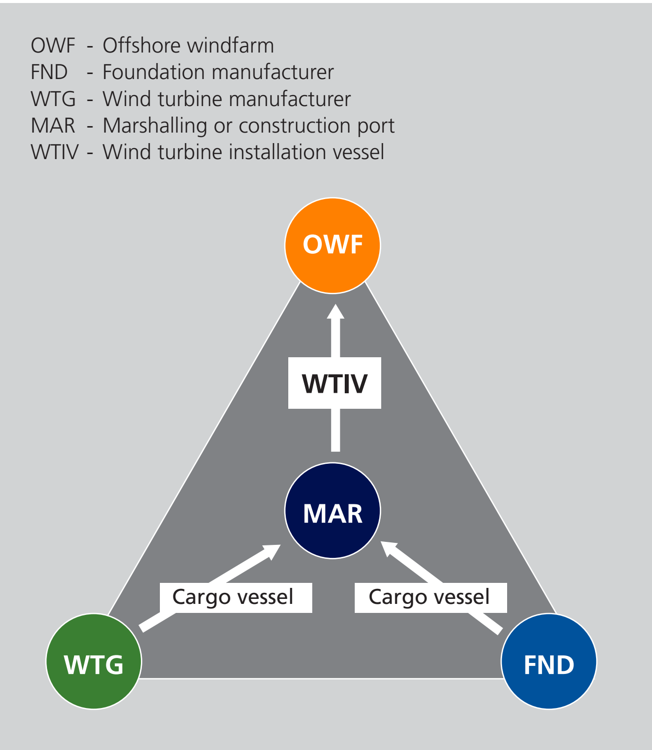


Figure 23 - Marshalling ports: reduce installation vessel voyage durations

Cost benefit analysis will reveal which of the two scenarios (option 1 or option 4) is preferable. This involves a comparison between:

- the installation vessel's charter (and fuel) costs directly between (1) foundation (FND) and (2) wind turbine (WTG) manufacturers and offshore windfarm (OWF) as illustrated in Figure 23
- the cost of cargo vessels from foundation and wind turbine to a marshalling port (MAR) and additionally incurring the double-handling costs, and port fees etc. associated with using the marshalling port (MAR), as well as the costs of the wind turbine installation vessels (WTIVs) between marshalling port (MAR) and offshore windfarm (OWF) as illustrated in Figure 23

It is also worth considering the possible risk of damage during re-handling and storage, and the potential programme disruptions any delays associated with remedial works might incur. The cost benefit analysis should incorporate modelling of any additional items from the risk register associated with the various strategies.

3.3 Port infrastructure assessment methodology

A desktop screening methodology for conducting port infrastructure and logistics assessments has been developed by DNV GL. Figure 24 shows a flow chart illustrating this methodology which includes an initial "preparation phase" where the project, component specifications, vessel requirements and possible installation strategies are defined. Following this initial preparation phase the "port screening phase" can commence, which is a desk-based study, considering the suitability of offshore wind ports in Gujarat and Tamil Nadu to supply the potential offshore wind project demand for construction operations. The final stage is the more detailed "port readiness assessment" which includes site visits to promising construction ports.

Section 3.9.5 provides a high-level screening of possible O&M ports, based on those identified in the FOWIND Pre-feasibility reports. O&M activities can generally be facilitated from minor ports with minimal infrastructure development compared with the demands of a construction port; hence only a high-level screening was conducted which should be re-visited when specific projects are identified.

DNV GL proprietary in-house software tools support the process. Results are summarised in Section 3.9.6.

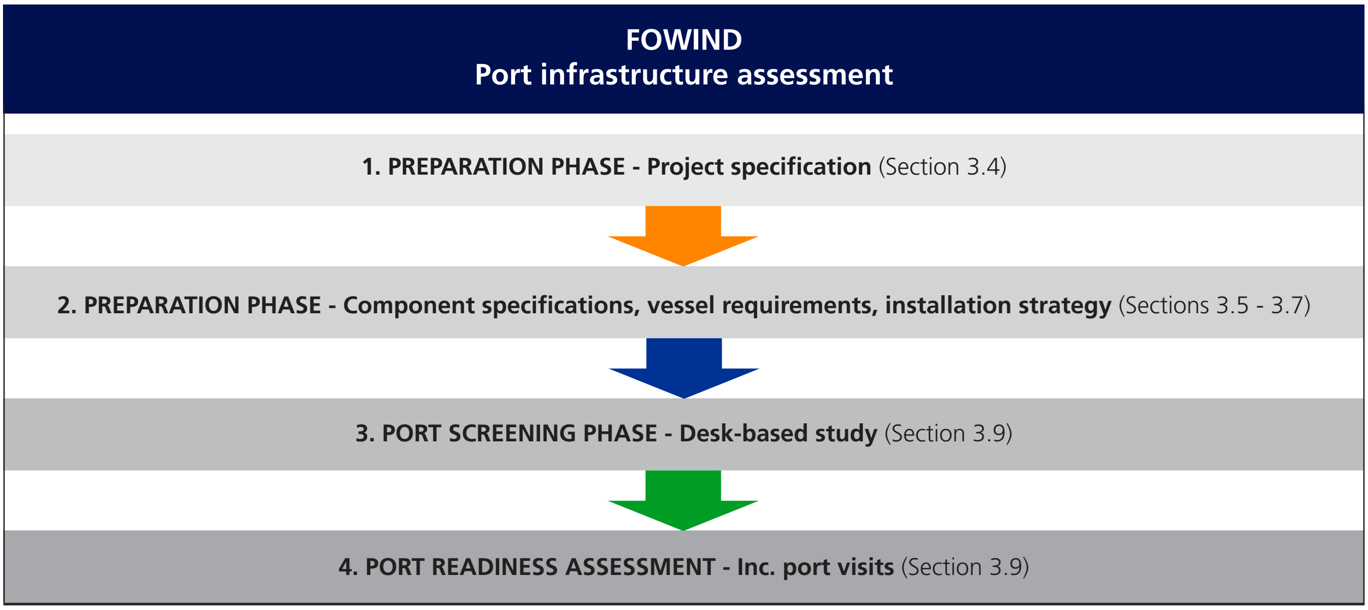


Figure 24 - Port infrastructure assessment - DNV GL summary methodology

3.4 Project specification

3.4.1 Introduction

In order to assess the suitability of port infrastructure for offshore wind activities in Gujarat and Tamil Nadu it is important to first define the envelope of project specifications that are anticipated within the regions (termed the demand). Key project parameters to be defined include:

- wind turbine MW capacities
- project MW capacities
- minimum distance to existing substation
- water depth
- foundation types considered and estimated masses
- requirement for an offshore substation

The basis for defining the range of anticipated offshore wind project parameters has been established from the recent Pre-feasibility Reports for Gujarat and Tamil Nadu[4]. A summary of the anticipated envelope of project parameters are provided in Section 3.4.2.

At this stage of the ports assessment study precise dimensions and masses of foundations are not required, but upper-bound values of each variable are established to an appropriate level of detail (see Sections 3.5.3 and 3.5.5. If the development is at an early stage, estimates must be used, based on past experience and engineering judgement. For the purposes of this study the WTG foundation mass and other pertinent information is established, like the megawatt capacity, and build-rate, including any multi-seasonal phased development options.

It should be noted, based on the assessment conducted by the FOWIND consortium and presented in the Gujarat and Tamil Nadu Pre-feasibility study reports[4], eight preliminary zones have been identified in each state for the development of commercial scale offshore wind farms. As a result of the high level of uncertainty associated with the preliminary constraints data (in particular seabed conditions and oceanographic parameters) and the lack of on-site wind measurements to validate the modelling process (note a LiDAR device is expected to be deployed in 2016 to conduct wind measurements), it must be stated that the results and conclusions presented in this Supply Chain, Port Infrastructure and Logistics study could be subject to change as the FOWIND project develops and updated input data becomes available.

[4] http://www.fowind.in/publications/report

3.4.2 Project specifications - PFR summaries

3.4.2.1 WTG and project capacity assumptions

Two indicative project capacities of 150 MW and 504 MW have been considered during the Pre-feasibility studies, since these are broadly representative of typical European commercial offshore wind developments. Similarly, two generic wind turbine generator sizes of 4 MW and 6 MW have been considered in the FOWIND Gujarat and Tamil Nadu PFRs. These capacities are representative of established (4 MW) and current (6 MW) offshore wind turbine designs.

3.4.2.2 Gujarat project specifications

Table 5 summarises the envelope of assumed offshore wind project parameters presented in the Gujarat PFR. These form the basis for inputs into the Port Infrastructure and Logistics assessment.

3.4.2.3 Tamil Nadu project specifications

Table 6 summarises the envelope of assumed offshore wind project parameters presented in the Tamil Nadu PFR. These form the basis for inputs into the Port Infrastructure and Logistics assessment.

Parameter	Range or assumption
Wind turbine capacities	4 MW and 6 MW
Project capacities	150 MW and 504 MW
Minimum distance to existing substation	9 to 45 km
Water depth	-15 to -43 m LAT
Foundation types considered	Monopile and jacket
Required for an offshore substation	OSS likely to be required (assumed required for projects >20 km from shore and/or >100 MW capacity

Table 5 - Gujarat project specifications

Parameter	Range or assumption
Wind turbine capacities	4 MW and 6 MW
Project capacities	150 MW and 504 MW
Minimum distance to existing substation	12 to 46
Water depth	-10 to -53 m LAT
Foundation types considered	Monopile, jacket and gravity base
Required for an offshore substation	OSS likely to be required (assumed required for projects >20 km from shore and/or >100 MW capacity

Table 6 - Tamil Nadu project specifications

3.5 Component specification

3.5.1 Introduction

The component specifications are defined by the range of component sizes which may be handled. The key drivers are (1) turbine type and (2) foundation type. As described in Section 3.4, Project Specification. Generic 4 MW and 6 MW wind turbines were chosen to be likely turbine types, hence these MW classes have been considered when estimating component sizes. Likewise the foundation types considered included monopile, jacket and gravity based structures, as described in Section 3.4.

This allows the formation of a database for the range of different sizes and weights of:

- wind turbine generator (WTG) components
- foundation components

Consideration must also be given to component sizes and weights of:

- offshore substation (OSS)
- cables (export and inter-array IAC)

The following Sections to 3.5.7 define the general handling methods, port requirements and estimated component sizes and weights for consideration in the Port Infrastructure and Logistics study.

3.5.2 Wind turbine generator components

3.5.2.1 Introduction

Wind turbine generators can be installed in a number of different ways as shown in Figure 25.

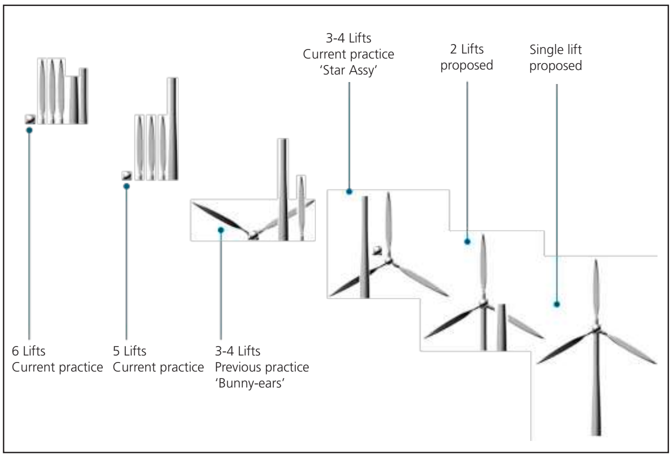


Figure 25 - Various assembly strategies for WTGs during installation

It is most common for turbines to be installed in six lifts:

- lower tower section
- upper tower section
- nacelle & hub
- blade 1
- blade 2
- blade 3

Some larger turbines are installed using the four lift star assembly method.

- lower tower section
- upper tower section
- nacelle
- 'rotor star' of hub, blade 1, blade 2 & blade 3

The largest wind turbine installation vessels (WTIVs) will have capacity for around 10 complete sets of components 'Siemens SWT 3.6 - 120' or five complete sets of components 'Senvion 6M's', including tower sections, nacelles, hubs and blades. The port requirements have been assessed on the basis of a large wind turbine installation vessel (WTIV).

The following sections contain component dimensions for generic wind turbines of particular 4 MW and 6 MW nameplate capacities. These are not specific models on the market, and the analysis will need to be repeated when specific turbine models are decided upon to confirm that the conclusions drawn remain valid.

3.5.2.2 Blades

The lightest components used are the blades but their long lengths make them one of the most challenging to handle, particularly onshore.
The following tabulated information (Table 7) contains blade dimensions for generic wind turbines of particular 4 MW and 6 MW nameplate capacities.

Parameter	Generic wind turbine size [MW]	
	4	6
Rotor diameter [m]	120	150
Hub diameter [m]	3	4
Blade length [m]	59	73
Blade mass [t]	19	28
Chord length [m]	4	5
Quayside for storage [m²]	363	527
Bearing area (2 contact blocks under frame [m²]	16	20
Bearing pressure under blocks (3 blades stacked) [t/m²]	3.6	4.2
Fabrication workshop length [m]	69	83
Reinforced area for mobile crane load-outs (crane capacity) [t]	76	112
Haul route strength between quayside and storage [t/axle]	7.8	9.6
Haul route strength between quayside and storage [t/m²]	10	10

Table 7 - Blade specifications and port requirements

Figure 26 - Blade handling trailers for road haulage and handling in port estates

3.5.2.2.1 Onshore transportation and storage

Transportation and storage of wind turbine components at the manufacturing facility shall be required prior to load-out and transport to the pre-staging harbour. Blades are manufactured under the cover of a fabrication facility which has suitable gantry cranes to lift and transfer the blades to bespoke trolleys, which are themselves used to ship the blades to a long/medium-term storage area. Figure 26 presents a wind turbine blade transport vehicle.

Long/medium-term storage of blades requires a large lay-down area, with single or multiple blades held within two frames, one located at the hub and one located along the blade span, as presented in Figure 27.

Where space is limited, multiple blades can be stored in larger frames as presented in Figure 28. The size of the storage frames will be determined by the capabilities of the vessel or quayside crane capacity used to load-out the wind turbine blades from the manufacturing and/or marshalling port.

Figure 27 - Wind turbine blade storage (single frame)

Figure 28 - Wind turbine blade storage (multiple frames)

3.5.2.2.2 Load-out

Load-out of wind turbine blades will be undertaken by vessel-based cranage or, in the case of non-self-propelled transport barges, port-based cranage. The transport vessel shall be required to moor against the quayside to allow for the efficient transfer of the blades from the quayside to the vessel.

Where the blades are being loaded using a single crane, specialist spreader beams will be required to provide two points of contact on the blade, while retaining a manageable under-hook height, as presented in Figure 29.

Figure 29 - Port cranage blade load out

Blades may also be transported as they are stored, in large bespoke transportation frames which can accommodate three wind turbine blades, as presented in Figure 30.

Figure 30 - Three blade load out

3.5.2.2.3 Summary of port requirements for blades

The following key parameters need to be investigated when assessing port facilities for wind turbine blade manufacture, storage and transportation:

- **Fabrication facility**
  Blade length is a major driver for the fabrication facility. A number of blades may be fabricated in parallel, requiring facilities that are wider than the sum of the fabrication moulds used to pre-lay the fiber-reinforced plastic that constitutes the blade structure. Since turbine blades are made of lightweight composites, light internal cranage (overhead gantry) will suffice for the transfer of the blades to their transport trolleys.

- **Load-out**
  Large heavy-lift cargo vessels are best used for transporting blades from the manufacturer to the marshalling port. They are increasingly fitted with container-twist-locked frames and loaded in groups of three at a time, which requires significant cranage lift-weight capacity and outreach only found on larger heavy-lift crane vessels. The installation vessel then typically carries out transportation from the marshalling port to the wind farm.

- **Quayside**
  There is only a light-weight requirement for haulage, but since for manoeuvring it is likely that a 2-bogey unit will be used, which concentrates load and therefore increases the requirement for deck strength. The maximum individual length of a blade will dictate the quayside length, and multiple blade storage alongside the vessel to be loaded will be required.

- **Depth**
  Blades are generally carried long distances as deck cargo on heavy-lift cargo vessels. These large transportation vessels will have a significant draft requirement within the port facility.

- **Mobile cranage**
  Wind turbine blades today weigh in the order of tens of metric tonne, however, these weights are likely to increase as technology trends push towards larger offshore machines. It is likely that transport vessels will load-out significant numbers of blades however blade weights are well within the capacity of suitable mobile cranage.

3.5.2.2.4 Specific port requirements - whole rotor assembly

A number of turbines, particularly the larger machines, have been designed to have the whole rotor pre-assembled before installation. This operation can either be conducted by transporting the hub and blades separately, and assembling the rotor on the deck just prior to installation, or by loading the pre-assembled rotor, as presented in Figure 31. Pre-assembly of rotors onshore requires large port assembly/storage areas.

Figure 31 - Full rotor assembly in port

A rotor is a very bulky object and it is extremely difficult to load installation vessels with more than one rotor per cycle, however to date some operations have transported up to 4 complete 5 MW rotor assemblies. Feeder vessels have been adopted in some cases to transport these unwieldy items to the site.

The rotor has always been transported to the site with its axis vertical (as per Figure 31), and requires specialist hub lifting equipment (as it needs a 90° twist during lift). While this is a complex lifting procedure, it has been carried out successfully by all of the major 5 MW turbine manufacturers offshore, and it appears that this rotor lift will remain the preferred assembly option for large turbines.

3.5.2.3 Tower sections

Tower sections are long and heavy. Just like blades onshore they are typically handled using specialist haulage units (see Figure 32).

Figure 32 - Goldhofer RA3 tower haulage unit

The tabulated information in Table 8 contains tower dimensions for generic wind turbines of particular 4 MW and 6 MW nameplate capacities.

3.5.2.3.1 Onshore transportation and storage

Wind turbine towers are manufactured under the cover of a fabrication facility with a production line set-up where steel plates are rolled into tower cans, which are in turn welded together into tower sections. Bespoke trolleys can be used to lift the tower sections and transport these around the port facility, as presented in Figure 33.

Storage of the towers involves laying them on their sides with bespoke frames providing support at either end and in the middle of the tower section (depending on tower section length), as presented in Figure 34.

Parameter	Wind turbine size [MW] 4	Wind turbine size [MW] 6
Tower length [m]	66	81
Tower mass [t]	185	250
Tower diameter [m]	5.0	6.0
Number of sections	2	2
Section length [m]	33	41
Section mass [t]	93	125
Storage area per section [m²]	245	340
Bearing area [m²]	16	16
Bearing pressure [t/m²]	6	8

Table 8 - Tower specifications and port requirements

Figure 33 - Tower section transportation

Figure 34 - Tower section storage

In port estates it may be more appropriate to handle tower sections using Self Propelled Modular Transport units (SPMTs), see Figure 35.

Figure 35 - Self-propelled modular transport units

SPMTs generally come in 4 or 6 axle units, with individual axle capacities of between 15 and 40 tonne. They can be built into long configurations, and with a few transport cradles, can be used to transport tower units. Great care is needed to ensure that corrosion protection coatings applied to the tower sections are not damaged, so soft faces are provided on these cradles. In general SPMTs can operate on ground with 10 tonne/m² bearing capacity, but by increasing the number of axles used, lower ground bearing capacities can be accommodated, but at a cost premium.

3.5.2.3.2 Load-out

Load-out of wind turbine towers is undertaken by vessel-based cranage or, in the case of non-self-propelled transport barges, port-based cranage. Towers are usually fitted with lift frames at either end of the tower sections which provide lift points for the lifting frames. The frames also allow for towers sections to be stacked on board the heavy lift transport vessel, as presented in Figure 36.

Figure 36 - Tower section vessel cranage load-out

As the tower is vertical when fitted, rather than engage in offshore up-ending during the final installation, it is best if the tower is transferred to the offshore site in an upright position. However, as depicted in Figure 36, during transportation of tower components from the manufacturer's facility to the staging harbour, it is usual to transport the tower sections horizontally.

The upper flange of each tower section has bolted connections which are designed to take the considerable thrust loads of the turbines, so these form ideal points for locating lifting attachments. These are usually fitted to the tower sections before being loaded onto the deck of the installation barge and left in place; they are only removed (and stored until arrival of the next towers) once the tower has been installed in position.

Offshore the towers are heavy and long, and, with the rolling movements of a vessel, are capable of exerting significant loads on the transport vessel's deck. As stated above, the towers are often transported in a vertical position. Ideally, if the whole tower were to be fitted together, this would require only one offshore lift. However, the very long and heavy structure may be too heavy for the crane to lift when in one piece; therefore, transportation in smaller sections is necessary.

Other considerations include whether or not it is economical to design a deck frame substantial enough to react to the considerable loads which sea transits could inflict on the deck, and the difficulty of finding local deck areas with sufficient capacity to accommodate frameworks to withstand these loads from the lower tower flange bolts to bulkheads below decks.

3.5.2.3.3 Summary of port requirements for towers

The following key parameters need to be investigated when assessing port facilities for wind turbine tower manufacture, storage, and transportation:

- **Workshop**
  Workshops with adequate headroom under the cranage will be necessary to ensure the tower bases can be lifted from rolling equipment. Towers require conical rolling, and rolling is more onerous than for cylindrical piles, and tower walls are far thinner so the equipment required is much smaller.

- **Rail**
  The welding of cans (e.g. a can is a plate rolled into a cylinder with the longitudinal seam welded) will benefit from rails to align cans. Rail-mounted rollers will only require lightweight capacities, as tower walls are much thinner than piles.

- **Length**
  Transportation will probably be via barges, but may use HLCVs so the length of the latter has been used as the limit, but this may be reduced if barges to be used are <100 m.

- **Quayside**
  Towers are long components and require a long length heavy duty SPMTs which achieve a lightweight ground bearing pressure.

- **Depth**
  Transportation will probably be via barges, but may use HLCVs so the draft of the latter has been used as the limit, this may be reduced if barges are used.

- **Mobile cranage**
  It is becoming increasingly common to install complete towers offshore to reduce offshore operations, so a large crane capacity may be required.

- **RoRo**
  If rolling load-outs can be used, these may well reduce costs, though this is a desirable feature of the port, rather than a hard limit. The diameters of towers are larger than the height of lorry-trailers (16′ 6″ in the UK), so RoRo quays designed for haulage with restricted headroom are unsuitable – hence the requirement for unrestricted headroom.

- **Haulage**
  Tower sections may well be transported by SPMT or heavy haulage trailer, a minimum number of axles will likely be used to save costs, which may lead to

- **Haulage**
  Tower sections are relatively cheap and may be ordered well in advance of the installation phase, as there is little cost and it reduces the risk of late delivery if production delays occur on a tight timetable. They will then require storage in large numbers and, if laid down, will require individual access for lifting and thus even larger areas. They are not typically stacked when stored horizontally. If space is at a premium they can be stored upright, at the cost of additional cranage, so this must not be taken as a hard limit.

3.5.2.4 Nacelle

Nacelles are amongst the heaviest pieces which require transportation, but their relatively compact size makes them easier to handle. They are highly complex pieces of machinery, and have precision finished steel flanges and internally have high-value mechanical and electrical and electronic components, so should not be stored in areas where there is an environment of either dust or iron ore. Port areas where there is bulk loading or offloading of coal are generally avoided, but sites where iron ore is handled are also unsuitable for nacelles, as the magnetised iron can attach to machined steel components and can cause accelerated corrosion or mechanical damage.

The following tabulated information (Table 9) contains nacelle dimensions for generic wind turbines of particular 4 MW and 6 MW nameplate capacities.

Parameter	Wind turbine size [MW]	
	4	6
Nacelle mass [t]	162	330
Storage, lift and sea lashing frame mass [t]	16	33
Nacelle and frame total mass [t]	178	363
Nacelle width [m]	5.2	7.4
Nacelle length [m]	13	18
Nacelle storage area [m^2]	111	185
Number of rows of SPMT's	1	1
Number of lengths of baulk timber	2	2
Nacelle bearing area [m^2]	27	35
Bearing pressure (baulk timber under columns) [t/m^2]	7	10
MIn. number of SPMT axles for nacelle	8	15

Table 9 - Nacelle specifications and port requirements


Source: ALE

Figure 37 - Siemens SWT 3.6 on SPMT trailer

3.5.2.4.1 Onshore transportation and storage
Wind turbine nacelles are manufactured under the cover of a fabrication facility which has suitable gantry cranes to lift and transfer components that constitute the nacelle (gearboxes, generators, etc.). Upon leaving the fabrication facility, nacelles are usually transported around the port facility using SPMTs, as shown in Figure 37.

Bespoke frames are mounted on the tower-top flange which provides support for the lay-down of the nacelles. The nacelle is pre-assembled before offshore transportation. It will be watertight and effectively complete when leaving the manufacturer's facility.

For offshore wind turbines, though the components themselves may have been sourced from specialist manufacturers worldwide, the final assembly of turbine nacelles occurs adjacent to the water.

Source: Vattenfall

Figure 38 - Port cranage nacelle load-out

3.5.2.4.2 Load-out
Load-out of wind turbine nacelles will be undertaken by vessel-based cranage or, in the case of non-self-propelled transport barges, port-based cranage, as presented in Figure 39. The transport vessel shall be required to moor against the quayside.

The frame mounted on the tower-top flange may be used to ensure that the connection between the nacelle and the deck is of adequate structural strength to tolerate the accelerations, which the cargo will endure during transit. The weight of this frame therefore needs to be considered in any load-out lift.

It can have a further function, which is to speed connection to rolling and floating transport. There will be some form of bolted or welded connection on the underside, which is designed to marry with a pre-installed mating part, fitted to a structurally sound area of the deck. This ensures rapid assembly and offshore removal of sea lashings, and helps to precisely align the cargo with the under deck stiffening of the vessel's structure.

The sea-lashing frame may also form a lifting cradle, to which lifting tackle on a custom spreader beam arrangement attach, for swift lifting during loading and unloading. This optional functionality may add considerable weight to the frame, and it may be preferable simply to attach lifting tackle to the upper structure of the nacelle.

Source: Renewableenergyfocus

Figure 39 - Crawler crane nacelle load-out

3.5.2.4.3 Summary of port requirements for nacelles

The following key parameters need to be investigated when assessing port facilities for wind turbine nacelle manufacture, storage, and transportation:

- **Fabrication facility**
  Fabrication facilities for the final assembly of nacelles will require cranes individually capable of handling the largest components. Electric Over-Head Travelling (EOHT) crane capacity of up to 75 tonnes may be required for the movement of components within the facility. The nacelles will likely be built with the capability for SPMTs to manoeuvre underneath the nacelle's tower-top flange crane, jack-up and transit out of the facility.

- **Haulage**
  A maximum ground bearing pressure resulting from the use of SPMTs of 10 tonne/m^2 has been assumed and this will be a requirement of all haul routes from storage areas to load-outs.

- **Storage**
  Nacelles are principally stored on frames, with the frame bolted to the nacelle at the tower/nacelle transition.

- **Load-out**
  It is vital in this case that any quayside can accommodate heavy-lift cargo vessels, as components will be sourced worldwide, so both material input and delivery of manufactured items may well involve large cargo vessels.

- **Quayside**
  Nacelles are usually transported by SPMT so it will be possible to vary the number of units used to ensure that ground bearing pressure is within acceptable limits.

- **Depth**
  Nacelles are generally carried long distances as deck cargo on heavy-lift cargo vessels, possibly the same vessels used to transport blades. These large transportation vessels will have a significant draft requirement within the port facility.

- **Seabed**
  Large offshore wind farm installation vessels may well collect turbines from manufacturer's premises so jack-up capacity will be required of the quayside. Measurements of the soil strength adjacent to the quayside will be needed to ensure that layering of sub strata does not include thin hard layers of soils overlaying weaker soils to avoid jack-up leg punch-through.

- **Mobile cranage**
  The largest offshore nacelles today weigh in excess of 300 tonne; however, these weights are likely to increase as technology trends push towards larger offshore machines. It is likely that transport vessels will load-out significant numbers of nacelles. Multiple 350 tonne mobile cranes would provide adequate capacity for load out.

- **RoRo**
  Rolling load out is cheaper than lifting in some circumstances, so this capacity is desirable.

3.5.3 Foundations - monopiles and transition pieces

Given the relative size of monopiles and transitions pieces, compared with other foundation solutions, it is possible to manufacture and transport these to staging harbours using heavy-lift transport vessels. Once mobilised at the staging port, suitable installation vessels are used to transport the foundations to the wind farm site for installation.

Monopiles are generally transported and stored horizontally, but because of the more delicate secondary steelwork, transition pieces are generally transported and stored vertically (see Figure 40).

The tabulated information in Table 10 contains monopile and transition piece dimensions for generic wind turbines of particular 4 MW and 6 MW nameplate capacities. The dimensions and masses have been derived from DNV GL's in-house foundation database.

Figure 40 - Monopiles and transition pieces in port storage area

Design depth [m]	Parameter	Wind turbine size [MW] 4	6
–	TP (Transition Piece) mass [t]	280	550
	TP min number of SPMT axles	12	22
	TP Storage area [m²]	82	101
	TP Bearing area [m²]	11	13
	TP Bearing pressure [t/m²]	25	42
20	Monopile mass [t]	500	1,076
	Monopile min number of SPMT axles	20	44
	Monopile base diameter [m]	5.5	6.5
	Length [m]	56	66
	Storage area [m²]	435	578
	Total bearing area (10 block supports) [m²]	40	40
	Bearing pressure under blocks [t/m²]	13	27
30	Monopile mass [t]	675	1,464
	Monopile min number of SPMT axles	27	59
	Monopile base diameter [m]	6	7
	Length [m]	69	79
	Storage area [m²]	568	729
	Total bearing area (10 column supports) [t/m²]	40	40
	Bearing pressure under blocks [t/m²]	17	37

Table 10 - Monopile specifications and port requirements

The following information details the port requirements for manufacturing facilities as well as staging ports:

- **Width**
  The access channel width requirement should be qualified by stating that port access widths are customarily quoted as being the widest beam of two equally sized vessels which can pass through the narrowest part of the port approaches, whether this is the port's dredged access channel, harbour entrance or other restriction.

- **Heavy-lift cargo vessel drafts**
  It will be necessary for heavy transport to transit the monopiles between the manufacturer and the staging port if the monopiles are fabricated overseas. The transportation of monopiles using heavy lift cargo vessels will ideally require approximately 8 m to Chart Datum of water.

- **Installation vessel drafts**
  It will also be necessary for either an installation (jack- up) vessel to transit the monopiles between the staging port and the wind farm site or for bunged monopiles to be towed by a tug. The transportation of monopiles using a jack-up vessel will ideally require approximately 6 m to Chart Datum of water.

- **Headroom**
  The headroom requirement for the installation port was based upon the assumption that there is a strong possibility that a jack-up vessel or feeder barge will be used to carry the monopile from the port, and carry out the installation. During marine transit the legs are above the water, so they are unlikely to be able to pass under many bridge decks and power lines. For this reason it is important that the vessel options are well understood when considering available staging ports for a project. Overhead clearance of at least 40 m or more is typically required. There is no such requirement for the manufacturing base.

- **LOA**
  There is a range of overall lengths for heavy lift cargo vessels approaching 170 m, so to ensure future-proofing it is suggested that a figure of 170 m LOA port access be used, as this will be adequate for all but a small minority of these vessels.

- **Quayside**
  The usual method of transport of monopiles is SPMT units (see Figure 41) imposing ground-bearing pressures of approximately 20 tonne/m². As has been previously stated, this is not an absolute limit but is a reasonable capacity, which will be able to accommodate most types of units.

Figure 41 - Monopile onshore transport using SPMTs

- **Mobile cranage**
  If the cranage is placed so that the outriggers are adjacent to the quay wall, the sheet piling in an unsupported quay wall would experience loadings which may be enough to collapse the quay. It is customary for monopiles to be lifted by two cranes in a lift configuration referred to as being "top-and-tailed". The individual lift-weights are reduced by half, so figures of 1,000 tonne have been included to cover various anticipated lift configurations. The lift-weight of transition pieces is significantly less than that of their associated monopiles. There is therefore a reduced cranage requirement of 400 tonne.

- **Seabed**
  The seabed adjacent to the quayside will have a finite capacity to support loads, and may or may not be suitable to support a jack-up vessel, if it wanted to self-load from the quayside using the on-board crane.

- **Haul routes**
  The exact transit routes by which heavy loads are to transit from any storage areas to the quayside need to be defined, and the deck strength of any paved areas assessed to ensure that they are sufficient to support SPMTs and their payload.

- **Storage**
  Areas that are used for long-term storage of monopiles will be required to have sufficient deck strengths to accommodate the feet loads of storage frames. SPMT loading and unloading methodology is to pass under the load to be lifted and then jack up their upper load-bed, to raise-up and lift the payload. After transit to the destination, the jacks are lowered and the load is then again supported on the ground by the frame, and the SPMT is free to move out from under the load. Transition pieces are usually stored vertically, which avoids damage to paintwork. This means that the plan area required is about 10 m x 10 m to allow access around the structure.

Figure 42 - Jacket transportation on the quay

Figure 43 - Jacket storage on the quay

3.5.4 Foundations - jackets

Jacket structures for offshore wind turbine purposes are usually manufactured and delivered directly to the wind farm site using deck barges. Once mobilised at the wind farm site, a suitable installation vessel is used to install the structure. The present section details the port requirements for the manufacture, storage, and load-out of the jacket structures.

In the European market to date, all projects that utilise jacket foundations have involved turbines of greater than 4 MW. However, jackets are planned to be used in PR China and Taiwan for smaller turbines where ground conditions or vessel lift capacities are not conducive to the installation of monopiles.

In addition, it is unlikely that jackets would prove an optimal solution for a turbine in water depths of less than 30 or even 40 m, given the trend towards XL monopiles in recent years. However given the embryonic nature of the offshore wind industry in India and the possibility of fabrication restrictions for XL monopiles in the early development years, dimensions for jackets supporting 6 MW turbines in water depths of both 30 and 40 m below LAT have been considered. As with China Mainland and Taiwan, this is not to say that 4 MW WTGs deployed on jacket foundations could not be utilised if a suitable combination of environmental and supply chain conditions are found to exist in India.

The tabulated information in Table 11 contains jacket and pin pile dimensions for generic wind turbines of 6 MW nameplate capacities. The dimensions and masses have been derived from DNV GL's in-house foundation database.

The following information details the port requirements for manufacturing facilities as well as staging ports:

- **Width**
  The access channel width requirement should be qualified by stating that port access widths are customarily quoted as being the widest beam of two equally sized vessels which can pass through the narrowest part of the port approaches, be this the port's dredged access channel, harbour entrance, or other restriction.

- **Feeder barge drafts**
  It will be necessary for feeder barges to transit the jacket structures between the manufacturing port and the wind farm site. The transportation of jackets using barges will require a maximum of approximately 5.0 m of water below the Chart Datum (LAT).

Design depth [m]	Parameter	Wind turbine size [MW] 6
30	Jacket mass [t]	613
	Pin piles (4) mass [t]	328
	Number of SPMT axles	25
	Jacket leg separation [m]	17
	Height (leg base to TP) [m]	48
	Storage area (laid down) [m²]	1.302
	Storage area (standing) [m²]	441
	Bearing area (4 block supports to distribute load) [m²]	48
	Bearing pressure under blocks [t/m²]	13
40	Jacket mass [t]	684
	Pin piles (4) mass [t]	328
	Number of SPMT axles	28
	Jacket leg separation [m]	23
	Height (leg base to TP) [m]	58
	Storage area (laid down) [m²]	1.674
	Storage area (standing) [m²]	729
	Bearing area (4 block supports to distribute load) [m²]	48
	Bearing pressure under blocks [t/m²]	14

Table 11 - Jacket specifications and port requirements

- **Headroom**
  The headroom requirement has been based upon the assumption that the jacket will be stood upright upon the barge used to carry it out to the wind farm site. The likelihood is that this transit will be aboard a deck barge which will have low freeboard, so the figure of 75 m has been chosen to accommodate a 65 m high jacket aboard a barge with 5 m freeboard and to have a 5 m clearance. It is possible that the jacket could be loaded aboard a heavy-duty cargo vessel, but since there are always two cranes available and offshore upending is a practicable option, it has been assumed that the jacket would transit horizontally under these circumstances. It still remains a recommendation that only ports with unrestricted headroom be used as jacket installation ports, where possible.

- **LOA**
  Barges are likely to transport up to three jacket structures at any one time (see Figure 44), thereby requiring an overall length of the order of 90 m LOA port access.

- **Storage**
  The likely means of transport will still be SPMTs, but the ground bearing pressure required by SPMT units is likely to be lower than for monopiles, or can be arranged to be such, as the jacket is much larger in size and of reduced weight. This means SPMT arrangements can be set up which imposes ground bearing pressures of approximately 10 tonne/m^2. This figure is not an absolute limit but a reasonable capacity, which will be able to accommodate most types of unit.

- **Mobile cranage**
  If the cranage is placed so that the outriggers are adjacent to the quay-wall, the sheet piling in an unsupported quay-wall would experience loadings which may be enough to collapse the quay. It is unlikely that the jacket structure will be lifted by a single crane, and two cranes and spreader beams are envisaged. The maximum dead mass will be in the order of 700 tonne, so with half-load per crane a figure of 350 tonne has been taken.

- **Haul routes**
  The exact routes by which heavy loads are to transit from any storage areas to the quayside need to be defined, and the deck strength of any paved areas assessed to ensure that they are sufficient to support SPMTs and their payload. The transport of jacket structures will require considerable width and turning circles.

Figure 44 - Jacket load-out onto deck barges

3.5.5 Foundations - gravity base structures

Gravity Base Structures (GBS) transmit wind turbine loads to the sea bed using the mass of the structure to provide lateral stability. This simple concept makes GBSs suitable for a range of water depths. However, due to their size, they are difficult to handle and are therefore transported directly to the wind farm project site from the chosen manufacturing facility.

Table 12 displays generic specifications for GBSs at an assumed design depth of 40 m below LAT and supporting a 6 MW turbine. These are example specifications of generic foundations and are intended only to inform port requirements. Much of the experience of gravity bases at offshore wind farms are at relatively shallow depths of < 25 m, but the range at which GBS designs are now considered feasible extends to deeper waters.

GBSs can be considered for shallow waters in India under the right seabed conditions where hard scoured and fractured rock sea-beds are suitable. Whilst it seems unlikely that GBS's will prove a favoured solution in Gujarat, since the ground conditions are not known to be suitable across the identified development zones A to H, it should be noted that further seabed data is required to substantiate this conclusion in future FOWIND studies.

Parameter type	Parameter	Wind turbine size [MW] 6
General	Total mass without ballast [t]	5,970
	Diameter [m]	39
	Area of base [m²]	1,260
Quayside construction	Clearance around base during construction [m]	10
	Construction area (per GBS) [m²]	3,481
	Bearing area (quayside construction and storage) [m²]	504
	Bearing pressure (quayside construction and storage) [t/m²]	12
	Number of SPMT axles required to transport GBS	239
Dry dock construction	Un-ballasted bearing pressure distributed [t/m²]	5
	Clearance around base during dry dock construction [m]	3
	Minimum width of dry dock [m]	45
Barge construction	Clearance around base during barge construction [m]	2
	Minimum barge width [m]	27 or 32
	Barge length [m]	97 or 121
	Harbour area (per barge) [m²]	4,300
	Barge draft [m]	5

Table 12 - GBS specifications and port requirements for 40 m design depth

It however seems possible that GBSs may be feasible in Tamil Nadu, given the known presence of coral-rock below ground and the problems which piling related noise-pollution could cause, given the environmental sensitivity of the area.

It is clear from these specifications that the biggest requirement that GBS foundations impose upon ports is their sheer size, particularly their weight. To date, three methodologies have been developed for GBS construction. Each of these methods has its advantages and disadvantages and their appropriateness varies with GBS design and port capabilities. The methods are described in Sections 3.5.5.1 to 3.5.5.3 with the port requirements for each concept.

3.5.5.1 GBS Construction on quayside

Construction on the quayside will often require reinforcement of the quay as both the total mass and the bearing pressure applied are significant. An example of a project where reinforcement was required is Thornton Bank, located in Belgian waters (see Figure 45).

Figure 45 - Construction of GBS on the quay (Thornton Bank)

Construction of GBSs adjacent to the quayside allows the structure to be lifted directly for installation using a heavy lift vessel such as the Rambiz or Svanen. The wall of the quayside may need to be reinforced due to the forces imposed on it during this load-out. If it is not possible to site the substantial construction area required adjacent to the quayside then SPMTs can be used to haul the GBS for load-out.

Average bearing pressure for the port is the mass of the un-ballasted structure divided by the area – typically approximately 60 kPa or 6 tonne/m². In addition, if transport by SPMTs is necessary, the mass of the GBS will be distributed through the wheels of the SPMT with an axle load of up to 30 tonne per axle. Whether this is acceptable for individual ports is dependent on quayside but load spreading can help meet this requirement.

The following criteria need to be investigated when constructing GBSs on the quayside:

- **Width**
  The largest of the heavy-lift vessels used to install GBS structures is Svanen at 74.6 m beam, so a limit of 75 m has been selected to give minimum clearance. If a heavy lift vessel of reduced beam was selected, this criterion could be reduced.

- **Headroom**
  The headroom requirement has been based upon the assumption that a large sheerleg vessel will be used to carry out the installation. Svanen requires clearance of over 100 m, so it cannot realistically pass under any marine structures. Therefore, unlimited headroom is specified.

- **Depth**
  The largest of the heavy-lift vessels used to install GBS structures is Svanen, with a lift capacity of 8,700 tonne and a 6 m fully laden draft.

- **GBS fabrication area**
  The installation port is usually the point of manufacture of the GBS. A large area is required for GBS fabrication, as these structures tend to have plan areas of at least 30 m square. An area of 45 m x 45 m or ~2,000 m^2 per base gives a 15 m clearance around the base.

3.5.5.2 GBS Construction on barges

Barges are an attractive option for the construction of GBS structures, as they can be used in almost any port due to their minimal draft requirements.
This construction method is viable for GBSs as long as a barge large enough for the foundation can be found. Bearing in mind that the example base diameters given previously are representative of gravity bases on fairly strong soils (350 kPa allowable bearing pressure), the area can increase to the point where extremely large barges are required to accommodate construction.

Where barges are used, installation can be performed from a variety of vessels including existing heavy-lift vessels such as the Eide 5 barge used on Nysted or Rambiz used on Thornton Bank. As the construction occurs on barges, the GBS units can be towed on the construction barge to the wind farm site for installation, which removes the requirement for the installation vessel to interact with the port facility.

Figure 46 - GBS lift off construction barge using Eide 5 heavy-lift barge

The following criteria need to be investigated when constructing GBSs on barges:

- **Width**
  Port access channel of suitable width for construction barges (30 m standard barge width, increasing with GBS size).

- **Headroom**
  As above unlimited headroom is specified.

- **Depth**
  Water depth suitable for construction barge (> 5 mLAT).

- **Port berthing area**
  Significant port space available for long-term rent (several barges at > 30 m x 100 m).

3.5.5.3 GBS Construction in dry dock

Construction of GBSs within dry dock facilities with a float-out of the structure reduces the requirement for large installation vessels capable of lifting the whole GBS, thereby reducing vessel costs (see Figure 47). Dry dock space is more expensive then general port space, but extremely large GBS designs can be constructed in dry docks as the float-out allows some or all of the mass to be taken by the buoyancy of the GBS, thereby reducing required crane size.

The challenge with dry dock construction is producing at a sufficient rate for commercial installation considering the limited availability of suitable dry docks. Installation vessels for this construction method depend on the buoyancy of the design.

Figure 47 - GBS construction in a dry-dock facility (or graving yard)

The following criteria need to be investigated when constructing GBSs in dry dock facilities:

- **Width**
  For a lifted design a port access channel of suitable width for the installation vessels would be required. If a buoyant design the minimum width would be a safe clearance on the foundation width (assumed the structure is towed to site by tug vessels).

- **Headroom**
  Port access channel with unlimited headroom.

- **Depth**
  For lifted design, water depth suitable for installation vessels (> 6 mLAT). If a buoyant design the draft of the gravity base structure would need to meet the constraints of the launch site and transit channel.

- **Dry dock area**
  Large dry dock of width greater than the GBS.

3.5.6 Substation

The offshore substation consists of a topside (see Figure 48, right) containing the electrical equipment and a foundation (see Figure 48, left) which supports the topside.

3.5.6.1 Topside port requirements

Substation topsides represent the heaviest item in an offshore wind project, typically weighing 2000 to 4000 tonne. This extremely heavy mass and large size means substation topsides tend to require similar port requirements to GBS foundations.

As discussed in section 3.5.3, the topside will often be lifted directly off the quayside for installation by a heavy-lift installation vessel such as Rambiz or Svanen. The installation port must be able to accommodate such large vessels. If a separate port is used for manufacture and assembly, but not installation, then the manufacturing port must also be able to handle heavy-lift vessels, or have a large enough crane in port to load-out onto a transport vessel. Due to the difficulty of handling large substations, they will typically be installed directly from the manufacturing port.

As with GBS foundations, the typical transport methodology for substation topsides within the port is via SPMTs due to the large weights of the substation topside (typical load per axle of an SPMT is 30 tonne/m^2). Smaller substation topsides may also be carried within the port by crawler crane, but this becomes problematic as larger sizes are reached.

Some large projects and those far from shore utilise multiple offshore substations, and this approach can hence reduce the substation topside sizes and handling requirements. For example the 630 MW London array has two HVAC offshore substations, this not only reduces

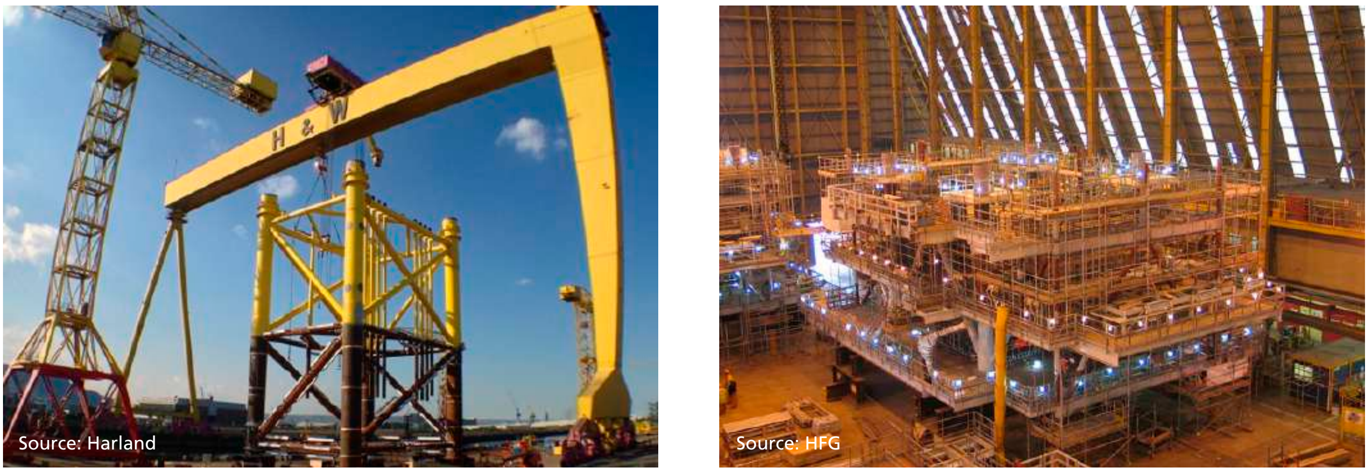


Figure 48 - Offshore substation jacket foundation and topside

the topside mass compared with having one platform but it also provides redundancy for the electrical distribution system. A further example is in Germany where many projects are >100 km offshore and HVDC transmission is utilised. In this case offshore substations are required to both step-up AC voltages from the array but also to convert AC to DC electricity for transmission to shore. For example the Borwin 1 substation, weighing 3200 tonne, is only performing the AC to DC conversion, the voltage already having been stepped up by the Bard 1 offshore substation.

The following criteria need to be investigated when constructing the topside of an electrical substation onshore:

- **Width**
  Port access channel of suitable width for installation vessels (> 75 m).
- **Headroom**
  Port access channel with unlimited headroom (based on Svanen).
- **Depth**
  Water depth suitable for installation vessels (> 6 m LAT).
- **Quayside**
  Quayside reinforced for assembly and storage of topside (> 2,500 tonne at 20 tonne/m^2).
- **Load-out**
  (1) RoRo load out would require a heavily reinforced quayside similar to those required for an O&G topside, e.g. 20 tonne/m^2 (2) Lifted load-out typically requires two heavy lift crawler cranes working in tandem (3) Lift and carry load-out uses the installation vessel to directly lift topside from the quay.

3.5.6.2 Substation foundation port requirements

Offshore substation foundations are typically jacket structures weighing 700 to 1000 tonne. However monopiles or GBS foundations are also possible and have been deployed. For the purpose of this study jackets are considered henceforth.

The first approach in selecting a substation foundation is to verify whether the wind turbine foundation type selection can be extended to the substation (possibly scaled up or slightly modified), which will reduce costs. The lower the substation's weight, the smaller the change in design required for the substation foundation compared with the wind turbine foundations. If possible these synergies may result in less costly manufacturing and installation.

In deeper waters or in cases of very large substation weights where the project's turbine foundation concept cannot be viably used for the substation, jacket foundations are often selected. While this report provides figures for foundation port requirements, substation foundations will typically be larger and heavier. Also, they are less tapered, due to the large area of the substation.

The following criteria need to be investigated when constructing the foundation of an electrical substation onshore:

- **Width**
  Port access channel of suitable width for installation vessels (> 75 m)
- **Headroom**
  Port access channel with unlimited headroom (based on Svanen)
- **Depth**
  Water depth suitable for installation vessels (> 6 mLAT)
- **Quayside**
  Quayside reinforced for assembly and storage of the jacket (> 1,000 tonne at 20 tonne/m^2)
- **Load-out**
  (1) RoRo load out would require a heavily reinforced quayside similar to those required for an O&G jacket, e.g. 20 tonne/m^2 (2) Lifted load-out typically requires heavy lift crawler cranes (3) Lift and carry load-out uses the installation vessel to directly lift jacket from the quay.

3.5.6.3 Self-installing substation port requirements

Notable deviations from the above requirements are self-installing and floating substation designs (see next page, Figure 49, left). Self-installing designs come with an incorporated jacking foundation, where the legs can simply jack up at site to secure the substation in place. Floating designs can be attached to a pre-laid base-frame upon installation (see next page, Figure 49, right). Both designs require only transport to site, which can be done by tug, after they are placed in the water at the port. As such, port requirements are reduced to either the crane capacity to place the substations in the water, a sufficient slipway, or a dry dock within which to construct the substation.

Figure 49 - Self-installing and floating substation designs

3.5.7 Wind farm electrical plant

Electrical cabling for an offshore wind farm includes both the inter-array cables connecting strings of wind turbines to the substation and the export cables connecting the offshore substation to the onshore substation. Both cables can be produced by a single manufacturing port facility. Where a staging port is used, the cable vessels and cable handling impose similar requirements as encountered at the manufacturing port.

3.5.7.1 Array cables

Array cables are lighter than export cables, weighing approximately 20 to 40 kg/m depending on the location within the array and the material (copper is heavier than aluminium).

It is more common for array cables to be stored at a staging port as they are lighter, can be transported in shorter lengths, and are more flexible and therefore less onerous to handle. In addition to being wound onto an on-board carousel, turntable, or cable tank, array cables can also be lifted pre-wound from the port to the vessel deck. By lifting the cables on drums, using the staging port becomes more practical.

For array cabling, the advantage of using a staging port is that it allows the cabling to be transported using a HLCV rather than a specially equipped cable vessel. Such a vessel can travel faster, with lower fuel burn.

To load a pre-wound cable drum onto a vessel requires a heavy crane lift, so the port must be able to accommodate a heavy crane to achieve this. Alternatively, a heavy lift cargo vessel may be able to pick up the array cables pre-wound using its on-board crane.

Where pre-wound cable drums are used, each will be loaded with enough cable to connect at least a string of wind turbines. The total load out of array cable may be split across a number of drums.

Manufacturing port requirements are the same as for export cables, as similar cabling vessels will be used, and similar infrastructure is required to handle the cabling. One additional requirement of the port, if the capacity to lift cable drums is desired, is for a heavy crane.

The following criteria need to be investigated for Manufacturing Port requirements for Array Cables:

- **Width**
  Port access channel width for cable installation vessels (> 28 m).
- **Depth**
  Water depth suitable for cable installation vessels (> 5 mLAT).
- **Quayside**
  Quayside length adequate for installation vessels (LOA > 100 m).
- **Workshop**
  Long fabrication workshop (>100 m x 10 m) and the facility should be located adjacent to quayside.
- **Cranage**
  Heavy lift crane adjacent to quayside (if lifting of drums is desired).

As staging ports may be used to store cable, a crane or a carousel to load and unload cables may be required. The crane would need to be adjacent to the quayside and sufficient space for cable storage would be needed. In the case of a carousel, storage is covered by the carousel itself.

The following criteria need to be investigated for Staging Port requirements for Array Cables:

- **Width**
  Port access channel width for cable installation vessels (> 28 m).
- **Depth**
  Water depth suitable for cable installation vessels (> 5 mLAT).
- **Quayside**
  Quayside space for crane and cable storage or carousel.

Figure 50 - Offshore wind cables stored onshore

3.5.7.2 Export cable

Export cables impose certain specific requirements to a construction program due to their extreme length and weight. Taking into account the difficulties in joining cables offshore, it is usually desirable to fabricate and load the entire export cable onto a vessel in one continuous length. A typical load-out speed is approximately 6 m/min or almost 9,000 m per day. This means that an export cable load out for an offshore wind farm will typically take a period of several days, excluding initial setup of the load-out. In order to avoid the inconvenience and risk to cables of off-loading and reloading cable at a staging port, and due to the specialized equipment required (extremely large cable carousels) for cable transport and storage, it is usual for installation to occur directly from the manufacturing port (see Figure 51).

Figure 51 - ABB's high-voltage manufacturing facility in Sweden

As discussed above, the majority of export cable installations will be performed by transiting to the site directly from the manufacturer. The demands export cable manufacturers place on ports are driven by the availability of premises for fabrication near the quayside for direct load-out of cables, and for large areas for the manufacturing of cables. In addition, the ground must have reasonable strength to withstand the mass of the cables (these are closely coiled, with an AC export cable weighing approximately 70 to 100 kg/m).

For a cabling manufacturing site, a surface area of approximately 70,000 m^2 is recommended, though this will vary significantly depending on estimated rates of production. Storage of cables will usually utilise turntables measuring approximately 30 m in diameter with a bearing pressure of 10 tonne/m^2 at capacity. As such, the storage area may need to be reinforced, but this can be a distance away from the quayside loading area as long as there is a direct path for feeding the cable to the vessel.

Cable laying vessels used on offshore wind farms have lengths of up to 130 m, so a minimum length of port quayside of 150 m is recommended for safety, though most cable vessels are less than 100 m. Due to the long load-out time, the cabling port must have sufficient draft for the fully laden vessel at low tide.

The following criteria need to be investigated for Manufacturing Port Requirements for Export Cables:

- **Width**
  Port access channel width for cable installation vessels (> 28 m).

- **Depth**
  Water depth suitable for cable installation vessels (> 5 mLAT).

- **Quayside**
  Quayside length adequate for installation vessels (LOA > 100 m).

- **Workshop**
  Long fabrication workshop (> 100 m x 10 m) and the facility should be located adjacent to quayside.

It should be noted that cabling manufacturers will often serve the telecoms markets as well, so manufacturing port requirements are often also intended to match the needs of submarine communications installation.

Figure 52 - Busy scene during construction of Thanet OWF

3.6 Vessels

3.6.1 Introduction

This section specifics different types of vessels used in offshore wind farm construction, including their limitations, specific construction roles and port access requirements.

Figure 52 shows the 300 MW Thanet offshore wind farm under construction in 2010, this represents a common marine operations scene for large scale offshore wind. It is easy to see that there are a number of vessels simultaneously operating, a situation abbreviated as SIMOPS. In the foreground Normand Mermaid is engaged in laying array cables. A workboat is passing through the scene possibly transporting a turbine commissioning team. The Stanislav Yudin, a 2,500 tonne crane vessel is engaged in placement of the substation topside. In the far distance the jack-up MPI Resolution is engaged in turbine installation.

In these situations operations must be meticulously managed and close attention must be given to good practice guidance regarding the governance of such circumstances in order to ensure the safety of all crew, vessels and equipment. The IMCA guidance on SIMOPS is well regarded in this respect[9].

A number of vessel types have been developed, adapted or have been proven directly suitable for OWF installation in Northern Europe (see examples in Figure 53 and descriptions in later sections).
It has been assumed a similar range of vessels may become available for the construction of OWFs in India. Their key dimensions have been used within this study to establish the approximate physical size of port facilities required in India.

It should be noted that the actual vessel overall dimensions have been used to establish whether a port passes or fails the initial screening. In reality, a safe clearance would be required on both the vessel beam and its draft etc, but since there is a range of vessels in each class considered, it is reasonable to suppose that at least some specific vessels within each class would be suitable. Hence the vessel selection criteria within the port study (Section 3.9) is simply based on the key vessel characteristics.

[9] IMCA IMCA M 203 - Guidance on simultaneous operations (SIMOPS) - www.imca-int.com

Towed 'dumb' barge with crane

Shearleg crane-barge

Semi-submersible/heavy-lift vessel

DP2 Heavy-lift cargo vessel

Leg-stabilised crane vessel

Self-propelled jack-up

1. Stemat 79 2. Taklift 7 3. Thialf
4. Jumbo Javelin 5. Sea Energy 6. MPI Resolution

Figure 53 - A selection of vessel types used during OWF installation

The remaining Sections 3.6.2 to 3.6.8 describe the key characteristics for different offshore wind vessel classes. Section 3.6.9 describes the suitability of different vessel classes for different construction activities.

Section 3.6.10 presents a high-level preliminary screening for vessels known to be available in India. Section 3.6.11 summarizes typical vessel port access requirements in terms of draft (depth) and beam (width).

3.6.2 Dumb barge

3.6.2.1 Vessel characteristics

The cheapest floating lift-craft is formed by placing a land-based crane on to a dumb barge. This is the most common type of vessel used to support river, coastal and estuarine marine construction projects, see Figure 54.

The 360° rotational capability of the crane, coupled with a reasonable lift capacity, potentially greater than 100 tonne, means that it is a versatile vessel. This type of vessel is often used for piling and maintenance of ports and harbours. Grabs, grapples or dragline buckets can be fitted to the crane for rock-armour handling, dredging, or material handling duties, and man-cradles allow inspection of marine structures.

The barge can be fitted with retractable legs, called spud-legs. When the crane is towed into position, by a tug, the legs are lowered to the seabed, and this both locates the craft in position, and if the legs are clamped provides some additional stability when lifting – but should in no way be considered as an equivalent to the stability provided by the legs of a jack-up.

Dumb barges are the most basic of craft, and any additional equipment to enhance their capability must be added to the deck of the barge. This often includes items from the following list:

- Accommodation, storage, containerised diving-support units and office units
- Generators, compressors, fuel bowsers, scour protection, and grouting equipment and materials
- Mooring winches, anchors, mooring cable, or array cable etc.

Figure 54 - Dumb barge with spud-legs, and crawler crane

3.6.2.2 Possible offshore wind roles

The limited stability of this configuration of craft means that it is unsuitable to act in the role of the principal installation vessel. However, crafts of this type will often be used for a multitude of small roles on any offshore construction site, and may fulfil the role of a feeder vessel – but offshore unloading will most likely be carried out by the main installation vessel in all but the most benign sea conditions.
Table 13 illustrates the key features and dimensions of a typical dumb barge.

Dimension	Value [m]
Length	91
Beam	27
Draft - laden	5.0
Air draft (with jackets on-board)	80

Table 13 - Key dimensions of a typical dumb barge

This type of vessel has not found widespread use in Northern European offshore wind farms sites, but is quite capable of carrying out operations like pre-piling duties for jackets in benign weather windows.
Other foundation placement roles could conceivably be carried out in shallower sites. In a number of UK sites, cable-runs pass through very shallow or drying areas, and crane barges of this type have found roles trenching using airlifts, or other digging equipment, and are then available to support main-line installation should conditions be suitable.

It has totally inadequate stability to carry out the turbine installation function.

3.6.3 Self-propelled and towed jack-up craft

These two distinct types of vessel have been placed under a single class heading for simplicity because, aside from their means of propulsion, they fulfil similar roles in offshore wind construction.

3.6.3.1 Vessel characteristics

Early smaller wind farms (less than 100 MW) used one individual jack-up vessel for virtually every conceivable operation on a piled foundation windfarm, because it was most economic to use one versatile vessel for all tasks. This is a contrast to today's multi 100 MW wind farms where a number of customised vessels are mobilised to carry out specific roles.

The type of jack-up vessel shown in Figure 55 (towed self-elevating platform) has been in use within the marine construction and offshore oil-rig maintenance and conversion markets for many years.

Figure 55 - Fugro Seacrore's Excalibur towed jack-up installing a monopile

The towed jack-up or self-elevating platform (SEP) is effectively a dumb barge with a heavily stiffened hull retro-fitted with jack-legs. Early usage of these vessels was primarily focused on inshore marine construction where a flexible deck layout was required to meet site specific needs. However today jack-ups used in the wind industry have permanent fitted cranes.

As offshore wind projects have grown is number, MW capacity and complexity (e.g. larger capacity farms, larger/heavier WTGs with higher hub heights and bigger foundations) a new class of jack-up vessel has evolved to meet these specific industry demands and have become known as the Wind Turbine Installation Vessel (WTIV), see Figure 56.

Jack-up vessels are often referred to as jack-up barges or JUBs and may be fitted with a number of propulsion types:

- diesel or diesel/electric propellers, with or without azimuthing thrusters
- dynamically positioned vessels with diesel/electric azimuthing thrusters, and bow thrusters
- no propulsion at all i.e. towed jack-up barges

The leg-jacking mechanisms are generally hydraulic jacks, but the means of connection between the jacks and the legs can be:

- hydraulic pin-jacked
- pneumatically gripped
- rack and pinion drive

Figure 56 - Wind turbine installation vessel MPI Resolution at Thanet OWF

The leg structures themselves can be:

- tubular
- rectangular
- lattice type

The stable-base provided by a jack-up barge (JUB) is equivalent to working onshore, and if an onshore crane is retro-fitted, onshore lift-specifications can be used (except when lifting from floating plant or another dynamic lift). Dynamic lifting offshore is not recommended practice for onshore cranes. This stability makes JUBs ideal for installing the nacelles and blades of turbines, which are the most precise lifts required anywhere on a project due to strict bolt alignment tolerances and insensitivity to the wave state. Hence jack-up barges (JUBs) effectively dominate this area of work.

Historically there were fears regarding offshore wind vessel shortages, and if installation rates do indeed increase to previously planned levels, jack-up vessels will likely be restricted to turbine installation work, and attract a premium, while floating solutions will be used for the majority of other activities.

The ever increasing water-depths and foundation and turbine weights have rendered obsolete the vessels which carried out the first installations in water depths of less than 25 m. Upgrading of leg lengths can be undertaken up to particular engineering limits, but this is always a compromise. Increasing operational water depth may well decrease the operational metocean limits because it is rarely feasible to couple leg extensions with the increased hull and jacking house loadings.

There are a few JUBs with longer legs, and a number of new-builds are joining the marketplace with capacities to carry out the larger 6 MW+ class turbine installation work in water depths from 30 to 45 m. It is noteworthy that lattice legged jack-ups are the vessel of choice for the oil and gas industry for water depths over 50 m. This is due to a reduced mass to stiffness ratio and reduced wave loading on the legs, and vessels designed with both marketplaces (O&G and wind industry) in mind are generally of the lattice legged type.

An example of a jack up vessel design with a good combination of leg length to overall size for pre-pilling and small wind turbine installation is the Gusto MSC NG2500x (see Figure 57). This is a relatively small barge, but with 60 m depth working capacity in benign waters and 48 m in harsh conditions.

Figure 57 - Gusto MSC NG2500x installing Siemens SWT 3.6 107 at Walney 1 offshore windfarm

There are several vessels of this type available to the offshore wind industry spot-charter market, and indeed some are owned by Gulf Marine Services, a vessel operator in the Middle East, which is only around 1,000 nautical miles from Gujarat.

3.6.3.2 Possible offshore wind roles

Dynamic Positioning (DP) jack-ups are capable of most roles on wind farm sites, but their stability means that they dominate the turbine installation role.

Most jack-up barges in use in the wind industry have been designed by Gusto MSC, and their model codes are used henceforth for simplicity. The NG 2500x model has been used for 4 MW class WTG machines (Figure 57), but it is unlikely to prove suitable for 6 MW classes due crane capacity and deck area limitations. Small vessels of this type with longer legs are likely to find favour for the pre-piling of jacket foundations in deeper waters.

Larger vessels like the NG 9000C (examples including Brave Tern and Bold Tern, see Figure 59) are capable of installing both 6 MW class turbines and most piled foundations. There have been several studies on installing substations in sections utilising the main WTIV vessel, but to date in Northern Europe, where there are several heavy lift vessels suitable for lifting oil and gas topsides, modular substation installation has not been adopted. Similarly there exist quite a large number of offshore oil and gas installations off the Indian coast so the single-lift installation may again be preferred.
But it will at least be prudent to revisit whether the local installation cost drivers may make modular substation installation a preferred option in India.

Figure 58 and Table 14 illustrate the key features and dimensions of a typical Small WTIV.

Figure 58 - A small DP2 WTIV Seajack's Kraken

Dimension	Value [m]
Length	61
Beam	36
Draft - laden	3.7
Air draft (with jackets on-board)	100
Lift capacity (tonne)	300

Table 14 - Key dimensions of Kraken

Many smaller jack-up vessels are not capable of either providing the under-hook height to install larger turbines (which occasionally require lifts in excess of 100 m above MSL) or their on-board cranes have insufficient lift capacity.

A large number of new-build WTIVs with cranes in the lift capacity range of 800 to 1,500 tonne, and capable of working in +40 m of water have entered the offshore

Figure 59 - Large DP2 WTIV - Fred Olsen Windcarrier's Bold/Brave Tern pre-piling jackets

wind fleet in recent years. These vessels are capable of installing both the larger +6 MW class turbines, and all but the largest foundations.

Figure 59 and Table 15 illustrate the key features and dimensions of a typical Large WTIV.

Dimension	Value [m]
Length	132
Beam	39
Draft - laden	6
Air draft (with jackets on-board)	100
Lift capacity (tonne)	800

Table 15 - Key dimensions of Bold Tern

3.6.4 Sheerleg heavy lift vessel

3.6.4.1 Vessel characteristics

The Sheerleg is fundamentally a very heavy-lift configuration of a dumb barge. The lifting frame fitted to the deck is permanent, and many are self-propelled, but they are not generally equipped with dynamic positioning.

The lift-frame can be derricked (i.e. raised or lowered) and can often be fitted with a fly-jib, which is a boom extension affording greater outreach, or under-hook lifting height, at the expense of lift-capacity.

This type of vessel is mainly designed for heavy-lifting in sheltered waters like harbours, rivers and estuaries, but the larger vessels (over 500 tonne) usually have some limited capability to operate offshore, in varying levels of sea-state.

Vessels of this type are available in Northern European waters up to 3,300 tonne capacity and widely available across the Asia region. They can transit in seas with significant wave heights of well over 1 m, but are generally limited to carrying out lifting operations in seas of between 0.5 and 1 m significant wave heights, depending on craft size.

Since lifting is always over the end of the barge, sheerleg cranes require less beam than ship-type crane vessels of an equivalent lift capacity which can carry out 360° fully-rotating lifts. This is a major advantage in ports with narrow lock-gates, and in fact lead to their selection as part of the installation methodology adopted for one recent UK site.

3.6.4.2 Possible offshore wind roles

Given that piling hammers are far lighter than the piles that they drive, a role is emerging for sheerleg crane vessels to deliver monopiles, jackets or tripods to jack-up piling vessels (see Figure 60). In this case the jack-ups are pre-stationed at the foundation site and the sheerleg lowers the foundation onto the seabed, or if a monopile, into the pile-guides at slack water. The jack-up vessel is then used to drive the piles.

Figure 60 - Sheerleg crane-vessel working in tandem with a jack-up piling vessel

Recent experience on one site led to weather related programme delays due to the sheerleg's metocean limits for foundation placement on the seabed. It is unlikely that Sheerlegs will be used widely in this role far offshore in anything but summer weather windows and or due to a lack of available and suitable vessels. Sheerlegs are however often used during the installation of offshore substation topsides due to the one-off nature of this lift as presented in Figure 61.

Table 16 illustrates the key features and dimensions of a typical Sheerleg.

Source: Mercator Media

Figure 61 - Rambiz 3, 300 t SHLV installing a substation topside

3.6.5 DP2 Heavy lift cargo vessels

3.6.5.1 Vessel characteristics

Cargo vessels deliver loads rapidly and cost effectively around the world, and by fitting heavy cranes to the vessel, they can collect and deliver cargo from ports which do not have adequate crane capacity to handle the shipment. Often these are individual large units for chemical plants or transformers for power station projects – and are described as project cargo.

Some of these vessels have been fitted with dynamic positioning (DP) meaning they have the capacity both to deliver components rapidly to offshore sites, at speeds of 15-20 knots, and also lift and position them accurately. Essentially DP is a computer-controlled system which compares Global Positioning System (GPS) satellite location data with the desired position of the vessel, as set by the helmsman. DP takes control of all vessel propulsion to pilot the vessel to the desired location, or onto the desired course at the set speed etc.

Being ships, their hull-form is far sleeker than the majority of crane vessels. This may prove advantageous in development of wind farms in areas where port access widths are limited. However, their increased draft would require careful considerations.

Source: Jumbo Shipping

Figure 62 - Heavy lift cargo vessel - Jumbo Javelin

Dimension	Value [m]
Length	70
Beam	32
Draft - laden	6
Air draft	85
Lift capacity (tonne)	1,800

Table 16 - Key dimensions of Matador 3, Sheerleg Heavy Lift Vessel, SHLV

3.6.5.2 Possible offshore wind roles

With their high transit speeds, heavy-lift capacity, and lower day-rates than other equivalent lift-capacity vessels, it is likely that this type of vessel will see a greater role in future wind farms.

They have been used successful by the oil and gas industry for a wide variety of offshore installation duties. Figure 63 shows a screenshot from an animation of a jacket installation, during which the vessel carries not only the jacket structure but also the pin piles, piling spread and grouting spread. Likewise tripods would appear to be another potential application.
The two-crane tandem lift configuration largely avoids problems with the limited under-hook height with which many single-crane vessels struggle with when installing deeper water structures.

Figure 63 - Heavy lift cargo vessel - jacket installation

Table 17 illustrates the key features and dimensions of a typicel DP2 heavy lift cargo vessel.

A large number of companies operate heavy-lift cargo vessels, with the largest project cargo vessels fitted with twin 1,000 tonne cranes capable of 2,000 tonne tandem lifts, but two vessels are currently being built for Jumbo Shipping which have a 3,000 tonne tandem lift capacity.

Dimension	Value [m]
Length	144.1
Beam	26.7
Draft - laden	8.1
Air draft (with jackets on-board)	100
Lift capacity offshore (tonne)	1,000
Lift capacity in port (tonne)	1,800

Table 17 - Key dimensions DP2 Heavy Lift Cargo Vessel, Jumbo Javelin

A number of these vessels are also equipped with dynamic positioning, including:

- two of Jumbo Shipping's J-1800 class
- both of Jumbo Shipping's K-3000 class new builds
- both of SAL Shipping's type 183 vessels

Jumbo Javelin, a J-1800 class has been successfully used during offshore wind farm installation for the placement of transition pieces in significant wave heights of up to 1.5 m. The SAL vessels have also carried out pre-piling of jackets at Wikinger OWF in the Baltic Sea.

Heave-compensation systems have been retro-fitted to these vessels, and offshore vessel-to-vessel transfers have been achieved. This suggests they could find favour as feeder-vessels as wind farms move further offshore. These vessels however lack the stability necessary to install wind turbines, so jack-ups will continue to dominate in this role.

3.6.6 Leg-stabilised crane vessel

3.6.6.1 Vessel characteristics

So far only two vessels of this class have entered the wind farm installation fleet and both were owned by A2Sea – Sea Energy and Sea Power. However Sea Energy was recently sold to the Oil and Gas company OIS and is currently working in the Gulf of Guinea. They were standard cargo ships before being retro-fitted with legs and pedestal mounted Terex Demag cc 2600 crawler crane upper-works (in 400 tonne lift-configuration). More recently, Sea Power's crane was upgraded to a pedestal mounted, Terex Demag cc2800, which has a 600 tonne capacity when in crawler configuration but experiences down-rating to 230 tonne at 15 m radius when the boom is extended to allow for a 100 m under-hook height above deck.

This adaption has proved a versatile low-budget installation craft, which was ideal to install wind turbines in the shallower sites of the early European wind farms.

The stabilisation legs are a hybrid between the passive spud-legs, which are clamped in position, and jack-legs, which actively jack the vessel out of the water. There is some level of downward pressure exerted by the legs, which helps to react the overturning moments associated with the lifted loads.

The origins of these vessels mean that they have good hydrodynamic hull forms and transit rapidly and economically. This has allowed some projects to collect turbines from the manufacturer's load-out facility and deliver them straight to site in reasonable cycle-times, with the additional saving of the costs of a construction mobilisation and storage port. It has also won them feeder vessel duties on at least one recent project.

Figure 64 - A2Sea Sea Energy / Sea Power - Leg-stabilised crane vessels

3.6.6.2 Possible offshore wind roles

The 24 m maximum working water depth means that their suitability is limited in the installation marketplace. They may well be used for turbine, or possibly transition piece installation in shallow areas, but they are more likely to find ongoing work in the O&M vessel fleet for the existing wind farms which they helped to install, and where they have the leg-length to operate.

Table 18 illustrates the key features and dimensions of a typical leg-stabilised vessel.

Dimension	Value [m]
Length	92
Beam	21.6
Draft - laden	4.25
Air draft	50
Lift capacity (tonne)	230

Table 18 - Key dimensions, leg-stabilised vessel, A2Sea Power

3.6.7 DP2 Offshore supply vessel

3.6.7.1 Vessel characteristics
The offshore supply vessel (OSV) is the work-horse of the offshore oil and gas industry and they are universally available, often at extremely competitive charter rates. There are several names used for supply vessels utilised by the offshore industry but many are similar in appearance and would be equally capable of fulfilling the functions required on an offshore wind farm site. There are three main categories of OSVs, namely Anchor Handling Tug Supply (AHTS), Platform Supply Vessel (PSV), and Construction Support Vessel (CSV). Construction support vessels tend to be better equipped with equipment like knuckle boom heave compensated cranes, ROV hangers and tend to be slightly larger.

3.6.7.2 Possible offshore wind roles
Dynamic positioned OSVs have become a favoured option for array cable laying. They have high power propulsion, and often have rated “bollard pulls” for towing, which means that they can pull cable ploughs and jetting equipment for cable burial. Several have at least one ROV hangar, and work class ROVs (WROVs) can be used for specialist installation operations like cable or pipeline crossings, and removal of obstructions like old cables, anchor-chains, fishing nets and etc.

Tracked cable-layers with “follow-sub” capability could be integrated with the DP controls of the vessel. As the cable is laid by the ROV, the vessel can be set to “follow” the “sub”-merged cable laying equipment, while also maintaining the cable tension on deck by also coupling the DP system with the cable engine. However only the best equipped cable installation contractors will have equipment with the sophistication to deliver this level of capability.

Many vessels in this class are equipped with heave-compensated knuckle-boom cranes which can be used to load cable-reels etc, as well as deployment and recovery of ploughing and jetting sleds. They can also be used for the pull-ins of the array cables up the J-tubes, as can be seen in Figure 65.

Furthermore, since this class of vessel is generally used in close proximity to fixed offshore oil and gas installations they are often equipped with laser or radar ranging devices. This allows the GPS location to be supplemented by additional positioning information, to ensure the highest level of accuracy when carrying out precise marine operations like cable pull-ins in close proximity to WTG foundations.

Table 19 illustrates the key features and dimensions of a typical offshore supply vessel.

Figure 65 - DP2 offshore construction support vessel installs array cables - Normand Mermaid

Dimension	Value [m]
Length	90.1
Beam	21
Draft - laden	7
Air draft	40
Lift capacity (tonne)	100

Table 19 - Key dimensions of Normand Mermaid, DP2 OSV

3.6.8 Semi-submersible heavy lift vessel

3.6.8.1 Vessel characteristics
This type of huge vessel has been developed by the oil and gas industry to carry out placement of oil rig modules in harsh offshore conditions. The hull can be flooded, greatly increasing the deadweight of the craft, and it is designed so that this ballasting operation dramatically increases the craft’s period of roll. This change in vessel dynamics effectively tunes-out the wave effects on the craft and therefore the avoidance of the problem of inopportune wave-periods leading to resonance. It sits effectively motionless in the water, unaffected by all but the harshest wave states. Clearly the huge structure presents a large surface to the wind, but again, the overall stability is such that even delicate lifting operations can be carried out in deep water during relatively strong wind conditions.

3.6.8.2 Possible offshore wind roles
The use of Thialf at Alpha Ventus (Figure 66) was primarily due to particular circumstances on that project. It is unlikely that this vessel type will be used on offshore wind farms for turbine or foundation installation in the future. Day rates for this extremely expensive class of vessel are prohibitive to the offshore wind installation market in general.

Figure 66 - Jacket installation at Alpha Ventus, by Thialf

It is possible that such vessels may be used as a vessel of opportunity again, if a particular vessel is in the area and has no commercial charter, but this is unlikely.

Occasionally there could be a role for these craft in large substation installation in onerous sea conditions, particularly if there is a HVDC topside, which are generally larger than their HVAC counterparts.

Since the availability of this class of vessel is unclear in India, the vessel type has only been included for completeness but no example vessel has been used in the ports assessment. Such craft are unlikely to enter a port due to their large size.

Table 20 illustrates the key features and dimensions of a typical Semi-submersible heavy lift vessel.

Dimension	Value [m]
Length	201.6
Beam	88.4
Draft - laden	11.8 - 31.6
Air draft (approximately)	75
Lift capacity (tonne)	14,200

Table 20 - Key dimensions of a typical semi-submersible vessel

3.6.9 Suitability of vessels for various OWF installation activities

This section aims to categorise the key construction activities for offshore wind sites with monopile, jacket and tripod foundations in various water depths, and then identify the suitability of each class of vessel as described in Sections 3.6.2 to 3.6.8. This is presented in the form of a vessel class suitability matrix in Table 22.
Key symbols used to define this high-level suitability are given in Table 21.

Substation jackets are not included as they can be handled by the wind turbine generator (WTG) jacket vessel, or by the HLV installing the topsides.
Note, several options which are technically possible would be uneconomic, unless there was a vessel available at greatly below the market rate (for example the semi-submersible heavy lift vessel).

3.6.10 Construction vessel screening in India

A high-level local vessel screening for India was conducted as part of the FOWIND Pre-feasibility reports[4] and is reproduced in this section.
India has a total of over 700 offshore vessels with a total gross tonnage of over 800,000. Most of these vessels are used for the offshore oil and gas industry. To date no newly designed, offshore wind installation vessel exists in India. Table 23 provides an overview of offshore related vessels available in India and their potential scope for offshore wind installation.

Based on the results of this vessel availability desk top survey, the following three opportunities for offshore wind deployments in the Gujarat and Tamil Nadu region should be considered:

- Modifications of the existing oil and gas, fishing or civil engineering vessels specific to the requirements for both construction and operation and maintenance phases of offshore wind projects. This option should be considered at least for offshore support vessels and work boats;
- Design of specialised vessels for offshore wind project installation. The development of specialised vessels is largely dependent on the scale of deployment of offshore wind in India;
- Using the services of the existing European or Asian offshore wind vessels may be a favourable short term solution. This option should be considered for wind turbine, foundation and substation installation vessels.

One issue that has been raised in the Indian market is the availability of vessels. It is noted that Gujarat is relatively close to the Middle East. Gulf Marine Services[10] located in Abu Dhabi own several jack-up vessels which are commonly in use in the northern European offshore wind industry and are approximately 1100 NM from Gujarat. Chartering Middle Eastern jack-up vessels may well potentially be a viable means of support for early developments in the offshore wind industry in Gujarat.

[4] http://www.fowind.in/publications/report
[4] http://www.fowind.in/publications/report

Vessel suitable	√
Vessel may be suitable under certain circumstances e.g. modification or special marine operations required	~
Vessel unsuitable	X

Table 21 - Key to vessel class suitability

Activity	Water depth [m]	Floating dumb barge with crane	Sheerleg crane barge	Semi-submersible heavy lift vessel	DP2 Heavy lift cargo vessels	Heavy lift cargo vessels (no DP)	Leg-stabilised crane vessel	Self-propelled and towed jack-up craft*
Monopile driving	< 10	~	~	√	~	~	√	√
	10 –	~	~	√	~	~	~	√
	20 –	X	~	√	~	~	~	√
	> 30	X	~	√	~	~	X	√
Jacket/tripod pre-piling	30 –	~	~	√	√	~	√	√
	40 –	~	~	√	√	~	√	√
	50 –	~	~	√	√	~	√	√
Jacket installation	30 –	~	√	√	√	~	X	√
	40 –	X	√	√	√	~	X	√
	50 –	X	√	√	√	~	X	√
Tripod installation	10 –	~	~	√	√	√	X	~
	20 –	~	~	√	√	√	X	~
	30 –	X	~	√	~	~	X	~
	40 –	X	~	√	~	~	X	~
	50 –	X	~	√	X	X	X	~
Transition piece installation	10 –	~	√	√	√	√	√	√
	20 –	~	√	√	√	√	~	√
	30 –	X	√	√	√	√	X	√
	40 –	X	√	√	√	√	X	√
	50 –	X	√	√	√	√	X	√
Turbine installation 4MW	10 –	X	X	X	X	X	√	√
	20 –	X	X	X	X	X	~	√
	30 –	X	X	X	X	X	X	√
	40 –	X	X	X	X	X	X	√
	50 –	X	X	X	X	X	X	√
Turbine installation 6MW		X	X	X	X	X	X	√
Substation topside		X	√	√	√	~	X	X

* depending on water depth limits and lift capacity

Table 22 - Technical suitability of vessel types for offshore wind farm installation activities

Vessel type	Potential scope	No. of vessels
Offshore supply vessels	Construction support and supply vessels	113
Anchor handling tower support vessel (AHTS)	Construction support and supply vessels	4
Multi-purpose support vessel (MPSV)	Construction support and supply vessels	1
Motor stand-by vessel (MSV)	Work boats	1
Barges	Turbine and foundation transportation	39
Floating cranes	Turbine and foundation transportation and installation vessel	1
Dredgers	Construction support and supply vessels	36
Tug vessel	Construction support and supply vessels; work boats	322
Passenger service vessels	Crew transfer vessel	57
Port trusts and maritime board vessels	Requires investigation	95
Specialised vessels for offshore services	Requires investigation	38
	TOTAL	**707**

Table 23 - Offshore related vessels available in India

3.6.11 Vessel port access requirements

DNV GL used their in-house Vessel Port Access Requirement charts as a means of making the initial screening of the ports in both Gujarat and Tamil Nadu (see Section 3.9). An explanation of this process is provided within this section.

Table 24 summarises the dimensions of the key vessels identified to represent those commonly used as OWF installation vessels. Plotting the vessel beam (fully laden) and vessel draft on a Vessel Port Access Requirement chart (see Figure 67), the beam and draft requirements for each vessel can be clearly represented graphically.

Description	LOA	Draft	Beam	Air-gap
Small JUB/WITV	61	3.7	36	100
Large WTIV	132	6	39	100
HLCV/MPV	144	8	26.7	47.3
Feeder barge	91	5	27	15
Offshore supply vessel	93	6.3	21	40
Heavy lift vessel (2,500 t)	183	9	36	50
Sheerleg HLV (1,500 t)	70	6	32	85

Table 24 - Summary table of dimensions of example OWF installation vessels

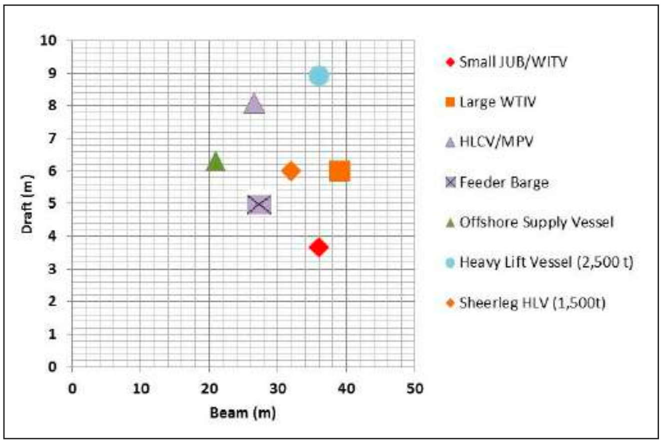


Figure 67 - Vessel port access requirement charge for example vessels

The high and low water depths available and any marine access width restrictions at suitable berths in ports within the selected areas, can be plotted on the same axes. This approach allows for a comparison between the vessel's basic requirements for water depth and width, versus those available at the various port locations.

3.7 Installation strategy

3.7.1 Introduction

When developing project specific Installation and Logistics methods it is necessary to capture a representative range of options in terms of installation strategies for the specific offshore wind project.
The installation strategy must include corresponding marine operations and related transport and installation (T&I) vessels and plant.

The installation strategy will to a large extent define the vessel requirements and in turn the port characteristics required to facilitate operation of these vessels. Clearly this is a multi-dimensional puzzle in order to arrive at an all-encompassing Installation Logistics solution because vessel availability and port availability within the local supply chain are also critical factors in defining the strategy.

This section defines a limited number of typical installation strategies that have now become best-practice within the European market (there are numerous others and variants but this section only covers the key strategies at high-level). See Section 3.7.2 for further examples.

The following strategies are outlined within this section in high-level detail:

- Three different foundation construction strategies are illustrated in Sections 3.7.3 to 3.7.5 which are amongst the 30 or 40 which have been defined for transport and installation (T&I) of the foundation components
- One strategy is illustrated for transport and installation of turbines, see Section 3.7.6
- T&I strategies and plant for offshore substation foundation and topsides are also discussed in Section 3.7.7
- T&I strategies and plant are discussed for inter-array cables, see Section 3.7.8

3.7.2 Vessel port access requirement

A wide range of alternative installation strategies are possible for the various components and the vessels required to carry out these offshore wind operations. In order to provide further detail to the port selection study these various strategies and anticipated vessel dimensions required to facilitate them have been estimated. A selection of these are summarised in Table 25.

3.7.3 Monopiles and transition piece installation strategy

3.7.3.1 Driven monopiles

The majority of foundations installed to date have been steel monopiles. The advantages of this foundation type are that it is relatively cheap to manufacture, requires little or no sea bed preparation, and can be installed with one simple piling operation in a wide range of soil conditions. In harder ground conditions alternative methods include "drive-drill-drive"(see Section 3.7.3.2) and "rock-socketing" (see Section 3.7.3.3).

The foundation installation strategy discussed within this section follows the standard approach by the majority of the early Northern European OWFs. Foundation components (monopiles and transition pieces) are transported from the manufacturing port, either direct to the offshore wind farm, or to a marshalling port, generally by dumb barges, or cargo vessels.

The monopile (MP) and transition pieces (TP) are typically connected by placement of high-strength structural grout within a narrow annulus between MP and TP. In order to prevent downward sliding of the TP it is now considered best practice (offshore standard DNV-OS-J101) to provide monopile grouted connections with either a straight sided annulus with friction enhancing shear keys or alternatively a tapered cone connection between MP and TP. In early cases before revision of the design standards where downward sliding of transition pieces occurred in a number of projects remedial elastomeric bearings were post-installed, but this is now only considered for remedial repairs.

Figure 68 - Transportation of monopiles FND to MAR, using a dumb barge

Strategy description	MAXIMUM	
	Beam	Draft
4 MW Turbine installation - small WTIV	36	3.65
6 MW Turbine installation - large WTIV	39	6
Pre-pilling 4 MW Jacket - small jack-up barge (JUB)	36	5
Pre-pilling 6 MW Jacket - small jack-up barge (JUB)	36	5
Pre-pilling 4 MW Jacket - floating option	27	8.1
Pre-pilling 6 MW Jacket - floating option	27	8.1
Installation of 4 MW Monopile - heavy lift vessel (HLV)	26.6	8.1
Installation of 4 MW Monopile - sheerleg & small JUB	36	6
Installation of 4 MW Monopile - large WTIV	39	6
Installation of 6 MW Monopile - heavy lift vessel (HLV)	26.6	8.1
Installation of 6 MW Monopile - sheerleg & small JUB	36	6
Installation of 6 MW Monopile - large WTIV	39	6
Installation of 4 MW Jacket - heavy lift vessel (HLV)	26.6	8.1
Installation of 4 MW Jacket - sheerleg	32	6
Installation of 4 MW Jacket - large WTIV	39	6
Installation of 6 MW Jacket - heavy lift vessel (HLV)	26.6	8.1
Installation of 6 MW Jacket - sheerleg	32	6
Installation of 6 MW Jacket - large WTIV	39	6
Grouting of 4 MW Jacket/transition piece - offshore support vessel (OSV)	21	6.3
Grouting of 6 MW Jacket/transition piece - offshore support vessel (OSV)	21	6.3
Array cable laying - offshore support vessel (OSV)	21	6.3
Export cable laying - offshore support vessel (OSV)	21	6.3
Substation installation - heavy lift vessel (HLV)	27	8.1
Sub-substation installation - sheerleg	32	6

Table 25 - Alternative OWF installation strategies for various components

Alternative bolted monopiles have also been seen in some projects in Europe and China. In shallow sites these can involve monopiles directly bolted to the turbine tower with secondary steel attached using cages that are friction fitted over the monopile (for example, Kentish Flats Extension, UK). Alternatively in deeper sites a bolted monopile to transition piece can be used (for example, Humber Gateway, UK).

The remainder for this section focuses on installation strategies for grouted MP to TP connections.

Monopiles can be transported in a number of ways including:
- Plugging the pile and floating it to site, using its own buoyancy (provided the monopile is of sufficiently large diameter)
- Loading one or more piles onto the deck of the installation barge/jack-up
- Using a feeder vessel to transport the piles out to the site

Transition pieces are generally up-ended and transported vertically; this is primarily to protect and prevent damage to the attached secondary steel components (platforms, boat fenders, ladders and anodes).

Monopiles can be installed using the following vessels:
- Towed deck barges, with or without spud-legs – this requires dynamic offshore lifts (cheap spud-legs offer some stability for offshore lifts - multiple vessel options)
- Jack-up barges (static offshore lifts, more expensive than deck barges)
- Floating crane vessels, with or without heave-compensated cranage (costly)
- Cargo vessels with or without cranes fitted (fast, but dynamic lifts)

Figure 69 - Jack-up upending a monopile in preparation for piling

Figure 70 - Piling frame on Excalibur awaiting a floating monopile

The most common monopile installation methodology is to use a jack-up vessel as a piling guide, and to use the on-board crane to both lift the pile into a guide-frame (also called the piling gate), and place the hammer on top for pile-driving, as shown in Figure 69.

Lifting the pile vertical usually requires cranage with a lift capacity in excess of the mass of the pile. Two exceptions to this vessel crane lift-capacity limitation exist:

- A technique called semi-buoyant lifting, in which the pile is plugged and the lift-weight seen by the installation crane is reduced. This technique potentially allows installation vessels with relatively small lift capacities to install heavy foundations. It does however require complicated marine operations planning and supervision, and is not a preferred technique for most installation sites.
- A specialist piling frame, for example as seen fitted to jack-up Excalibur in Figure 70, which has a jack-up pile-guide which lifts and rotates the pile into the vertical, independently of the crane.

If the installation vessel does not have cranage in excess of the mass of the pile, it is possible to use a different vessel which does have the required cranage in conjunction with the installation vessel as a piling barge (see Sheerleg crane in Section 3.6.4, Figure 60).

In summary the typical installation sequence for driven monopile and transition pieces is as follows:

1. If scour protection is required place filter layer on seabed before monopile driving;
2. Transport monopile to installation site (typically dumb barge or WTIV or bunged monopiles);
3. Up-end pile using vessel crane or up-ending tool (typically using JUB or WTIV or sheerleg vessel);
4. Drive monopile to design depth using suitable piling hammer (typically using JUB or WTIV);
5. Place scour protection material if required;
6. Clean pile of marine growth (using manual equipment or specialist pile cleaners);
7. Transport (vertically) TPs to installation site (various vessels suitable);
8. Lift transition piece onto pre-installed monopile (various vessels suitable) and level using hydraulic jacking system;
9. Attach grouting lines and fill grouted annulus (either TP installation vessel equipped with grouting spread or separate grouting vessel).

Monopile diameters installed to date have varied from 4 m upwards and diameters of 8.0 m or larger are being discussed for installation in wind farms in the future, with forged piling hammer anvil diameters being the limiting factor. At present there is a piling anvil effective limit of approximately 7 m diameter.

A key design factor is the fatigue life of the monopile circumferential and transition piece attachment welds. Great care must be taken regarding the planned driving sequence during monopile design, as driving the pile too hard could reduce the fatigue life of the monopile below which is needed for the 20 to 25 year wind turbine operational design life.

3.7.3.2 Drive-drill-drive technique

The ground conditions of some sites include layers of harder material which cannot be driven through without damaging the pile. The installation technique in these circumstances is “drive-drill-drive”. This technique consists of driving the pile down to the harder layer, before using a large-diameter reverse circulation drill, to remove the upper layers, and then drilling through the hard layer, generally at a slightly smaller diameter than the pile to ensure subsequent good contact between the pile and the soil. The drill is then removed and the pile is driven down to its target depth.

This technique is clearly far more time-consuming than simply driving the pile, and given the fact that jacket-leg piles can be made far more robustly, and driven through harder sub-strata, it would appear logical to revert to jacket foundations if monopiles cannot be driven. However, given the large cost differential between the monopile and steel tubular jacket-structures, and the sea bed preparation which they sometimes require, it is often economical to carry out drilling operations rather than to install jackets. Jackets may also not be best suited due to structural dynamic effects; their inherent high structural stiffness can make it challenging to meet the wind turbines natural frequency window when jackets are deployed in shallow waters.

This same reverse circulation drilling equipment is often required as a contingency if site investigations show great local variations in ground conditions, or in areas where there are known to be glacial till deposits (as glacial scouring often entrains large boulders). Hence in these cases drilling may be required to allow the pile to achieve target depth.

3.7.3.3 Rock-socketed monopiles

It is possible to install steel monopiles in rock. A similar drill to that described for drive-drill-drive installation is used to drill a hole slightly larger in diameter than the monopile. The monopile is then lowered into the socket, and is grouted in place. Two early offshore wind farms have installed monopiles in this way to date – Blythe in the UK, and Yttre Stengrund in Sweden.

This technique is considerably slower than impact piling. However, it shares the advantage that there is no requirement for sea bed preparation at most sites. It has a further advantage that no piling noise is generated, so there are some sites where this technique may afford the opportunity to install foundations during periods which the project environmental assessment has concluded that piling noise would be unacceptable.

This significant advantage must be offset against the likelihood that there will be environmental constraints placed on the discharge of the drill uprisings. During drive-drill-drive operations at early wind farms off North Wales, foundation contractors were allowed to discharge the cuttings straight over the side of the barge, to form an added layer of scour protection around the bottom of the pile. This allowed large plumes of turbid water to form, and with the strong currents at the site, the impact would have been felt well downstream from these sites. It has been shown that this had little measurable material environmental impact in this case and it is understood that it may be accepted in future developments, and may form a test-case for other sites, although there may be stricter constraints placed on works by other jurisdictions.

3.7.4 Jackets structures installation strategy

Jacket foundations may be installed with pre-installed or post-installed piles (see Figure 71). Post-installed piles have the advantage that one vessel could be used for the entire operation but the foundations will likely be heavier as a result of the attached pile sleeves. Pre-installed piles enable two vessels to be operating simultaneously (shorter installation time) and lighter jacket structures as sleeves are not required to resist pile driving forces.

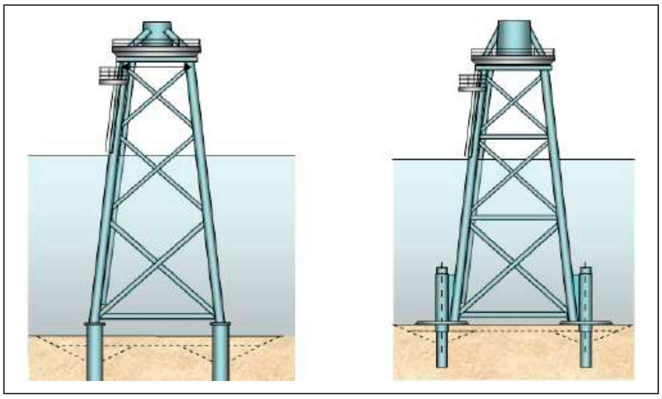


Figure 71 - Wind turbine substructure concept - jacket (pre-piled & post-piled)

In both options the pile to jacket connection is typically achieved using a grouted annulus connection.
One alternative to grout is swaging, although not widely used, (except for the two pilot jackets in the Beatrice project, Scotland) where a metal to metal connection between pile and jacket sleeve is made using a specialist hydraulic tool. The swaging tool is inserted into the pile and applies high/localised internal pressure to make a controlled structural deformation between pile/sleeve which directly interlocks the two tubulars together. The two most common jacket installation methods, pre-installed and post-installed piles, are described in Sections 3.7.4.1 and 3.7.4.2.

Figure 72 - Small pile-driving jack-up, with yellow under-slung pre-piling template

3.7.4.1 Pre-installed piles

Pre-installed pile types are becoming favoured for larger jacket projects in Europe for the following key reasons:

- Optimisation of the jacket installation sequence by enabling simultaneous operation of two vessels (pin-pile installation vessel and jacket placement vessel), thereby removing any conflict between the two operations and giving potential for more unit installations per weather season.
- Reduced jacket mass compared with post-piled (approximately 10% reduction) by replacement of multiple heavy pile sleeves with one universal seabed template across the project.

The sequence of offshore operations in this scenario can be described as follows:

1. Pin-pile load-out

The pin-piles are loaded out onto a small jack-up vessel using a crawler crane. It is generally assumed that the barge can accommodate up to four pin-piles (one foundation set). Further to these, a pin-pile template is loaded out. All items are sea-lashed to the deck as part of the vessel's seaworthiness preparations.

2. Pin-pile installation

A degree of sea bed levelling may be required prior to the arrival of the jacket and this would be undertaken using dredging equipment with high-resolution sonar. The requirement for sea bed dredging will be wholly driven by the results of any geological campaign at individual turbine locations.

Next, a piling template is lowered onto the sea bed. The template is assumed to be part of the jack-up spread and is re-usable for each turbine location (see Figure 74). Piles are individually lowered into the pile-guides and a suitable hydraulic hammer is used to drive them to their design depth.

3. Jacket installation

The template is then removed and the jacket is lowered into the piles. Stab-ins on each of the jacket legs fit internally into the pre-driven piles, as shown in Figure 73.

Jackets are not normally off-loaded from the barge after load-out and are usually installed offshore straight from the feeder barge (see Figure 74). So the marshalling port rarely sees a requirement for onshore logistics, and the storage requirement is to ensure that there is adequate quayside to moor alongside, and adequate moorings laid in sheltered waters for the maximum number of delivery barges envisaged.

The jackets typically arrive on site by the means of a capable feeder barge, a suitable jack-up barge (JUB) such as a wind turbine installation vessel (WTIV) will be pre-stationed and jacked up at the installation location, the feeder barge will then go alongside for the WTIV to lift off a jacket and install it.

4. Grouting

Grouting of the foundations will follow. This can either be done by the WTIV if it has a grout spread aboard, but this may be an expensive method given the very high day-rate of such craft. For this reason, grouting is often carried out by means of a dedicated grouting vessel which is usually a standard dynamic position offshore supply vessel (DP OSV) fitted with cement tanks below deck and a grout mixing spread on deck (see Figure 75).

If a separate vessel is used for grouting, its dimensions will have to be incorporated within the ports assessment, as it is likely to have a higher draft than the jack-up barge and may be a limiting factor. However, if marshalling involves delivery by Heavy Lift Cargo Vessels (HLCV), these are likely to be of greater beam and draft that the OSV.

Figure 73 - Jacket leg stab-ins at point of insertion into pre-piled foundation

Figure 74 - Transportation of jackets FND to MAR/OWF, using a dumb barge

Figure 75 - Grouting spread on the aft of an offshore supply vessel - Borkum West II

3.7.4.2 Post-installed piles

The sequence of offshore operations in this scenario is as follows, ensuring that the seabed is level (or micro-siting the turbine to find a level area within the vicinity of its proposed location):

1. Lower the jacket to the seabed (temporary support on jacket's mud-mats)
2. Locate a pile into the sleeve on each leg of the jacket
3. Drive the piles and grout

The pile-guides need to be substantial structures to survive the piling operations, and this adds approximately 10% to the overall mass of the structure. Not only does this increase material and fabrication costs, but also requires a larger installation vessel (as the jacket lift is the largest lift, and is the driver for vessel selection).

3.7.5 Floating and lifted gravity base structures (GBS) installation strategy

Concrete Gravity Base Structures (CGS/GBS) have been used very effectively in the Baltic, but have not tended to be the foundation of choice in the North or Irish Sea wind farms. GBS's are often favoured in hard or rocky ground conditions as is found in the northern coast of the Baltic Sea, as the ground cannot be piled, and there is no requirement to drill.

The installation method for GBS foundations depends on their design and construction. The difficulty with offshore GBS installation lies in the mass of the structure. To handle this large weight, several methodologies are available, namely:

- ***Quayside construction***
  If the GBS is constructed on the quayside (or transported to the quayside once constructed), a sufficiently powerful heavy lift crane vessel is required to lift the GBS directly from the port and transport it to the site for installation. Alternatively, multiple GBSs can be loaded onto a barge using the heavy lift vessel, then transported to the site, where the heavy lift vessel is used again to lower them onto the sea bed.

- ***Barge construction***
  If the GBS is constructed on a barge, the barge needs to be taken to the site, where a sufficiently powerful heavy lift crane vessel is required to lift it from the barge and onto the sea bed.

- ***Dry dock construction***
  If the GBS was constructed in a dry dock; there are two options for transportation to the site and installation. The GBS can be made semi-buoyant and towed to site, using a barge with a frame/support structure, or a crane vessel supporting the mass of the GBS. Alternatively, the GBS can be made fully buoyant and towed to site using an appropriate barge or vessel. Once at the site, the GBS can then be lowered and ballasted.

Figure 76 - Rambiz up-ending the leg-sheered jacket at Beatrice

Often, the ground at the site needs to be prepared before the GBS can be placed on the sea bed. In order to improve the soil bearing capacity, dredging is often performed to remove the layer of quaternary deposits. This can be carried out using a fall-pipe vessel or even a grab-crane, the GBS is then lifted onto the prepared area of seabed.

The prevailing ground conditions in Gujarat are believed to be pile-able cohesive soils of reasonable strength, the prevailing seabed ground conditions off Tamil Nadu are known to include areas of rock with over laying sands, albeit in some areas a layer of coral rock, which may be soft enough to pile through.

In these latter areas it is anticipated that gravity based structures may be considered as viable alternatives to more conventional piled steel foundations. This is also due to the close proximity of numerous environmentally sensitive sea areas, with populations of a variety of protected marine mammals.

Sections 3.7.5.1 and 3.7.5.2 describe the two most widely utilised strategies for installing gravity based foundations.

Figure 77 - The bespoke heavy lift vessel Eide 5 lifting GBS foundations at Rødsand

3.7.5.1 Lifted GBS's

This method involves installation using very large heavy lift vessels (HLVs). The installation can be carried out with the vessel directly cycling between port and the wind farm site or by the method shown in Figure 77 where multiple foundations are pre-loaded onto a barge and transported to the installation site.

If the water depth is larger than 10 to 15 m, the mass of the GBS increases rapidly, and it is then necessary to have a very large HLV. A modification to the Eide 5 dumb barge (see Figure 77), involving the addition of a bespoke lift-frame, allows installation of GBS's of up to 1,800 tonne in the relatively benign waters of the Baltic sea, but like other craft based upon dumb barges, this vessel would be unsuitable to operate in onerous far-offshore waters. Some semi-submersible installation barges have also been proposed as solutions.

3.7.5.2 Floated GBS´s

There has been much research and development work done on the potential for buoyant gravity base structures. A number of designers have been tendering for work, and amongst these, the BAM and Gravitas (see Figure 78) designs are two of the front-runners. However to date, apart from a few met masts which have been deployed in this way, no large scale deployment of this foundation type has been seen on an offshore wind farm.

The significant advantage that floating designs have over lifted designs is clearly that during the transport and installation phase there is no requirement for anything other than tugs to tow the device, thus saving significantly against the costs associated with expensive installation vessels.

Figure 78 - Towing a floating Gravitas GBS foundation

3.7.6 Wind turbine generators installation

The assembly of the turbine on whatever foundation type has been selected, involves a number of operations, some of which require great precision and stability.

Heavy lift cargo vessels (HLCV) are generally used to transport wind turbine generator (WTG) components from the manufacturer's port(s) to the marshalling port. As described in Section 3.5 wind turbine generators can be installed in a number of different ways.

Ideally a buffer stock of two complete cycles of the installation vessel is stored, and preassembly of rotors can be carried out, if required. This level of storage is probably the optimal quantity, and only experienced contractors, who are very competent at construction programme planning, are capable of achieving such a low level of storage. For the purposes of the ports assessment, it will be assumed that approximately half of the project's WTG units may be stored at any one time.

Figure 79 - Heavy lift cargo vessel, used for wtg transportation

Once sufficient WTG sets are ready at the marshalling port, these are loaded onto a wind turbine installation vessel (WTIV) that will carry out the complete installation cycle. Alternatively, the WTIV can load corresponding WTG components at the WTG manufacturer's port of delivery and transit straight to the project site for installation, and will probably do so, if a cost benefit analysis shows that this is cheaper than incurring local marshalling port costs.

Figure 80 - Wind turbine installation vessels

3.7.7 Offshore substation foundations and topside installation

Due to their size, a large number of offshore substations have been installed on jacket foundations but as stated in Section 3.5.6.2 offshore substations have also been installed on both monopiles (e.g. the two OSSs at the 630 MW London Array project, UK) and also gravity bases (for example the OSS at the 400 MW Anholt project, Denmark).

Figure 81 - Barge for transport and SHLV for installation of OSS foundation and topside

As discussed in the FOWIND Pre-feasibility reports[4], there exist a number of strategies for transport and installation of OSSs depending on the substructure and topside concept:

- ***Lifted substructure and topside***
  Lifted Substructure and Topside – this is the most common installation method for HVAC offshore substation (OSS) to date where both the substructure and the topside of the OSS will be transported from the manufacturing base to the marshalling port, or straight to site, aboard a towed offshore barge (in some cases both may be transported on the same barge, particularly if manufactured at the same site, Figure 81). When a suitable weather window is available, the OSS substructure will be delivered to site aboard the barge, where it will be lifted off and installed by a heavy lift crane vessel (HLCV). Once the substructure is completed, the OSS topside will be transported to site and installed, often done using the same HLCV as for the foundation. The topside installation will typically be the heaviest lift in an offshore wind project, with topside weights in the region of 2000 to 4000 tonnes (foundation could be 700 to 1000 tonnes). In topside design the installation lift will often be the driving load case, hence requires careful consideration and handling during lifting operations.

[4] http://www.fowind.in/publications/report

- ***Self-installing substructure and topside***
  A novel method (used in BARD Offshore 1, Germany) to avoid the use of HLCVs. Both the substructure and buoyant topside are designed to float and are then towed to site; where the substructure is then lowered to the seabed and following this the topside is raised clear of the water using an in-built jacking system.

- ***Subsea base frame and floating jack-up topside***
  In this method a lattice base frame (substructure) is pre-installed on the seabed and the buoyant/enclosed topside is floated over and using in-built jack-up legs is installed and raised clear of the water (used for the BorWin Beta HVDC converter station, Germany).

- ***Topside float-over installation***
  This approach has strong synergies with the O&G industry in the Gulf of Mexico and the Middle East. A jacket substructure is pre-installed with two up-stands. The heavy topside is then floated out by barge. During high water the barge is located between the two jacket up-stands, de-ballasted and the topside lowered and located into position. Following this the topside is jacked-up clear of the water (used for SylWin Alpha HVDC convertor station, Germany).

Figure 82 - Dedicated cable laying vessel for export cable installation

3.7.8 Subsea export and inter-array cables installation

3.7.8.1 Subsea export cable installation

There are two potential methods by which the export cables can be installed:

- Installing the cables from the wind farm to shore or
- Installing the cables from shore to the wind farm

Due to the lengths of cable involved, it is envisaged that the cables would be installed using a subsea cable plough, which would bury the cables simultaneously with the laying of the cable from the main cable installation vessel.

The cable would be stored in either a static cable tank or a powered cable carousel. The cable installation vessel would also be equipped with cable handling equipment to control the tension during the cable lay and to provide holdback to control the rate of cable pay-out.

Dedicated cable laying vessels are generally based upon vessels rather than barges. Export cables are loaded at the manufacturer's premises in a single length of possibly tens of kilometres, and taken direct to the offshore wind farm site. There is a strong likelihood that the export cable laying vessel may never actually visit any port in the area of the OWF site, unless they are using the port as a safe haven. They are therefore unlikely to represent the most onerous vessel when assessing the port.

The following procedure is to install the export cables from the shore landing point to the offshore wind farm:

- The cable installation vessel arrives at a location close to the shore landing point approaching the shore at high water;
- The cable end is passed from the cable installation vessel and connected to a tow wire from an onshore winch. The cable end is then floated off from the vessel and towed towards the shore. When the cable end reaches the beach it is pulled up to the cable onshore jointing chamber;
- The cable end is then secured at the joint transition pit;
- The subsea cable plough is then deployed to the seabed. The cable installation vessel slowly moves away from the shore;
- The subsea cable plough is then launched from the cable installation vessel and the simultaneous lay and burial of the cable commences with the vessel moving away from the shore;

Figure 83 - Subsea cable plough burying cable at the shore

- Figure 83 shows a cable plough burying cables at the shore and being pulled towards the host barge, which has been deliberately grounded on the beach before re-floating at high tide and moving away to the wind farm. The plough is simultaneously laying and burying the subsea cable;
- The plough cuts a narrow trench in the seabed and buries the cable to a target depth, typically around 1-2 m;
- With the cable installation vessel at its closest acceptable position to the turbine or OSS where the export cable is connected, the cable installation vessel recovers the subsea cable plough onto the deck of the cable installation vessel;
- With the plough recovered on deck, the cable is then released from the cable pathway in the plough and the cable end is then floated off from the vessel towards the foundation structure. A roller quadrant is often suspended from the crane on the cable installation vessel during this cable handling operation to facilitate safe and careful handling, as presented in Figure 84.

Figure 84 - Cable installation adjacent to a wind turbine

- At the substation, the cable is connected to the end of the messenger line exiting the J-tube's bell-mouth. The messenger line allows the cable to be pulled up the J-tube;
- The cable is then pulled up the J-tube in a controlled manner;
- When the cable reaches the cable termination point, the pulling operation ceases and the cable is clamped in place using a cable hang-off fitting;
- This installation procedure would leave a section of cable unburied from the point of subsea plough recovery to the J-tube bell-mouth. This section of cable is then buried at a later date.

Figure 85 - Cable transportation and installation

3.7.8.2 Inter-array cable installation

Inter-array cables (IACs) are often pre-cut and stored on individual cable drums, and then transported by a standard cargo vessel to the marshalling port at such a delivery rate as to ensure that sufficient buffer stock is continually maintained.

Alternatively, inter-array cables (IACs) can be delivered straight onto the cable-laying vessel (which may be a dumb barge) at the cable manufacturer's delivery port using a carousel.

Cable laying is either carried out by a dumb barge fitted with a carousel (see Figure 85), or alternatively by a standard DP offshore service vessel (OSV) fitted with corresponding cable-laying gear (see Figure 86). In this case cable laying gear includes a means of handling individual IAC cable reels or a carousel equipped with a cable pulling engine. The vessel is often equipped with an A frame to deploy the cable plough or jetting equipment.

Figure 86 - Inter-array cable laying using an offshore supply vessel

the following procedure can be used to install the inter-array cables:

- A cable barge or a specialist cable installation vessel would be mobilised to the project site. The cables will be supplied either on cable reels or as a continuous length;
- The vessel transits to site and takes up station adjacent to a wind turbine structure. A cable end is then floated off from the cable reel on the vessel towards the wind turbine structure and connected to a pre-installed messenger line in the J-tube;
- The cable is then pulled up the J–tube in a controlled manner. When the cable reaches the cable termination point, the pulling operation ceases and the cable joint is then made;
- The cable is laid away from the first J-tube towards the J-tube on the second wind turbine structure;
- If the cable is being buried simultaneously with the lay of the cable, this would be achieved with the use of a subsea cable plough. Alternatively, the cable would be laid into a trench in the seabed and buried later using a remotely operated vehicle (ROV) which is purpose built for cable burial. Figure 87 presents the Global Marine 'Eureka' ROV, an example of this type of vehicle;
- When the cable installation vessel nears the J-tube on the second wind turbine structure, the cable end is taken from the reel, ready for pulling up the second J tube;
- The cable end is attached to the messenger line from the bell-mouth of the second J-tube. The pulling operation is repeated in the same manner as was employed at the first J-tube;
- It is probable that a 'lay loop' of cable would be laid on the seabed close to the second J-tube to accommodate the slack, or over-length allowance (as the final cable end is released from the cable drum).

Figure 87 - Subsea remotely operated vehicle (ROV)

3.8 Port infrastructure

3.8.1 Introduction

Sea ports exist across the world and to some degree their facilities have become standardised. As an example, containers are standardised items and therefore container ports for receiving and distributing this cargo will have similarities across the globe. This section of the report describes standard types of port infrastructure that can be found in ports surrounding India and describes their suitability and adaptability for offshore wind operations (see Sub-section 3.8.2). The section also introduces the requirements for international port compliance (see Sub-section 3.8.3).

When specific facilities were assessed as part of the port study (see Section 3.9) only the characteristics of the most capable berths were considered, but when projects reach the detailed planning phase, each possible berth will need to be included.

The physical requirements for offshore wind ports are often more onerous than for more traditional cargo. Wind turbine components are large structures, which impose significant bearing pressures on the ground surface and also require significant storage space at the port. The most common example of this is the ground bearing capacity in the storage area and at the quayside; some of the down selected ports in Gujarat and Tamil Nadu will require soil strength improvements before they can fully support offshore wind project construction.

In areas where self-propelled modular transporters (SPMTs) are to be used, a minimum bearing capacity of 10 tonne/m^2 is recommended to allow storage and transportation of wind farm components. Also, to support the lifting and/or movement of onshore cranes, either in the storage area or at the quayside, additional ground strength is likely required and will be determined by the size of the load and specifications of the crane.

3.8.2 Categories of port infrastructure

There are several types of port facility which have evolved to service and facilitate the various types of cargos and operations required to be handled by different port estates across the world. These different port infrastructures can be categorised using an adopted terminology which is presented in the IHS Fairplay (formerly Lloyds) Port and Terminals Guide[11].

In Sections 3.8.2.1 to 3.8.2.9 nine terms which IHS use to describe berths and other key capabilities are presented with brief explanations.

[11] IHS Fairplay Port and Terminals Guide

3.8.2.1 Break bulk facilities

Break bulk cargo or general cargo are goods that must be loaded individually, but they are not containerised or in loose bulk (like coal or iron ore). It usually takes the form of some type of cargo in protective packaging which may be a crate, a drum, a bag, or it may be on a pallet. Facilities to handle this sort of cargo generally have rail-mounted or wheeled harbour cranes, which vary in capacity from as little as 10 tonne to a the larger capacities of the Gottwald Model 8[12] or Liebherr LHM600 which have around 200 tonne capacity. Earlier this year Liebherr launched the LHM 800 which has a capacity of 308 tonne, but harbour cranes are generally towards the lower end of the lift capacity range quoted.

Figure 88 - Harbour crane LIEBHERR LHM 800[13]

The quayside decks, and haul routes to and from general cargo berths tend to be light-duty, and suitable for conventional road haulage vehicles. Such vehicles tend to have individual axle loads of 8.5 tonne for driving axles and 10-12 tonne for other axles, varying little worldwide. This type of berth therefore will almost certainly be perfectly adequate for handling blades, but may well be unsuitable for the heavier loads which are the norm for offshore wind farm components.

There is a category "project cargos" described within shipping and logistics which refers to the extra-large components. These are generally major items in particular construction projects, hence the name. Typically, there are only one or two unique items of this type per project. Offshore wind however tends to have components of the same size as project cargos, but there are tens or hundreds of these components. Onshore and offshore wind have therefore become major players in the global project cargo logistics market.
Project cargos tend to be transported onshore using self-propelled modular transport units (SPMTs), which have individual axle loads which generally vary between 15 and 40 tonne, and require 10 tonne/m^2 bearing capacity. A general cargo berth with in excess of 10 tonne/m^2 bearing capacity would be suitable for load out of offshore wind components. Additional SPMT units will spread the load and lessen individual axle loads, and likewise reduce the bearing capacity requirement, but at a cost premium. Although it is possible that this will make a particular berth usable which would otherwise appear to be of insufficient strength.

3.8.2.2 Container facilities

With the global markets greatly contracted from past levels and still stagnating, there is significant over-capacity in the container vessel marketplace.
For efficiencies of scale, there is an ever increasing trend for larger and larger vessels to cut unit costs on major cargo routes. The latest generation of super-sized container vessels can accommodate around 20,000 twenty-foot container equivalent units (20,000 TEU). They have a requirement for deep draft and so take the premium berths in most port facilities, with berths in the 12 to16 m draft range being the norm.
The characteristic container unloading cranes tend to run on heavily supported rails running along the edge of the quay. This strength provided by this reinforced rail area would be ideal for offshore wind, to allow SPMTs to operate close to the quayside edge, but potentially also to allow crawler cranes to load and unload components. But in both cases, civil structural evaluation work is required to ensure adequate capacity.

Container berths also tend to have extended areas of "high and heavy" paved storage just inboard of the quayside. This would certainly be a great advantage as offshore wind can have high demand for lay-down areas in the order of 10,000 to 100,000 m^2, which is an unusual requirement for most other activities carried out in port estates.

Since the whole loading and unloading arrangement is run as a highly efficient computer-controlled operation, there is no appetite to share the facility with other types of cargo, so container berths are not likely to be used by the offshore wind industry where other suitable facilities are available.

[12] Gottwald Model 8 - http://www.terex.com/port-solutions/en/products/harbour-cranes/mobile-harbour-cranes/model-8/index.htm
[13] Liebherr LHM 800 - http://www.liebherr.com/MCP/en-GB/products_mcp.wfw/id-11603-0/measure-metric

It is unclear what the recent extended period of reduced trade in this sector will do for port utilisation, but where under utilised container facilities exists, there may be an opportunity to use these facilities, but conditions will vary on a case by case basis.

Figure 89 - Container port

3.8.2.3 Dry bulk facilities

Cargos like fertilisers and minerals tend to be loaded and unloaded by specialist equipment. This is generally based on conveyor systems, pneumatic systems or the historic grab-cranes. But they tend to carry out long-distance transport with conveyor systems, taking the cargo directly to and from warehousing. Foodstuffs like grain are handled in a similar manner, but are stored in silos.

Coal and iron ore are very common in major Indian ports (see Figure 90). They are stored in open bulk mounds and because of the sheer areas which are often required; these may be several hundred metres inshore from the berth. Transport of this material is typically facilitated using long conveyor belt systems which by their nature give rise to low headroom clearances around the port estate. Both coal and iron ore are dirty cargos and whilst coal can be cleaned-off by a simple jet-wash, iron ore tends to be magnetic, and adheres to the metal components of wind turbines. If precision machined parts become impregnated with iron dust there is great potential for damage. For this reason turbines are unlikely to be unloaded or stored in areas where bulk coal or iron ore are handled.

The major issue with bulk cargo facilities is that the conveyors effectively act as a barrier to the transit of "high and heavy" cargos (and most wind turbine components are in this category). Ports tend to put the conveyor systems to one side of their port estate to minimise the impact of the headroom restriction.

3.8.2.4 Dry-dock facilities

In most cases the presence of dry dock facilities for repairing ships is largely irrelevant for offshore wind farms. However, there is an opportunity to cast gravity based structures (GBS) in a dry-dock and then flood the dock to launch the structures. The launch can either involve a float-away method if they are buoyant or to allow access to a heavy lift vessel if they are not. In Tamil Nadu the rock seabed may make the consideration of GBSs more attractive, so dry docks may be worthy of consideration, however no dry docks existed within the

Figure 90 - Dry bulk facilities

Figure 91 - Dry dock facilities

key facilities identified in the port selection study. It is recommended to investigate the potential use of floating dry docks which can be mobilised at harbour facilities that have the capacity to accommodate GBS production.

3.8.2.5 Liquid facilities

Liquid cargos are offloaded and transported by pipelines for several hundreds of metres and stored in large clusters of storage tanks often referred to as tank farms.

In the same way as the conveyor systems for bulk cargo handling, these pipe line systems tend to form an effective barrier to wind farm components. Again ports tend to put their liquid cargo berth at one extremity of their site or another, and ports handling both types of cargo therefore become bounded by liquid facilities on one side and bulk on the other.

3.8.2.6 LPG facilities

It is of no great significance to offshore wind whether LPG facilities exist, but in the same way as liquid facilities these imply restricted access due to pipework.
It is noteworthy that some pipework may be mounted above ground and some buried, but in either case can be an obstruction (see Figure 92). Pipes above ground have limited headroom passage beneath them. Buried pipes may well limit the axle loads which can pass over them.

Figure 92 - LPG facilities

3.8.2.7 RoRo facilities

"Roll-on and Roll-off" (RoRo) has significant implications with regard to vessel, port infrastructure, and mechanical plant selection. RoRo is most commonly associated with passenger car ferries, where both commercial vehicles and private cars are loaded and unloaded onto the vessel by driving on and off ramps using a customised port access device called a link-span.

Many onshore wind farm components can be transported using RoRo vessels, however, large offshore components are unlikely to be transported using ferries, as their components are generally larger than even the largest freight transport for which the ferries and link-spans are designed; they are also too large to be road-hauled via infrastructure designed for similarly-sized vehicles. However, this methodology is applicable to loading and unloading components which may be transported by barge, and some cargo vessels have decks which can be used for RoRo cargos.

While some ports may not have permanent RoRo berths, it is possible to accommodate this facility by using a mobile RoRo ramp. This is a highly specialised piece of equipment, as it enables extension of a port's capability beyond that of its fixed infrastructure.

There are some general cargo vessels and heavy-lift cargo vessels which have aft and/or bow ramps designed for RoRo cargos. Some vessels are designed with reinforced decks, and will only accommodate the RoRo cargos as deck loads, while others have more elaborate arrangements for accommodating the cargo below deck.

Figure 93 - 180 tonne RoRo linkspan

The 180 tonne RoRo ramp at Larne in Northern Ireland (see Figure 93) has allowed the port estate to be used as a marshalling port for turbine blades manufactured at a facility in Scotland. The ferry shown in Figure 93 was used to transport the blades. As stated some facilities may have concrete ramps which can be used to allow the delivery and load-out of large components, see Figure 94.

Figure 94 - Concrete ramp, used for RoRo load-outs

3.8.2.8 Passenger facilities

Passenger facilities are of relevance for several reasons, firstly, the services are generally run on a scheduled timetable and port authorities will generally prioritise the departure and arrival of these services above commercial construction traffic. It is unlikely that this will be of great impact but on occasions delays may be experienced waiting for a ferry and this could lead to an operation missing a tide for example.

The fact that large numbers of passengers need to travel through the port means that the road and rail access to the port is likely to be good. This may be of relevance to the operation and maintenance aspects of the work as a large number of technicians need to travel to and from the O&M facility daily and good transport links can facilitate this, particularly if the O&M facility is located adjacent to the passenger terminal.

3.8.2.9 Multipurpose facilities

By their very nature multipurpose berths are more complex to assess, and if they are considered, would require individual assessment. Some berths have both liquid and general cargo facilities, and some are used for handling bulk and project cargos as well.

Multipurpose vessel is another name given to vessels like heavy lift cargo vessels. They are generally more suited to project cargo handling than the lighter duty general cargos and break bulk cargos. There is an expectation that "high and heavy" cargos will use these berths, and haul routes will be specified to allow for the axle loadings associated with SPMTs rather than conventional road haulage.

3.8.3 International port compliance

3.8.3.1 ISPS Compliant

The IMO International Ship and Port Facility Security code ensures that cargos can be transported internationally and since at the present time there is no Indian offshore turbine manufacturer there is a strong possibility that there will be a requirement for importation, which will require an ISPS compliant port.

3.8.3.2 CSI Compliant

Based on the same logic as ISPS Compliance, since turbine wear components and spares are likely to be transported by containers, it would be advantageous if the port where O&M facilities are located has Container Security Initiative (CSI) compliance. This will allow delivery of spares from the WTG manufacturer directly to the O&M facility port.

3.9 Offshore wind port study

3.9.1 Introduction

This section presents the final stage of the Port Infrastructure and Logistics assessment, namely the port screening phase. The methodology presented in Section 3.3 has been followed, with Sections 3.4 to 3.8 presenting the research findings from the preparation phase. These sections provide the baseline inputs for this port study and DNV GL's proprietary in-house software tools have supported the process.

The preparation phase has defined and/or investigated the following:

- the envelope of project specifications for Gujarat and Tamil Nadu (e.g. turbine power rating and project MW)
- the range of components that are likely to be handled and stored (physical dimensions and mass – used to define minimum storage requirements in the port)
- possible installation strategies (in turn defining likely
- vessel specifications (used to define minimum port requirements to facilitate operations)
- standard port infrastructure specifications and suitability for offshore wind

This desk-based screening study has utilised the above preparation phase information to consider the suitability of ports in Gujarat and Tamil Nadu to supply the potential Indian offshore wind project demands for construction operations. This screening process (see Section 3.9.2) was developed further during the more detailed port readiness assessment (see Sections 3.9.3 and 3.9.4) which included site visits to promising ports.

In terms of maritime limitations, some technical requirements stem from the physical dimensions of the vessels used for either the construction phase or for transportation (as logistical elements of the supply chain, described in Section 2); in these contexts the following items need to be considered:

- vessel beam
- laden and un-laden draft (water depth required by the vessel should also include an additional amount for safety, and changes in level, and silting up)
- their overall length (to a lesser extent)
- overhead clearance (sometime referred to as air-draft)

Other hard technical limits result from the dimensions and mass of wind farm components, at the various stages of assembly at which they are transported between manufacturing and construction facilities (pre-staging ports), where the following factors need to be considered:

- physical size range of components, for each project to be supported from each port
- length, breadth, and height required – not only of the component itself, but of the area surrounding it in any storage areas to allow access for the lifting and other mechanical handling plant required to move it; and
- numbers of components that will likely require storage during conventional project programs

For the construction pre-screening, a comparison is therefore made between the port requirements and its published capabilities, to establish whether it is suitable to accommodate each combination of wind turbine, foundation and construction strategy.

Information is readily available from international references for these desk based studies, for example the IHS Fairplay Maritime Ports and Terminals Guide[14]. The 2015/6 edition was used during the early screening of suitable ports.

[14] IHS Fairplay Maritime Ports and Terminals Guide https://www.ihs.com/products/maritime-ports-terminals-cd.html

Once ports have been pre-screened (see Section 3.9.2, port screening), visits were arranged to confirm that there are no other previously unforeseen circumstances which may mean that the port is, or is not suitable (see Section 3.9.3, port readiness assessment).
A key consideration is the port development plans; as offshore wind farms are long-lead time projects and ports rarely stay exactly the same for long periods.
The opportunities and challenges associated with proposed modifications must therefore be factored into any suitability assessment.

Section 3.9.5 provides a high-level screening of possible O&M ports, based on those identified in the FOWIND Pre-feasibility reports.

3.9.2 Construction port screening

The Ports Screening Process involves the comparison of two sets of data, (1) the requirements which the project components, vessels and installation strategies place upon the port; and (2) the physical dimensions and characteristics of the port to meet the demand. This is assessed in a quantified and systematic approach in order to assess the supply and demand of port infrastructure. This involves establishing:

- the port infrastructure characteristics required by each combination of turbine model/foundation type/ construction strategy
- the port infrastructure capacity of the most capable berth within each of the various ports within reasonable geographic proximity of the development zone

Lastly a comparison of the two is made to establish which ports are suitable to facilitate which types of installation strategies, without any requirement for port redevelopment. Further studies could then establish a cost gap-analysis to evaluate how much it would cost to bring any given port's facilities up to the requirements of any particular approach to transport and installation (T&I), and this would allow a project level cost-benefit analysis to be based upon the value of the identified capital expenditure.

3.9.2.1 Key assumptions

It is assumed that components will be raised off the ground during storage, as shown in Figure 95. This enables self-propelled modular transport (SPMTs) to manoeuvre underneath, jack-up to take the mass of the component, and transit to the quayside for load-out. A sufficient gap must therefore be left for the SPMT beneath the component. The typical method to achieve this is to use transport frames with metal columns to raise the component off the ground and baulk timbers to distribute the load to the ground. In deck strength requirement calculations, it has been assumed that baulk timbers are 30 cm by 30 cm and can distribute load nearly uniformly over their area.

Figure 95 - Nacelle storage at port

It is also assumed that blades are stored in stacks of three and the frames are supported by 4 m long blocks at both ends. In deck strength requirement calculations, for nacelles, it is assumed that similar transport frames with four columns would support the structure and would rest on timbers the length of half of the nacelle.

The transition pieces are assumed to rest on a frame, which rests on four columns, the mass distributed over two pieces of baulk timber as long as the diameter of the transition piece. The monopile foundations are assumed to be stored on ten columns at five points along the foundation, each column resting on a 4 m long piece of baulk timber. It has often been found to be cheaper to support monopiles on multiple parallel bunds (see Figure 96), but this approach may not be suitable for all ports. SPMTs can then drive between the bunds and lift the monopiles as required.

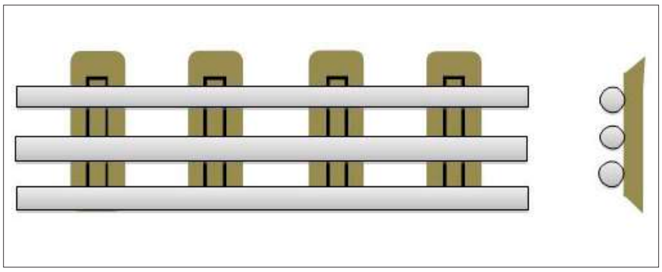


Figure 96 - Monopile storage on bunds, of the same height as an SPMT

Lastly, the jacket foundations are assumed to be stored upright or on their sides, at the manufacturer's premises, and each of the four contact points resting on 12 m^2 load spreading mats. It should be noted, however, that it is not recommended for the jackets to be stored at the staging port, but loaded immediately onto a barge from the manufacturing port and kept there until ready for installation. Jacket foundations are particularly fragile and this method avoids multiple handling and potential damage.

3.9.2.2 Screening ports in Gujarat

The State of Gujarat has over 1,600 km of coastline (the longest in India) and a significant number of developed and protected harbours. In the FOWIND Gujarat Pre-feasibility study report a total of 38 ports have been identified in the Gujarat region (see Figure 97).

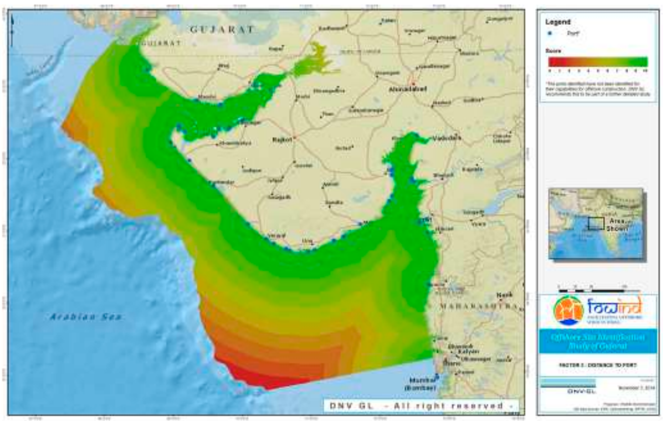


Figure 97 - Ports in Gujarat
Please see Appendix A for a larger map.

Out of the total 38 in the Gujarat region, a selection of ports have been initially screened and considered potentially suitable for construction activities. The ports of Bhogat, Chhara, Mahuva and Vansi Borsi are proposed under development and, hence have not been selected at this stage for further analysis. In addition, the ports at Diu and Alang have not been selected since they are small ports mainly involved in fishing activities and would incur significant capital investment costs.

Out of the remaining ports, five have been identified (see Figure 98) with some potential and taken forward for further investigation in the ports readiness assessment in section 3.9.3.

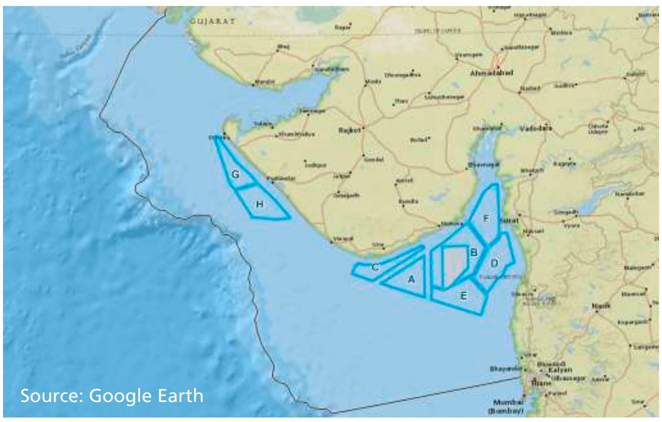


Figure 98 - Offshore potential ports in Gujarat
Please see Appendix A for a larger map.

The five selected facilities of interest are as follows:

- The ***Adani port facility*** has potential to be used as wind turbine marshalling facility during construction
- ***Larsen and Toubro's fabrication facility*** in Hazira would be a possible fabrication site for several types of offshore wind foundations and possibly substation topsides
- The ***Port of Pipavav*** has facilities to accommodate foundations and potentially turbines if suitable coal dust insulation is used
- ***Bhavangar*** has a narrow lock-gate on the approach channel so is unsuitable for installation vessels. There is however a well-developed limestone handling facility, could be utilised as a base of scour protection marshalling during construction and O&M phases
- ***Port Okha***, the nearest port to development zones G and H, however would require substantial infrastructure development before being suitable to support offshore wind developments

It should be noted that in Gujarat in particular there is a tendency to have ports with offshore deep-water anchorages, and to bring cargos ashore using barges or lighters. This sort of technique is usually used in shipping for break bulk and general cargos and for small volume bulk transport, but in general it is not considered appropriate for project cargos.

In the present study, whilst it is acknowledged that it may be technically possible to handle offshore wind components by offloading them from a heavy lift cargo vessel onto feeder barges for example, it was not considered that this was an optimal construction strategy, and so the ports assessment is based upon the larger vessels being able to come alongside a berth in the port facility. If the assessment were based on a "mother and daughter lightering" arrangement, and feeder vessels, some of the ports with low water depths but deep water offshore anchorages might be considered suitable. This approach would have to be revisited when specific offshore wind farm sites are under development.

The development zones identified during the Pre-feasibility study are mostly concentrated around the Gulf of Khambhat that is within the eastern part of Gujarat. The Gulf of Khambhat is known to have very strong currents, with up to six knots having been noted. High currents can lead to large-scale scouring, additional hydrodynamic loading and significant installation and O&M challenges. Existing fixed facilities in the Gulf of Khambhat can be seen to have very extensive scour protection features around their bases (see Figure 99).

Figure 99 - Structure in the river showing heavy scour protection

It is also significantly more difficult to conduct offshore installation operations in these conditions. Recently, in northern Europe projects, significant work has been conducted to demonstrate the operational capabilities of various jack-up and dynamically positioned vessels in such conditions. This work has been largely driven by the embryonic tidal energy industry in the UK and its requirement to install tidal stream generators in these harsh tidal conditions. GeoSea recently conducted an extreme current trial in Raz Blanchard, France where the jack-up *Goliath* was successfully stationed in 10 knot (5 m/s) in 56 m of water, see Figure 100. This expertise and the lessons learnt could well be leveraged to great advantage during marine operations planning for installations in the Gulf of Khambhat.

Figure 100 - Jack-up 'Goliath' in strong current in the Raz Blanchard

3.9.2.3 Screening ports in Tamil Nadu

In Tamil Nadu, three major and 22 minor ports have been identified during the Pre-feasibility study (see Figure 101). The potential and suitability of the three major ports for construction is discussed in the following sections.

The development zones identified during the Pre-feasibility study are mostly concentrated around the Gulf of Mannar.

There are three facilities which are of interest in the present construction port study:

- ***Kattapalli*** - the deep water port of Ennore is provided with a dedicated terminal for handling coal, general and liquid cargo and a vast hinterland. Closest development zone is H, which is approximately 310 km.
- ***Chennai*** - the deep water port of Chennai is provided with a dedicated terminal for oil, iron ore and general cargo and 24 hour 7 day operations, and a passenger terminal. Closest development zone is H, which is approximately 290 km.
- ***Tuticorin*** - the port of Tuticorin is provided with an oil & coal handling jetty and 24 hour 7 day operations, general, break-bulk, container and bulk cargo handling facilities, dry and liquid cargo storage facilities and a passenger terminal. Closest development zone is A, which is approximately 20 km.

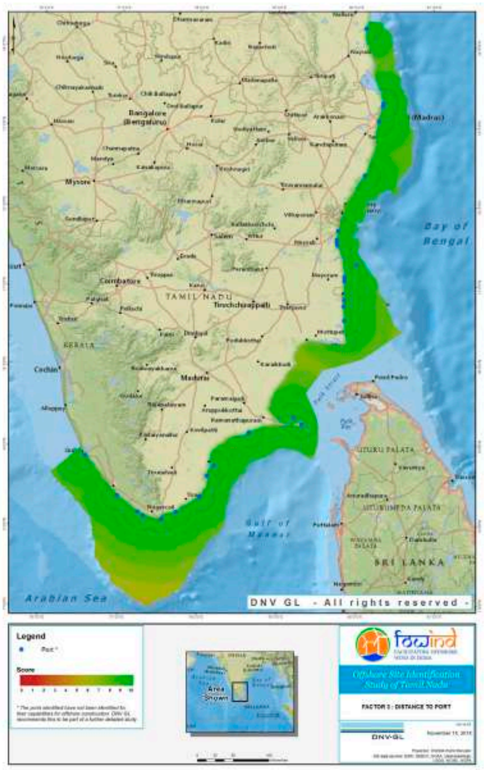


Figure 101 - Ports in Tamil Nadu
Please see Appendix A for a larger map.

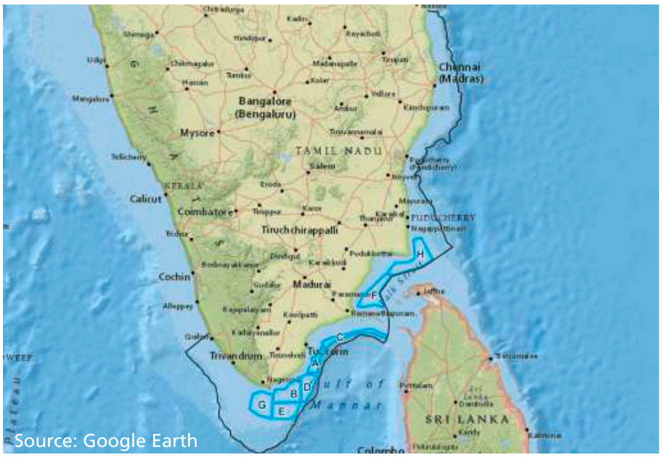


Figure 102 - Offshore potential ports in Tamil Nadu
Please see Appendix A for a larger map.

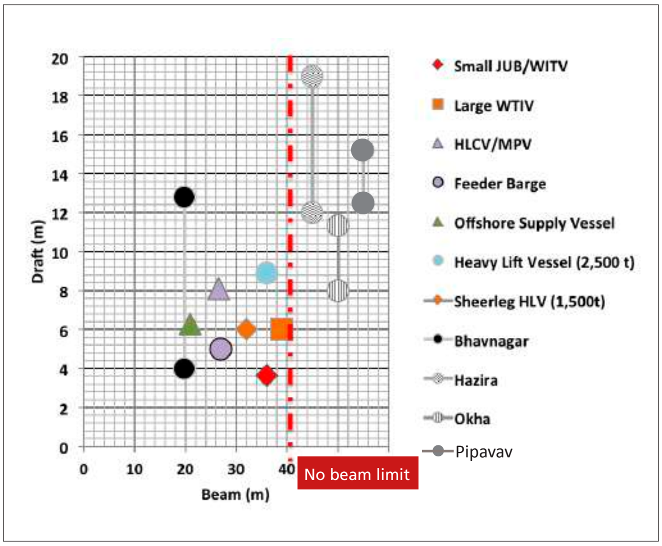


Figure 103 - Vessel port access requirement chart for vessels accessing ports in Gujarat

3.9.3 Port readiness assessment - Gujarat

This section develops the screening process further into a more detailed construction port readiness assessment for Gujarat. The assessment includes:

- considerations of vessel access requirements (Section 3.9.3.1)
- an appraisal of the suitability of specific ports for offshore wind (Sections 3.9.3.2 to 3.9.3.6)
- reports key findings from the port estate visits in Gujarat (Sections 3.9.3.2 to 3.9.3.6)

3.9.3.1 Installation vessel port access requirement chart - Gujarat

The vessel port access requirements which represent the most common ones used in offshore wind installation were described in Section 3.6.11.

The minimum width of vessel which can access each port and the depth at high and low tides are plotted versus the four ports (note L&T shipyard Hazira considered mainly for manufacturing purposes only) with the most potential for offshore wind construction in Gujarat, see Figure 103.

If the vessel is to the LEFT and BELOW the entire line associated with a particular port then it is both:

- narrow enough to fit into the port's tightest marine access requirement, and
- it's fully laden draft is less than the water depth at any state of the tide, meaning that the vessel can operate at that port at any state of the tide, and whether it is un-laden or fully loaded

If the port is to the LEFT of the vessel, the port is not wide enough to allow the vessel access.

If the vessel is ABOVE the lower limit of the line but BELOW the upper limit, the vessel can only operate at that port partially laden or tidally restricted.

It can be seen that Bhavnagar is unsuitable for any vessel to pass through its narrow access channel, but that all vessels can operate at Hazira and Pipavav, and most vessels can operate at Port Okha fully laden at most states of the tide, but HLCVs and OSV can only operate partially laden or tidally restricted. A further restriction at Port Okha is that the quayside deck strength is currently unsuitable for heavy project cargo traffic, and port infrastructure development would be needed before the facility could be used. Alternatively construction work could be carried out using floating storage vessels moored alongside existing quays but this flexibility would come at a cost premium.

3.9.3.2 Adani container port at Hazira

Adani Hazira port is a privately owned container port located on the west side of the Hazira peninsula. An entrance channel connects the port with the deep water of the Sutherland Channel. Allowing for the arrival and departure of ships up to a draft of 13 m. Development zones D and F are approximately 13 km away from the port. The layout and aerial view of the port can be seen in Figure 104 and Figure 105 respectively.

The straight approach channel has a clear width of 700 m at the seaward side tapering off to a width of 470 m between the breakwaters at the harbour entrance, to allow unobstructed and easy passage of ships.

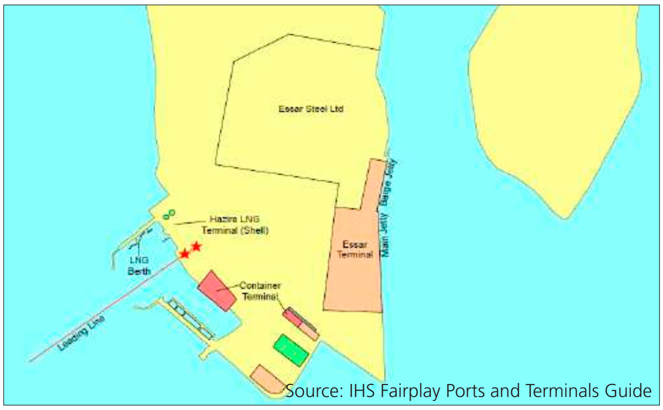


Figure 104 - Hazira - Adani container port terminal

Figure 105 - Adani container port terminal

There are proposals to deepen the channel and turning circle to accommodate capesize vessels in due course. The breakwaters provide protection for the berth from the SW monsoon waves and swells and for the currents parallel to the coastline. The port contains a turning basin with a radius of 300 m for manoeuvring tug-assisted ships during berthing and realignment before setting out to sea.

Ongoing development plans include establishing a rail-connection to join the main rail system around Surat. Development plans are currently flexible enough to include the capability to handle general and project cargos along reinforced haul routes within the decking on the northerly container berths. The southerly quay provides good shelter to the harbour.

Adani container port (key parameters)	
Draft	13 m
Harbour entrance width	470 m
Turning radius	300 m
Berth 1 - MP1, overall length (LOA)/beam Berth 2 - MP2, overall length (LOA/beam) Berth 3 - MP3, overall length (LOA/beam) Berth 4 - CB1, overall length (LOA/beam) Berth 5 - CB2, overall length (LOA/beam)	300 m/36 m 300 m/36 m 300 m/64 m 300 m/64 m 300 m/64 m
Infrastructure	- steel yard - liquid terminal - covered storage - open storage - containers

Table 26 - Adani container port key parameters

Available facilities			
Break bulk facilities	√	RoRo facilities	x
Container facilities	√	Passenger facilities	x
Dry bulk facilities	√	Multipurpose facilities	√
Dry-dock facilities	x	ISPS compliant	√
Liquid facilities	√	CSI compliant	√
LPG facilities	x	LNG facilities	√

Table 27 - Port facilities available at Adani Container Port Hazira

3.9.3.2.1 Specific berths of interest in Adani container port terminal

Existing port facilities consist of two piled quaysides with rail-mounted container cranes along both quaysides (see Figure 106). The northern quay is over 600 m in length and according to the IHS guide is designed for a permissible draft of 13 m, with a turning circle of 600 m diameter.

It has a concrete decked area of approximately 250 m width along the entire length which is mainly used for container storage. However some parts are narrower as a result of the location of the office complex, meaning that a theoretical 150,000 m^2 "high and heavy" storage area capacity would be reduced to approximately 100,000 m^2.

Figure 106 - Adani container port mobile harbour cruise

A heavily piled central area under the northern quay means that the port can be considered suitable for handling heavy project cargos using self-propelled modular transporters (SPMTs). The quay has a high freeboard, so all loading and unloading would have to be by crane, and RoRo options would require substantial ingenuity.

The southern quay is of approximately 950 m in length and is adequately wide to accommodate the container cranes and transport tractors and trailers, but little else. There is no storage adjacent to the quay.

A major issue regarding access is the tidal streams, which have a north – south direction but can be five to six knots according to the IHS guide. The port of Magdalla slightly upstream on the river to Surat and Hazira port entrance has a tidal range of 6.5 m[15].

There is the Hazira bird sanctuary limiting the northern development of the port estate, although some potential for reclamation appears to exist to the east.
Close proximity to a coal-fired thermal power station would potentially make offshore areas suitable for grid connection.

3.9.3.2.2 Suitability of Adani terminal to support offshore wind development in Gujarat

As identified in the FOWIND Gujarat Pre-feasibility study report444, Adani's geographic location means that it is well positioned to support the offshore wind development zones D and F on the northern and eastern areas of the Gulf of Kumbat. And will also be worthy of consideration as an O&M base for these two zones.

[15] https://en.wikipedia.org/wiki/Port of Magdalla#Tidal information

With suitable offshore wind development density in Gujarat and given the size of the port it is also possible, subject to availability, that manufacturers might give consideration to locating their operations here to serve the wider Gujarat offshore wind zones. However the lack of available development land at the site could be a factor in any such decision.

During the construction phase, the port is suitable as a wind turbine marshalling facility, and could also accommodate foundation marshalling of monopiles and transition pieces as well as jackets and pin-piles.

The water depths at this port are deep enough for conventional or heavy-lift cargo vessels to bring in offshore wind turbines for marshalling. If cabling were supplied pre-cut and transported upon individual cable reels, the port could easily cater for the cargo vessels which would most likely transport these, and their loading, off-loading and storage, as well as any offshore supply vessels which might be used to install them.

These berths would be suitable to receive monopiles, transition pieces or jacket pin-piles for marshalling, delivered by similar vessels, but great care would be needed in planning the haul route to any monopile and transition piece storage areas, as only a central corridor of the northern quayside is heavily reinforced for project cargo transportation using SPMTs. Bringing barges alongside with any of the above components aboard would require careful consideration of fendering and where necessary, loading & unloading arrangements, as the freeboard of the quay is far higher than the deck-level of even large barges.

Its geographic location means that the project offices, marine operations management and PPE & general storage facilities could be accommodated within the security fenced facility.

The quayside deck strength is unsuitable to allow the unloading of substation topsides, but the sheltered waters within the breakwater would provide safe haven for substation components on barges waiting on weather, and indeed any other vessels involved in the construction of wind farms during times of inclement weather.

The Port of Hazira is most suited as a marshalling port; however it would not be impossible to establish a blade manufacturing facility here. Though this would require usage of a considerable proportion of the currently available storage space within the port estate.

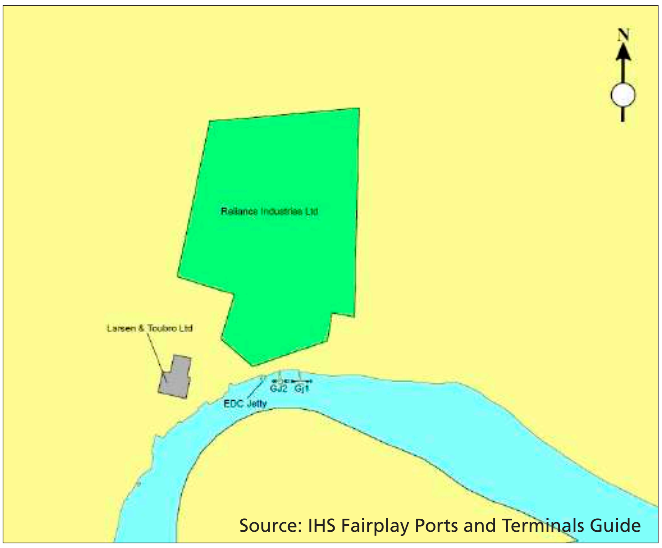

Source: Adani Ports

Figure 107 - Adani container berths with cranes

3.9.3.3 Port at Hazira

When considering ports for offshore wind farms it is always necessary to consider the location of potential fabrication facilities, especially when located at sites which may negate the need for a marshalling facility.

Larsen & Toubro's (L&T) are an extremely large privately owned construction group in India and they have a fabrication facility at Hazira. The facilities consist of a boiler and pressure-vessel manufacturer, with high-quality fabrication facilities for oil and gas, power and the nuclear industries. Development zones D and F are approximately 20 km away from the port.



Source: IHS Fairplay Ports and Terminals Guide

Figure 108 - Larsen & Toubro fabrication facility - Hazira


Source: Google Earth

Figure 109 - Larsen & Toubro port and fabrication facility Hazira

The site consists of a modular fabrication facility (MFF), heavy engineering & shipbuilding and power equipment manufacturing facilities. The factory buildings cover over 34,500 m^2 and the site has a heavy-duty load-out quay on the banks of the river Tapi, approximately 16 km from Surat, Gujarat. High and heavy haul routes to suitable storage areas are available for any foundation components, should they be fabricated here.
Overall their site extends to over two million square metres. The layout and aerial view of the port can be seen in Figure 108 and Figure 109 respectively.

L&T Port at Hazira[16] (key parameters)	
Draft Side launch facility Water depth Vessel deadweight (DWT)	4 m 160 m 5.5 m minimum 20,000 tonnes
Infrastructure	Shipyard located within a large scale heavy manufacturing facility. Shipyard equipped: - plate stockyard - automatic blasting and priming line - plasma cutting machines - marine coating shops - pipe shops

Table 28 - L&T port at Hazira key parameters

Available facilities			
Break bulk facilities	√	RoRo facilities (heavy project cargos)	√
Container facilities	x	Passenger facilities	x
Dry bulk facilities	x	Multipurpose facilities	√
Dry-dock facilities	x	ISPS compliant	x
Liquid facilities	x	CSI compliant	x
LPG facilities	x	LNG facilities	x

Table 29 - Port facilities available at L&T Hazira

3.9.3.3.1 *Specific berths of interest at L&H Hazira site*

The Larsen and Toubro (L&T) fabrication facility caters for critical and large sized equipment for process plant, nuclear and defence sectors. It is equipped with:

- heavy thick rolling machines of 3,050 Mt capacity (maximum plate dimensions for hot rolling 4,500 mm width X 225 mm thick, which are much thicker than even the heaviest-walled monopiles)
- CNC flame/plasma cutting machines (up to 450 mm thick alloy steel plates)
- floor mounted horizontal boring machines (12.5 m horizontal and 5 m vertical traverse horizontal/vertical deep hole drilling machine with maximum drill depth up to 1,200 mm)
- heat treatment furnaces (for jobs up to 50 m long) and quenching facilities, advanced welding equipment, positioners and power sources
- hydro test beds with capacity of 60 Mt/m^2, testing facilities
- ISO 17025:2005 NABL approved testing Lab
- heavy thick radiography, PAUT (Phased Array Ultrasonic Testing), TOFD (Time-of-Flight Diffraction) capabilities

In addition, the facility has one of the world's largest forging facilities, large scale material handling capabilities, a roll-on-roll-off slipway, and a shipbuilding facility for modern vessels. It has all of the facilities and the capability to fabricate monopiles and transition pieces.

The port has previous experience of manufacturing oil and gas topsides up to 2,000 tonne, which are directly analogous to offshore wind farm substation topsides, and this capability with heavy tubular offshore structures would allow production of jackets.

The facility has a heavy-duty load-out facility, but is heavily restricted by tides, with the IHS Guide quoting the channel depth as 3 m with some drying areas in the river at low water. With a tidal range approaching 7 m, large vessels can be berthed alongside, if they are suitable for bottoming, as can be seen in Figure 110, with the Roll Dock heavy lift cargo vessel alongside (which was fabricated at the site). However only low-draft vessels can approach all areas, even at high tide.


Source: L&T

Figure 110 - L&T Hazira site

A major issue regarding access is the tidal streams, which have a north–south direction but can be 5 to 6 knots according to the IHS guide. However, this high tidal range allows larger vessels to be brought in at high tide and bottomed out on the soft-silty riverbed alongside the heavy duty 'V' shaped load-out quay. There is also RoRo capacity to allow the transport of several thousand tonne modules using self-propelled modular transporters (SPMTs). This may not prove overly restrictive if transportation of bunged-monopiles is considered, as these do not require a high draft, and could be loaded out and towed for a high proportion of most tidal cycles.

[16] L&T Hazira

Figure 111 - L&T Hazira manufacturing complex

Being boiler and pressure vessel manufacturers they have the capacity to roll tubular heavy walled structures from steel plate. This ability to roll thick plates is similar to the requirements for the fabrication of offshore wind monopiles. In the past the facility has fabricated tubulars of up to 1,000 tonne and 100 m in length.
The facility has capacity to deliver extremely high quality tubular structures.

Whilst current order books cannot be taken as an indication of future activity, it is noteworthy that the facility is engaged in the fabrication of naval vessels, therefore there is very low utilisation of their heavy rolling and welding capacity. The facility clearly has a policy to accommodate fluctuating order books by having a diverse portfolio of capabilities, which bodes well for their capacity and interest in accommodating the requirements of new industries like offshore wind energy.

3.9.3.3.2 Suitability of L&T terminal to support offshore wind development in Gujarat

L&T's facility has great potential as a monopile or jacket foundation and offshore substation topside fabrication, and storage facility. The closest development zones to the site is zone D and F as identified in the FOWIND Pre-feasibility report, but the savings associated with the possibility of avoiding the need for a marshalling port may well mean that it is competitive for a wide range of the proposed Gujarat development zones.

It is unsuitable for marshalling turbines, as the water depths are too low for conventional heavy lift cargo vessels and in general, all cargo handling must best be accommodated by barges.

The port is further upstream than Hazira, and with the strong currents in this area, it is therefore unlikely to be given consideration as a base for O&M activities. Likewise even if manufacturing of components were to take place at the site, whilst it may be appropriate to locate the construction offices at the site, any Marine Coordination and crew transfer and storage facilities would most likely be located at a port facility directly on the coast of the Gulf of Khumbat.

3.9.3.4 Bhavnagar

Bhavnagar port is situated in Saurashtra region of Gujarat. Bhavnagar is managed by the Gujarat maritime board. It is an all-weather direct berthing port for smaller vessels. It is located in the Gulf of Khumbat.
Development zone F as identified in the FOWIND Pre-feasibility study report[4] is approximately 35 km away from the port. The layout and aerial view of the port can be seen in Figure 112 and Figure 113 respectively.

Bhavnagar Port (key parameters)	
Draft	4 m (lock gate)
Mean high water springs (MHWS)	12 m
Mean low water springs (MLWS)	8.3 m
Mean sea level (MSL)	3 m
Concrete jetty	Length 270 m, width 12.8 m
Vessel restrictions	Length 144 m, width 20 m
Commodities handled	- rock phosphate - coal - fertiliser - iron scrap - sulphur - wood and timber

Table 30 - Bhavnagar port key parameters

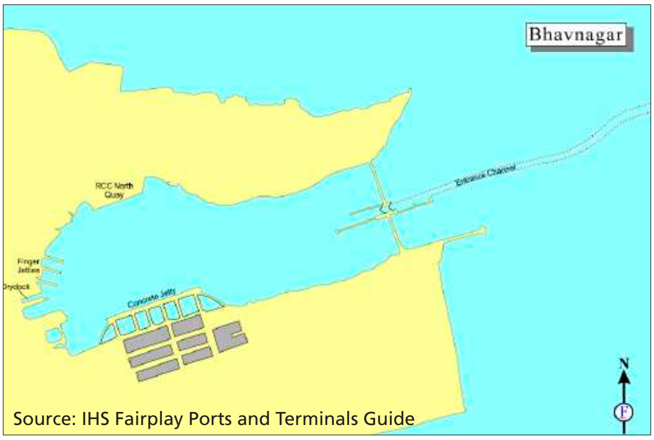
Source: IHS Fairplay Ports and Terminals Guide and GMB ports

[4] http://www.fowind.in/publications/report

Available facilities			
Break bulk facilities	√	RoRo facilities	x
Container facilities	x	Passenger facilities	x
Dry bulk facilities	√	Multipurpose facilities	x
Dry-dock facilities	√	ISPS compliant	x
Liquid facilities	x	CSI compliant	x
LPG facilities	x	LNG facilities	x

Table 31 - Port facilities available at Bhavnagar

Source: IHS Fairplay Ports and Terminals Guide



Source: IHS Fairplay Ports and Terminals Guide

Figure 112 - The port of Bhavnagar and approach channel


Source: Google Earth

Figure 113 - The port of Bhavnagar and approach channel

3.9.3.4.1 Specific facilities of interest at Bhavnagar

The port has a narrow lock gate on the approach channel of 19.8 m width, which also has a low air draft as can be seen from Figure 112 and Figure 114.

Bhavnagar's current major cargo is crushed limestone for use in the salt-producing areas in the hinterland of the port.

The port has a dry dock for repair of tugs, launches and barges. The port has two workshops. The general workshop is used to carry out repairs on flotilla units and mechanical instruments. The running workshop is used for the day-to-day repairs and maintenance requirements. Recently, the port has been connected with a broad gauge railway line.


Source: Beckett rankine marine consulting engineers

Figure 114 - Bhavangar Port - lifting gate lowered into position at high tide


Source: GMB ports website

Figure 115 - Bhavangar Port - lifting gate

3.9.3.4.2 Suitability of Bhavnagar to support offshore wind development in Gujarat

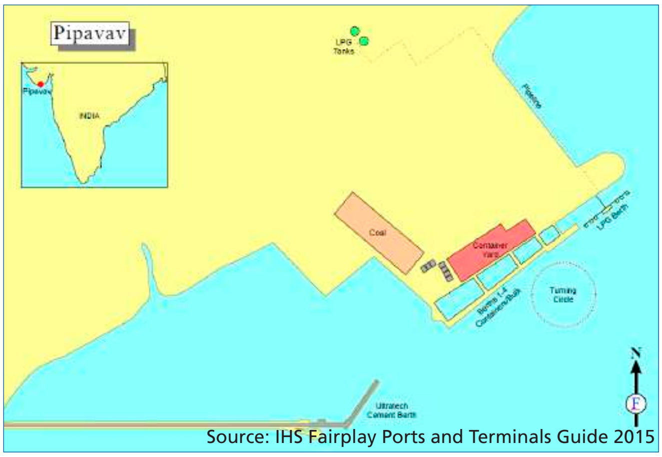
Due to its location and facilities it is unlikely that Bhavnagar will be able to perform any significant role in offshore wind development

However, due to its existing infrastructure associated with limestone handling. It could perhaps be utilised as a base for scour protection marshalling during the construction and O&M phases. The handling of bulk rock armour is quite damaging to quaysides, and many ports will be reluctant to use their facilities in this role, and this may well make utilising these existing facilities more attractive.

3.9.3.5 Pipavav

Pipavav is privately owned by APM terminals and is the largest port on the west side of the Gulf of Khumbat. The port is an all-weather port. The port's location in the state of Gujarat provides immediate access to key markets in northwest India. With a total land area of 631 hectares, there is plenty of land available for expansion of port-related services and businesses. Development zones A, B and C as identified in the FOWIND Gujarat Pre-feasibility report are approximately 23 km, 27 km and 13 km respectively from the port.

The port is along the major trade routes and is close to the major Indian port of Nhava Sheva (300 km away). It has been dredged to 14.5 m draft. There are eight quay cranes for containers and two mobile harbour cranes for handling bulk cargo. The layout and aerial view of the port can be seen in Figure 116 and Figure 117 respectively.



Source: IHS Fairplay Ports and Terminals Guide 2015

Figure 116 - Port facilities at Pipavav


Source: Google Earth

Figure 117 - Port facilities at Pipavav

Pipavav Port (key parameters)	
Draft	14.5 m
Mean high water springs (MHWS)	3.92 m
Low low water springs (LLWS)	-0.01 m
Mean sea level (MSL)	1.76 m
Currents	Between 2.5-3 knots (peak tidal)
Quay length	735 m
Cargo facilities	- container facilities (850k TUEs) - storage facilities (container freight station 7600 m²) - bulk cargo (quay length 690 m, 3 berth) - storage facilities (coal yard 100k m²) - liquid cargo (2 million Mt)

Table 32 - Pipavav port key parameters

Source: IHS Fairplay Ports & Terminals Guide 2015 & APM terminals

Available facilities			
Break bulk facilities	√	RoRo facilities	x
Container facilities	√	Passenger facilities	x
Dry bulk facilities	√	Multipurpose facilities	√
Dry-dock facilities	√	ISPS compliant	√
Liquid facilities	√	CSI compliant	x
LPG facilities	√	LNG facilities	x

Table 33 - Port facilities available at Pipavav

Source: IHS Fairplay Ports & Terminals Guide 2015

3.9.3.5.1 Specific berths of interest in Pipavav

The south-western flank of the main quayside area is engaged in bulk coal handling, with a conveyor and coal storage areas. This effectively forms a barrier to any offshore wind activities beyond the conveyor system. Foundation storage and handling is generally compatible with dirty bulk handling and storage facilities of this type, but turbine marshalling will not be ideal anywhere in close proximity to this area. Cleaner facilities would be required away from the bulk handling areas.

Figure 118 - Pipavav port facilities

In the north eastern areas of the port estate there is a tank-farm for bulk liquid storage. Along the north eastern edge of the facility there are pipes which are used to transport liquid cargos from the northern quay to the tank farm. This effectively forms a barrier along the other edge of the port facility to offshore wind farm activities, in the same way as the coal conveyor system forms a barrier along the other side of the port estate.

There is no heavy cranage available in the port and it would be necessary to bring in equipment by sea, but this is generally the case with general purpose and container facilities. The majority of vessels used in the offshore wind industry for handling project cargos are equipped with their own cranage.

The facility is engaged in drawing-up development plans and this would involve additional general purpose quaysides near the liquid cargo quayside and extending the piled-quays past where the existing liquid terminal is located. This would require the relocation of the liquid cargo quay to the most northerly quay which is planned after redevelopment. There is no concrete timeline for these developments, but if early engagements are made with the Port Management, facilities ideally suited to offshore wind farm development could easily be incorporated into these development designs.
These might include quaysides suitable for project cargo haulage to the quay-edge, with bearing capacity in excess of 10 tonne/m^2 and good turning circles for long structures like towers, and "high and heavy" haulage routes to large areas of storage. There is also adequate space within the port estate to accommodate manufacturing facilities, and consideration could also be given to ensuring that their requirements could be met by redevelopment plans.

The suitability of the ground adjacent to these quaysides to facilitate wind turbine installation vessels to jack-up and therefore allow them to use their on-board cranage to its full capacity has yet to be established. However, should the existing ground strength be inadequate, additional load-spreading work could be carried out to make localised areas suitable.

Also the deck strength may not currently have the full capacity to allow SPMT transportation of project cargos. So an investigation would be required to cost whether the usage of additional axles, to reduce the ground bearing strength requirement, or additional deck strengthening work would be the most economic remedial method.

The port handles deep water bulk carriers, and has adequate water depth at all of its main quays for all types of vessels currently in use within the offshore wind industry. To the south-west of the main port facility is an oil and gas industry repair and fabrication yard (Pipavav defence and Offshore engineering company limited). Several oil rigs were seen undergoing modification and repairs.

Figure 119 - Pipavav port - APM terminals

Figure 120 - Vessel berthed in Pipavav

Using Google Earth to look at images of the port facility, a heavy-lift crane barge can be seen in the facility with a heavy crane and a helideck (see Figure 121).
This vessel would appear to have some potential utility in the role of floating monopile installation. Enquiries are ongoing to establish if this craft was in transit or is available in the area.

At present there are limited opportunities for loading and offloading of project cargos at this facility. The piled container offloading jetties do not represent an ideal facility (see Figure 119). The dog-legged area in the centre of the container jetties appears to show some utility. The port is in an industrialised area with no residential areas within close proximity, and as such allows 24 hour operation, without fear of disturbance to local residents.

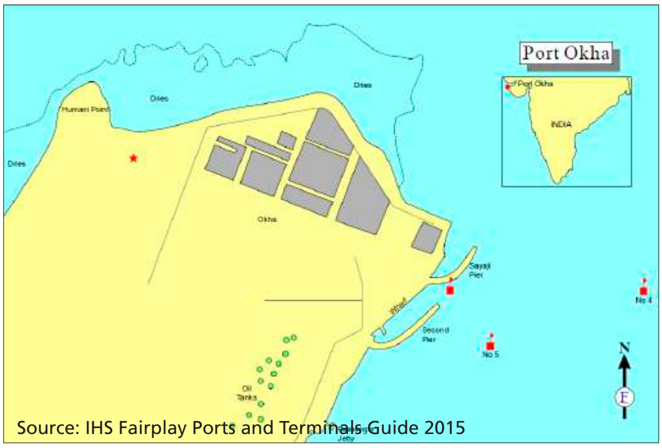


Figure 121 - Facilities at port Okha

3.9.3.5.2 Suitability of Pipavav to support offshore wind development in Gujarat

Pipavav is geographically well placed to serve the development zones A, B and C in the Gulf of Khumbat as identified in the FOWIND Gujarat Pre-feasibility report.

It has ample facilities to accommodate monopile & transition piece, and jacket pin-pile foundations and potentially turbine marshalling (although for turbines, appropriate coal dust protection measures may be required).

The water depths are deep enough for conventional or heavy-lift cargo vessels to bring in WTGs for marshalling. If cabling were supplied pre-cut and transported upon individual cable reels, the port could easily cater for the cargo vessels which would most likely transport these, and their loading, off-loading and storage, as well as any offshore supply vessels which might be used to install them.

The berths are all open to the Gulf of Khumbat, and there is no sheltered water to act as safe haven in inclement weather, but there are large areas protected by a breakwater at the adjacent oil & gas facility which it may be possible to use.

Its geographic location means that the project offices, marine operations management and PPE & general storage facilities could be accommodated within the security fenced facility. It will also be worthy of consideration that this port could later be used as a base for O&M activities for development zones A, B and C.

The oil and gas repair and fabrication yard to the south-west of the port may have some fabrication capabilities suitable for offshore wind[17], but its close proximity to coal handling facilities should be noted. At this stage, subject to further investigation, it might be assumed some capability exists for OSS structure fabrication and perhaps WTG fabrication (particularly jackets).

3.9.3.6 Port Okha

There are a limited number of substantial ports near the month of the Gulf of Kutch from which to support the construction phase of potential offshore wind. Okha port is an all-weather port with direct berthing facilities. The monsoon period is known to occur between May and September. The port is managed by the Gujarat maritime board. It is situated on the north-west coast of Saurashtra Peninsula, at the mouth of the Gulf of Kutch on the west coast of India. Development zone G, as identified in the FOWIND Gujarat Pre-feasibility report is approximately 40 km away from the port.

Anchorage is available 2.4 km offshore and vessels up to 7.5 m draught can be berthed at this port. Pilotage is compulsory.

Okha Port (key parameters)	
Draft	4 m (dry cargo berth), 8 m (Sayaji pier)
Sayaji pier	Length 180 m Width 20.5 m Approach 114 m 2 vessels at a time Draft 8 m
Dry cargo berth	Length 146 m Width 13.7 m Approach 216 m 2 vessels at a time Draft 4 m
MHWS MLWN MHWN MSL MLWS Commodities handled	3.5 m 0.4 m 3 m 2 m 1.2 m Coke, coal, wheat, sulphur and fertiliser

Table 34 - Okha port key parameters

Source: IHS Fairplay Ports & Terminals Guide 2015 & GMB ports

[17] http://pipavadoc.com/index.php/oil-gas

Available facilities			
Break bulk facilities	√	RoRo facilities	x
Container facilities	x	Passenger facilities	√
Dry bulk facilities	√	Multipurpose facilities	x
Dry-dock facilities	x	ISPS compliant	x
Liquid facilities	x	CSI compliant	x
LPG facilities	x	LNG facilities	x

Table 35 - Facilities at port Okha

Source: IHS Fairplay Ports and Terminals Guide

Figure 122 - Port Okha facilities

The Port has two jetties which can be equipped with modern mechanical handling systems to enhance the rate of loading/unloading. Capital dredging near the berth is being considered in the turning circle and entrance channel to increase the available draught. An exclusive repair facility in the form of a modern dry dock is also under consideration. The layout and aerial view of the port can be seen in Figure 122 and Figure 123 respectively.

3.9.3.6.1 Specific berths of interest in Port Okha

Both Sayaji Pier and Second Pier are concrete piled structures with solid decks (see Figure 123), but these are relatively light duty structures which are narrow and generally unsuitable for handling heavy project cargos. They have up to 8 m of water alongside so can accommodate substantial vessels including offshore supply vessels, survey, and even some heavy-lift cargo vessels, but the current mooring arrangements are not suitable for substantial vessels.

In-board of these quays there is extensive road and rail infrastructure which makes haulage of project cargos very difficult and substantial ingenuity would have to be applied to accommodate this activity. There is also limited space to facilitate storage in the port estate.

Precisely how far the fencing extends is an issue in some places and maintaining a large security-controlled area could be problematic.

Figure 123 - Okha port berth

3.9.3.6.2 Suitability of Port Okha to support offshore wind development in Gujarat

In general, this port does not have the capability to operate as an ideal or conventional offshore wind marshalling facility.

Whether a mother & daughter barge lightering system would be suitable in these relatively sheltered waters is worthy of consideration, as is the possibility of simply mooring a barge alongside the piers and operating the whole operation from floating storage. This system was successfully used for the construction of Gunfleet Sands offshore wind farm, where little more than a small river mouth was used with lesser facilities than exist at Okha.

The waters around Port Okha would be useful as a safe haven for vessels constructing within zones G and H, as they form a well sheltered natural harbour.

Due to its location at some distance from the proposed development zones, it is unlikely to be considered as a location for an O&M base, and locations around other facilities like Porbandar may well prove to be preferable locations for these activities.

3.9.4 Port readiness assessment - Tamil Nadu

This section develops the screening process further into a more detailed construction port readiness assessment for Tamil Nadu. The assessment includes:

- considerations of vessel access requirements (Section 3.9.4.1)
- an appraisal of the suitability of specific ports for offshore wind (Sections 3.9.4.2 to 3.9.4.4)
- reports key findings from the port estate visits in Tamil Nadu (Sections 3.9.4.2 to 3.9.4.4)

3.9.4.1 Installation vessel port access requirement chart - Tamil Nadu

The vessel port access requirements which represent the most common ones used in offshore wind installation were described in Section 3.6.11.

The minimum width of vessel which can access each port and the depth at high and low tides are plotted versus the three major ports in Tamil Nadu, see Figure 124.

If the vessel is to the LEFT and BELOW the entire line associated with a particular port then it is both:

- narrow enough to fit into the port's tightest marine access requirement, and
- its fully laden draft is less than the water depth at any state of the tide, meaning that the vessel can operate at that port at any state of the tide, and whether it is un-laden or fully loaded

If the port is to the LEFT of the vessel, the port is not wide enough to allow the vessel access.

If the vessel is ABOVE the lower limit of the line but BELOW the upper limit, the vessel can only operate at that port partially laden or tidally restricted.

It can be seen that there are no vessel type restrictions identified for offshore wind operations at Chennai, Kattupalli and Tuticorn.

3.9.4.2 Kattupalli

Kattupalli is 4 km north of Ennore in Tamil Nadu. The port was privately owned by L&T but it is understood that the facility in the northern part of the site has recently been purchased by Adani Ports Group. The port comprises of a 1.5 km northern breakwater, and a 3 km southern breakwater, forming a sheltered harbour area. Development zone H, as identified in the FOWIND Tamil Nadu Pre-feasibility study report[4] is approximately 310 km away from the port.

Container berths exist along the in-board side of the northern breakwater, but due to its geographic location at very significant distance from any of the development zones, these are of little interest and will not be considered further in this study. The layout and aerial view of the port can be seen in Figure 125.

There could however be possibilities to fabricate foundations at Kattupalli and in particular GBSs. There is known to be a coral–rock layer at the surface of the seabed along some of the Tamil Nadu coastline. Following discussions with local authorities, it might be suggested that the region lends itself to GBS type foundations in some areas. Where coral rock is present, it may well prove unsuitable for pile driving, without the significant additional complexity of either rock-socketing or “drive-drill-drive” installation methodologies.

On the site there are two other facilities that are still owned and operated by Larsen & Toubro Limited (L&T). One of these is a heavy-duty ship lift and further to the south of the site there is L&T's O&G fabrication facility with an area 1,200 m long by 400 m wide with 30 tonne/m^2 ground bearing strength.

L&T's heavy duty ship lift is 200 m long and 46 m breadth, and has capacity to launch and recover 18,000 tonne ships, and is ideally suited for the launching of GBSs.

[4] http://www.fowind.in/publications/report

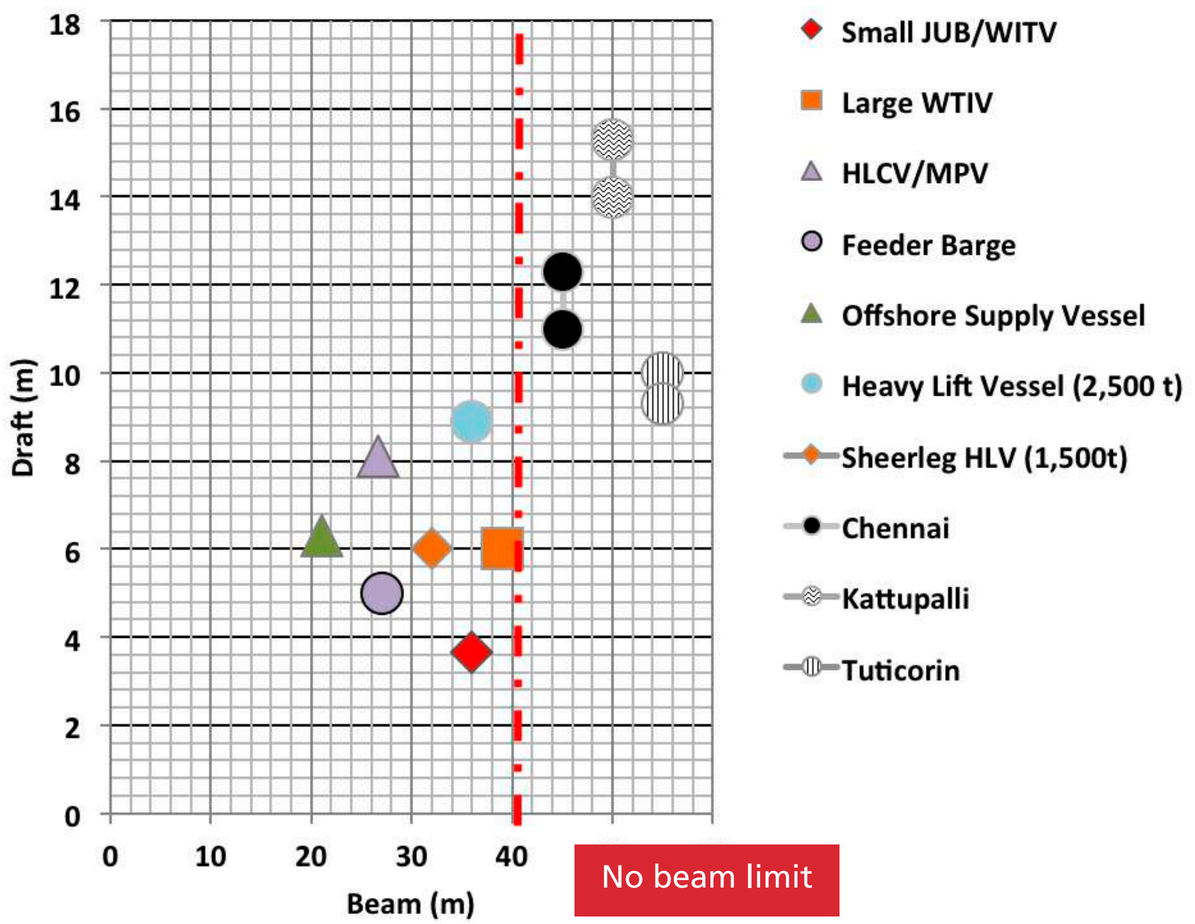


Figure 124 - Vessel port access requirement chart for vessels accessing ports in Tamil Nadu

There is 16.5 m of water alongside at the launch-end of the ship-lift which is deep enough for the vast majority of vessels to be floated on and off the ship-lift. Further, inshore of the ship-lift it is equipped with a heavy-duty rail system, which allows ships to be rolled to a series of six repair stations. Clearly this facility has a primary role in ship repair, however it would require little, or no adaptation, to allow for several GBSs to be cast in the repair stations, rolled to the ship-lift and either launched there or rolled onto a vessel for transportation to the offshore windfarm.

The waters between Sri Lanka and Tamil Nadu are extremely shallow. This does not allow the passage of any but the shallowest draft vessels. Therefore in order to transport any foundations manufactured at Kattupalli, it will be necessary to circumnavigate Sri Lanka, a journey of circa 900 NM.

Whilst it is generally possible to manufacture floating foundations, and tow them to site, a distance of this magnitude in deep sea conditions is not viable in the circumstances. If however foundations were either rolled directly from the ship lift onto the aft of a heavy transport vessel, or barge, such a craft could undertake the voyage.

Conceivably, an ideal solution could be to manufacture buoyant GBS structures, launch then via the ship lift, and then arrange them on the back of a semisubmersible heavy transport vessel. In this way they could be transported around the island of Sri Lanka, and discharge from the vessel by simply submerging the craft, and towing the GBS structures to site for storage or installation.

Figure 125 - Kattupalli port

Fabrication of other foundations or substation structures could also be possible at Kattupalli. L&T's large 1,200 m by 400 m oil and gas fabrication facility to the south of the site with its 30 tonne/m² ground bearing capacity could facilitate this. This site is used by L&T to fabricate large oil and gas jackets and there is a heavy duty quayside to the eastern edge which has 16.5 m water depth alongside, which is used to load-out the fabricated structures.

L&T are familiar with the construction of both tubular steel structures like jackets for foundations and topsides for oil rigs. It is therefore possible that, if the ground off Tamil Nadu proved suitable for drilling and grouting, and conceivably piling, that piled foundations like jackets may be a suitable type. L&T would then be one of the nearest fabrication facilities to the proposed development zones in Tamil Nadu.

Whether GBSs or steel WTG foundations are selected L&T would certainly be one of the oil and gas fabricators which might be interested in providing fabrication services for the substation topsides and jackets.

Kattupalli port (key parameters)	
Draft	14 m
Berth 1 - CB1	Length: 350 m
Berth 1 - CB2	Length: 360 m
Tidal range	Approximately 1 m
Outer channel length	2 km
Inner channel length	1.2 km
Channel width	165 m
Turning basin diameter	570 m

Table 36 - Kattupalli port key parameters

Source: IHS Fairplay Ports & Terminals Guide & L&T Kattupalli

Available facilities			
Break bulk facilities	√	RoRo facilities	x
Container facilities	√	Passenger facilities	x
Dry bulk facilities	x	Multipurpose facilities	x
Dry-dock facilities	x	ISPS compliant	x
Liquid facilities	x	LNG facilities	x
LPG facilities	x		

Table 37 - Port facilities available at Kattupalli

Source: IHS Fairplay Ports & Terminals Guide

3.9.4.2.1 Specific berths of interest in Kattupalli

The ship-lift and its associated rail infrastructure are of interest as a potential fabrication and load-out facility for the construction of GBS structures.

The heavy duty load-out capacity associated with the large fabrication area in the south of the site would be a potential fabrication and load-out site for a substation topside. It may also be a jacket load-out site if steel foundations prove to be considered as a viable option.

Figure 126 - Port facilities available at Kattupalli

3.9.4.2.2 Suitability of Kattupalli to support offshore wind development in Tamil Nadu

Kattupalli is highly suitable as a manufacturing site for a number of different offshore wind farm components. Most notably; GBS structures, jacket foundations and offshore substation topsides.

Load out facilities exist to allow loading of these fabrications aboard suitable vessels to transport them to windfarm development areas in the Gulf of Mannar.

Its geographic location at a great distance from even the northerly wind farm development zones mean that it will be very unlikely to be considered as a the local construction base, or indeed as an operational base for O&M when the wind farms are completed.

3.9.4.3 Chennai

The port of Chennai is situated on the Coromandel coast in Tamil Nadu. It has a main harbour enclosed by a breakwater with an entrance protected by an off-lying groyne. On the North side of the main harbour lies Bharathi Dock, sheltered from the North and East and Jawahar Dock lies on the South side of the main harbour. Ambedkar Dock is situated in between Bharathi and Jawahar and has 8 berths for handling cleaner cargoes.

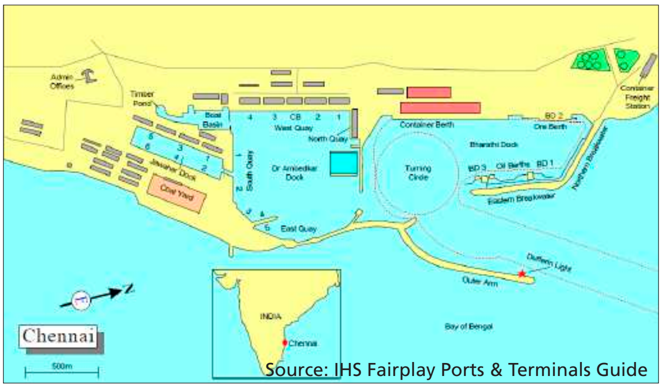


Figure 127 - Chennai port

Figure 128 - Chennai port estate

Chennai Port (key parameters)	
Length of channel Inner channel (depth) Outer channel (depth Width of channel Swell allowance Dr. Ambedkar dock	Approximately 7 km 18.6 m 19.2 m 244 m to 410 m 3 m Ringed by berths
Bharathi dock	2 x liquid facilities (BD 1 and BD 3) 1 x bulk ore (BD 2, draft 16.5 m)
Jawahar dock	2 x liquid facilities (JD2 and JD6) 1 x general cargo (JD4, draft 11 m)
Container terminal	4 x container berths (CCT1 to 4)
International container terminal	3 x deep water container berths, draft 15 m

Table 38 - Chennai port key parameters

Source: IHS Fairplay Ports & Terminals Guide

Available facilities			
Break bulk facilities	√	RoRo facilities	√
Container facilities	√	Passenger facilities	√
Dry bulk facilities	√	Multipurpose facilities	√
Dry-dock facilities	x	ISPS compliant	√
Liquid facilities	√	CSI compliant	x
LPG facilities	x	LNG facilities	x

Table 39 - Port facilities available at Chennai

Source: IHS Fairplay Ports & Terminals Guide

The harbour is completely artificial and has facilities for most cargoes. The layout and aerial view of the port can be seen in Figure 127 and Figure 128 respectively.

Chennai's location about 290 km north of the upper end of development zone H means that it is unattractive as a construction or operation and maintenance base even for the two northernmost development zones. The shallow water between the northern tip of Sri Lanka and Tamil

Nadu effectively block the passage of ships through this region and mean that access to the southern development regions from Chennai would require circumnavigating Sri Lanka which renders the site highly unattractive.

In some respects it is the very fact that Chennai is such a well-appointed and therefore busy port which is its least attractive feature. It has 60 Mt of cargo passing through it per year, on over 2,000 vessels.

Offshore wind operations regularly involve towing barges, with long bridle arrangements, and loading and offloading heavy project cargos to quaysides is an operation which can be sensitive to disturbances from the wash of any large vessel passing the berth. Ideally, ports which are to be selected as a major marshalling facility are less heavily trafficked, but clearly if a port is well used because it is so capable, these capabilities may outweigh the congestion.

Figure 129 - Chennai port estate

3.9.4.3.1 Specific berths of interest in Chennai

The port areas are divided into 5 terminals:

1. ***Dr Ambedkar Dock*** is ringed by berths, which are described above as the cleaner berths.

2. ***Bharathi Dock*** consists of two liquid facilities, BD 1 & BD 3 and a bulk ore berth BD 2. The liquid berths are unsuitable for offshore wind use.

   The bulk ore berth BD2 has a draft alongside of 16.5 m at high water (which is the value quoted in the IHS Directory), but it is necessary to remember that the tidal range is 1.3 m.

   North quay has a draft of 8.5 m, and access to some storage areas inboard, and would have utility. There are general and RoRo berths along the western edge. West Quay 1 & 2 are designated for vehicles. Centre Berth has a draft of 12 m and is for general cargo and West Quays 1 & 2 are 12 m and 11 m draft respectively, but warehousing immediately inboard of the berths will mean that it would be necessary to transport components to a storage area.

3. ***Jawahar Dock*** has three main dedicated berths; JD 2 & JD 6 are for bulk liquids and are unsuitable due to the physical requirements for offshore wind components as the liquid facilities impose restricted access due to the pipework (limited headroom passage if pipes above ground or limited axle load if buried beneath ground) see Section 3.8.2.5.
   JD 4 is a general cargo berth with 11 m draft which could be usable. Just inboard of this berth is an area described as the "Coal Yard", and there appears to be warehouse buildings covering the rest of the potential storage areas, so it would be necessary to transport components to a storage area.

4. ***Chennai Container Terminal*** consists of container berths CCT1-4 and is considered unsuitable for offshore wind as the terminal will operate solely with containers only in a very highly efficient loading and unloading operation, see Section 3.8.2.2.

5. ***Chennai International Container Terminal*** consists of three deep water container berths of 15 m draft. These are also unsuitable for offshore wind as the terminals are dedicated for handling standardised containers only, see Section 3.8.2.2.

3.9.4.3.2 Suitability of Chennai to support offshore wind development in Tamil Nadu

The major areas which appear most suitable for initial offshore wind development in Tamil Nadu are at such a vast distance from Chennai that it is unlikely that the port will find a role. It is however well appointed and would be technically suitable were local areas to be identified closer to the port.

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3.9.4.4 Tuticorin

The port of Tuticorin is an all-weather port and is designated as a major port in India. It is ideally located centrally to development zones A, B, C and D. Approximately 10 km, 63 km, 25 km and 51 km away from these zones respectively. The layout and aerial view of the port can be seen in Figure 130 and Figure 131 respectively.

The fact that the waters just north of zone C are shallow mean that there will be no major shipping lanes in this area, and could make zone C attractive as an early development zone.

Tuticorin also has a coal fired thermal power station located immediately adjacent to the port estate, which means that connection to an existing substation feeding into the grid could be feasible.

Source: IHS Fairplay Ports & Terminals Guide 2015

Figure 130 - Tuticorin port estate

Source: Google Earth

Figure 131 - Tuticorin port

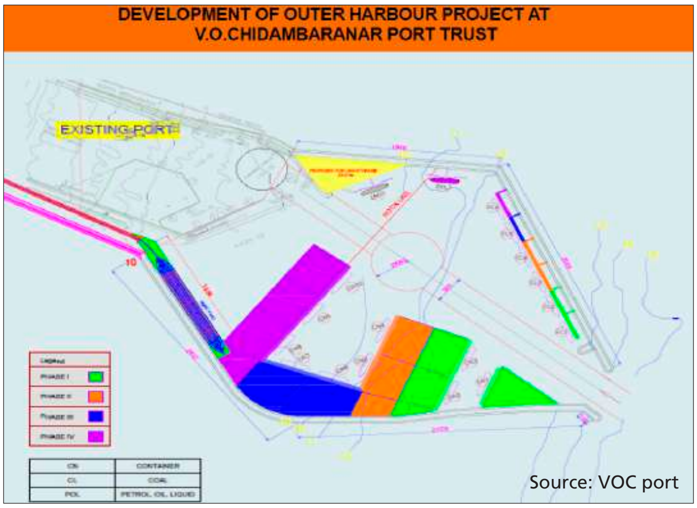
Tuticorin Port (key parameters)	
V.O.C. Berth no. 1	Draft 9.3 m/quay length 168 m
V.O.C. Berth no. 2	Draft 9.3 m/quay length 168 m
V.O.C. Berth no. 3	Draft 10.7 m/quay length 192 m
V.O.C. Berth no. 4	Draft 10.8 m/quay length 192 m
V.O.C. Berth no. 5 (AB.1)	Draft 8.6 m/quay length 168 m
V.O.C. Berth no. 6 (AB.2)	Draft 9.3 m/quay length 168 m
V.O.C. Berth no. 7 (container terminal)	Draft 10.9 m/quay length 370 m
V.O.C. Berth no. 8	Draft 10.9 m/quay length 345 m
Shallow water berth 1	Draft 5.85 m/quay length 140 m
Shallow water berth 2	Draft 5.85 m/quay length 110 m
Oil jetty	Draft 10.7 m
Coal jetty	Draft 10.9 m
Coal jetty II	Draft 10.9 m

Table 40 - Tuticorin port key parameters

Source: IHS Fairplay Ports & Terminals Guide & Tamil Nadu ports

Extensive port redevelopment plans are understood to be in an advanced stage. However these developments may not be constructed shortly and as such this study has only considered data relating to existing facilities, or those under construction or having passed their final investment decision (FID). It is worth nothing that should these development plans proceed there would be significantly larger facilities available at this location in the future.

The scale of these planned port developments are significant (see Figure 132). The southern breakwater (enclosing the purple, blue, orange and green areas in Figure 132) would be 5.4 km in length. If this area were to be fully developed, it would engender a requirement for a total review of the comments made within this port study.



Source: VOC port

Figure 132 - Tuticorin port development plans

3.9.4.4.1 Specific berth of interest in Tuticorin

The berths along the north breakwater are for bulk coal handling. Berths NCB I & II in the North Cargo Berth are 14.1 m draft and a third berth is to be constructed there. Coal Jetty 1 & 2 have a 12.8 m draft.

The areas along the south breakwater have several berths which are attractive for offshore wind.

Berths 5 & 6 (apparently also designated AB 1 & 2, according to IHS), in Figure 130 are designated as multi-purpose berths, although 5 is also described as for passengers. Berth 5 has a draft of 8.6 m and Berth 6 has a draft of 9.3 m, and they have lengths for LOA 183 m and LOA 245 m respectively. They are immediately adjacent to the Container Terminal areas. Within these areas, inside the security fence, there is 553,000 m^2 of open "high and heavy" storage.

Figure 133 - Corner on haul route from VOC 1-4 to container terminal

Whilst berth 7 is specifically designated for containers, berths 8 & 9 are for containers and general cargo and multipurpose/passengers respectively, and both have 12.8 m depth alongside. It would appear that the berths 5, 6, 8 & 9 and adjacent storage areas are highly suitable to act as a marshalling facility for turbines, monopiles, transition pieces, and any array cables stored on reels, and other general activities carried out during offshore wind farm construction.

The four berths at the south eastern extremity designated VOC I, II, II & IV are for general or dry bulk cargos. VOC's I & II have 9.3 m draft and VOC II has 10.7 m VOC IV has 10.8 m. Whilst there are warehouses immediately inboard of these berths, there is a heavy haul route along the quayside with gently radius bends allowing easy access to the container terminals.

Available facilities			
Break bulk facilities	√	RoRo facilities	√
Container facilities	√	Passenger facilities	√
Dry bulk facilities	√	Multipurpose facilities	√
Dry-dock facilities	x	ISPS compliant	√
Liquid facilities	√	CSI compliant	x
LPG facilities	x	LNG facilities	x

Table 41 - Port facilities available at Tuticorin

Source: IHS Fairplay Ports & Terminals Guide

3.9.4.4.2 Suitability of Tuticorin to support offshore wind development in Tamil Nadu

The port of Tuticorin is ideally situated to facilitate the construction of several windfarm development zones identified in Tamil Nadu.

There are several berths identified with adequately deep water to accommodate vessels engaged in the marshalling of wind turbines or foundations.

There is substantial "high and heavy" storage areas available within secure fenced areas, with good heavy haul routes between these areas and berths, suitable for load-out of components during the construction phase of an offshore wind farm. Their location is adequately separated from the existing bulk coal handling and storage facilities and it is believed that this would have little impact, but should be verified. If the extensive redevelopment plans are put in motion others sites may become available with improved facilities above and beyond those existing, and early engagement with the port management is advised to facilitate incorporation of appropriate features into proposed developments.

The facility would lend itself to having the construction offices, marine operations coordination and storage facilities located in a well-placed compound, adjacent to construction activities. Furthermore, such a facility could later be used as the base for operations and maintenance activities, since the port is located in close proximity to the development areas.

If required Tuticorin could potentially host a blade manufacturing facility. Subject to agreement with the port authority this development might be integrated within their future port extension plans.

3.9.5 O&M port assessment

In this section the results from a desk based screening of possible O&M ports for zones identified in Gujarat and Tamil Nadu are presented. The analysis is conducted at high-level and based on ports identified within the FOWIND Pre-feasibility reports.

Beyond the suitable construction and marshalling ports, identified in Section 3.9.2, in both Gujarat and Tamil Nadu it is also likely a number of smaller ports would be suitable for O&M support and could play a strategic role during the operation of specific projects.

As discussed in Section 3.2.5, the requirements for O&M ports are much less stringent than those for construction, hence most ports with the capability to accommodate even the smallest cargo vessels will likely have the capability to accommodate wind farm support vessels. In general it is important that the O&M port can be accessed close to 100% of the time under all weather conditions and is not significantly restricted by tidal constraints or lock gate limitations. O&M support vessels typically have a maximum draft of 2 m and a 10 m maximum beam; hence these values have been considered when assessing O&M port constraints.

The criteria for assessing O&M ports are given in Table 42. Essentially a port which has adequate water depth, is less than 25 NM from the identified development zones and with 24 hour accessibility is potentially suitable for an O&M base. While some ports in close proximity to the zones have been de-rated to "somewhat suitable" due to noted tidal restrictions[18], these should not be strictly excluded on the basis of this high-level assessment. In some cases it may be possible to develop these currently restricted ports with minimal marine/civil works, for example dredging and the addition of strategically placed pontoons.

[18] http://www.navionics.com/en, www.worldportsource.com/, https://www.nga.mil/Pages/Defaut.aspx

	CRITERIA
Considered suitable	< 25 NM
Somewhat suitable	< 25 NM & tidal restriction
Somewhat suitable	25 to 75 NM
Not considered suitable	> 75 NM

Table 42 - O&M Port screening criteria

This should be investigated in future studies, where the feasibility and cost vs benefit of port development works are identified.

The full screening matrices and conclusions for both Gujarat and Tamil Nadu O&M ports are provided in the following Sections 3.9.5.1 and 3.9.5.2.

Gujarat summary

- The selection of O&M ports will pose no significant barriers for offshore wind farm development in Gujarat
- One or more ports for each identified development zone meet the criteria for good O&M bases
- The extremely high currents which are known to exist in the Gulf of Khumbhat will either increase or decrease the transit times of windfarm vessels
- When planning O&M strategies, it will be necessary to appropriately model the site conditions

GUJARAT	ZONE							
	A	B	C	D	E	F	G	H
Top 3 ports	Pipavav	Pipavav	Navabandar	Vansi Borsi	Nargol	Hazira	Dwarka	Porbandar
	Jafrabad	Mahuba	Pipavav	Hazira	Jafrabad	Dahej	Bhogat	Mangrol
	Navabandar	Jafrabad	Diu	Magdalia	Pipavav	Mihivirdji	Porbandar	Bhogat
Distance to zones (NM)	13	13	5	5	22	4	5	8
	14	13	5	7	38	6	9	17
	16	18	5	11	38	6	12	26

Table 44 - Gujarat top 3 O&M ports

3.9.5.1 Gujarat

GUJARAT Port name	ZONE								Tidal restriction
	A	B	C	D	E	F	G	H	
Alang	57	18	52	35	60	60	168	142	Y
Bedi	148	150	129	182	172	172	68	71	Y
Beyt	175	188	151	225	205	205	20	57	Y
Bhavnagar	77	42	71	54	84	84	171	149	Y
Bhogat	147	165	123	203	190	190	9	26	N
Chhara	28	57	6	91	62	62	98	61	N
Dahej	85	43	80	44	81	81	188	165	Y
Dholera	82	46	76	58	88	88	172	151	Y
Dholera (proposed port)	82	46	76	58	88	88	172	151	Y
Diu	18	41	5	75	47	47	112	76	N
Dwarka	171	188	147	226	203	203	5	46	N
Hazira	68	23	65	7	49	49	197	168	N
Jafrabad	14	18	6	56	38	38	128	95	N
Jakhau	233	243	210	277	262	262	69	114	N
Kandia major port	169	168	156	193	193	193	96	103	Y
Khambhat	119	81	113	84	121	121	198	182	Y
Magdalia	75	31	73	11	56	56	203	175	Y
Mahuva	26	13	20	43	47	47	146	116	N
Mandvi (proposed port)	185	191	162	225	211	211	49	78	Y
Mangrol	71	96	47	132	106	106	54	17	N
Mithivirdi	62	23	57	37	65	65	171	146	Y
Mul-Dwarka	31	60	8	94	66	66	94	57	N
Mumbai port	111	105	141	87	74	74	269	231	N
Mundra	170	173	148	205	194	194	60	75	N
Nargol	71	36	80	18	72	72	220	186	N
Navabandar	16	35	5	69	43	43	116	81	N
Navlakhi	158	156	149	180	183	183	105	107	Y
Okha	177	189	153	227	207	207	20	58	Y
Old Dahej	85	44	80	46	83	83	188	165	Y
Pipavav	13	13	5	51	38	38	135	102	N
Porbandar	116	136	92	174	149	149	12	8	N
Positra	169	182	145	219	199	199	21	52	Y
Salaya	150	158	126	195	177	177	39	46	Y
Sikka	148	153	127	187	173	173	54	58	Y
Sutrapada	42	71	19	106	78	78	82	45	N
Vandinar	154	160	131	195	190	190	48	55	N
Vansi Borsi	72	25	71	5	48	48	206	176	N
Veraval	50	78	26	113	85	85	75	38	N

Table 43 - O&M port screening, Gujarat

3.9.5.2 Tamil Nadu

TAMIL NADU Port name*	ZONE								Tidal restriction
	A	B	C	D	E	F	G	H	
Chennai	321	360	262	340	370	201	396	1553	N
Colachel	58	25	88	50	30	705	11	695	N
Cuddalore	243	282	184	262	292	131	318	71	N
Ennore Minor	330	369	271	349	379	210	405	162	N
Kanyakumari	43	6	70	32	16	615	6	600	N
Karaikal	187	226	128	206	236	67	262	19	N
Kattupalli Minor	333	372	274	352	382	213	408	165	N
Kaveri	205	244	146	224	254	85	280	37	N
Koodankulam	32	7	58	22	20	585	15	595	N
Krishnapatnam	391	430	332	410	440	271	466	223	N
Manappad	8	9	35	6	32	572	40	582	N
Mugaiyur	289	328	230	308	338	177	364	117	N
Muttom	57	20	78	45	24	635	7	622	N
Nagappattinam	181	226	128	206	236	60	262	13	N
Pamban	55	96	15	80	109	6	129	41	N
Parangipettai	233	272	174	252	282	121	308	61	N
Punnakayal	8	24	22	19	48	111	56	141	N
Rameswaram	84	121	26	103	132	11	155	43	N
Silambimangalum shipyard	235	272	174	252	282	121	308	61	N
Thiruchopuram	237	276	178	256	286	123	312	63	N
Thirukkadaiyur	201	240	142	220	250	81	276	33	N
Thirukkuvalai	170	215	117	195	225	49	251	5	N
Tuticorin	10	31	13	26	58	100	64	134	N
Valinokkam	28	68	12	58	91	77	110	108	N
Vanagiri	204	243	145	223	253	84	279	36	N

Table 45 - O&M port screening, Tamil Nadu

* Note: assumes vessel can passage through the Palk Strait

TAMIL NADU	ZONE							
	A	B	C	D	E	F	G	H
Top 3 ports	Manappad	Kanyakumari	Valinokkam	Manappad	Kanyakumari	Pamban	Kanyakumari	Thirukkuvalai
	Punnakayal	Koodankulam	Tuticorin	Punnakayal	Koodankulam	Rameswaram	Muttom	Nagappattinam
	Tuticorin*	Manappad	Pamban	Koodankulam	Muttom	Thirukkuvalai	Colachel	Karaikal
Distance to zones (NM)	8	6	12	6	16	6	6	5
	8	7	13	19	20	11	7	13
	10	8	15	22	24	49	11	19

Table 46 - Tamil Nadu top 3 O&M ports

Tamil Nadu summary

- The selection of O&M ports will pose no significant barriers for offshore wind farm development in Tamil Nadu
- No identified port is tidally restricted
- Two or more ports for each identified development zone meet the criteria for good O&M bases
- In calculating the distance from the potential O&M port to the development zone, there is an assumption that vessels are passable through the Palk Strait. None of the identified three most suitable O&M ports, for any of the development zones, require passage through the Palk Strait.
- When planning O&M strategies, it will be necessary to appropriately model the site conditions

3.9.6 Summary

Following the port readiness assessments it can be concluded that no single port estate in Gujarat and Tamil Nadu is currently suitable to facilitate all offshore wind construction activities without some level of adaptation or with the strategic use of multiple port estates. For example ports may need development of quayside bearing capacities and handling/lifting equipment to facilitate large substructures and OSS components or expansion of storage areas for multiple foundations or insulation of port areas from damaging coal/iron ore dust.

During this study it has been assumed that ports appropriate for construction are also suitable for O&M activities due to the less stringent access and infrastructure requirements. In both Gujarat and Tamil Nadu it is also likely a number of smaller ports would be suitable for O&M support and could play a strategic role during the operation of specific projects. This is highlighted by the high-level O&M port assessment presented in Section 3.9.5.

Currently a number of the identified ports are highly active with large volumes of marine and quayside traffic. They are for example engaged with; handling containers and bulk handling of dirty cargos (e.g. coal and iron ore). Early consultations should be made, during the development process, with port authorities to establish any current and future conflicts of interest with regards to spatial planning and their appetite to facilitate offshore wind.

During the early development of offshore wind in India it might be anticipated that ports specifically associated with the supply of wind turbines, will mainly be required for temporary marshalling of overseas components. However as the market and local supply chain matures; purpose built fabrication and marshalling ports in the form of offshore wind hubs may be developed, such as those now seen and under development in Germany and the UK.

The construction port readiness assessment for Gujarat investigated five ports with the most potential:

- Adani container port facility in Hazira – Existing port facilities consist of two piled quaysides with rail-mounted container cranes. The closest development zones D and F are approximately 13 km away. The water depths at this port are suitable for conventional or heavy-lift cargo vessels and has potential to be used as a wind turbine marshalling facility during construction (see Sub-Section 3.9.3.2)
- Larsen and Toubro's fabrication facility in Hazira – The shipyard is located within a large scale heavy manufacturing facility and has a heavy-duty load-out quay on the banks of the river Tapi. It would be a possible fabrication site for several types of offshore wind foundations and possibly substation topsides (see Sub-Section 3.9.3.3)
- Bhavangar port – It has a narrow lock-gate on the approach channel so is unsuitable for installation vessels. There is however a well-developed limestone handling facility, which could be utilised as a base for scour protection marshalling during construction and O&M phases, (see Sub-Section 3.9.3.4)
- Port of Pipavav (APM terminals) – The all-weather port is the largest on the west side of the Gulf of Khumbat. The port has facilities to handle containers, bulk, break bulk and liquid cargo. The port has potential to accommodate foundation and wind turbine marshalling facilities during construction and possibly offshore substation fabrication. Suitable coal dust insulation may be required, (see Sub-Section 3.9.3.5)
- Port Okha – The port has two piers which are light duty structures which are narrow and generally unsuitable for handling heavy project cargoes. It is the nearest port to development zones G and H. The port would require substantial infrastructure development before being suitable to support offshore wind developments (see Sub-Section 3.9.3.6)

In Tamil Nadu three facilities were investigated:

- Kattupalli - This deep water port is provided with a dedicated terminal for handling coal, general and liquid cargo and a vast hinterland. Closest development zone is H, which is approximately 310 km. It has potential as a manufacturing site, most notably for GBS structures, jacket foundations and offshore substation topsides (see Sub-Section 3.9.4.2).
- Chennai - The deep water port of Chennai is provided with a dedicated terminal for oil, iron ore and general cargo and 24 hour 7 day operations, and a passenger terminal. Closest development zone is H, which is approximately 290 km. Given this vast distance it is unlikely the port will play a significant role unless a cost effective solution is found (see Sub-Section 3.9.4.3).
- Tuticorin - The port of Tuticorin is provided with an oil & coal handling jetty and 24 hour 7 day operations, general, break-bulk, container and bulk cargo handling facilities, dry and liquid cargo storage facilities and a passenger terminal. Closest development zone is A, which is approximately 20 km. The port is ideally situated and has potential to be used as a wind turbine and foundation marshalling facility during construction (see Sub-Section 3.9.4.4).

Port name	Vessel access restrictions	Distance to zones	Possible OW port type (ref. Section 3.2)
Adani Container Port (Hazira)	√	Zone D & F - 13 km	■ O&M (zones D & F) ■ Marshalling (WTGs and WTG foundations)
L&T Port (Hazira)	√	Zone D & F - 20 km	■ WTG foundation manufacturing ■ Offshore substation manufacturing
Bhavnagar	x	Zone F - 35 km	■ Scour protection marshalling during the construction and O&M phases
Pipavav	√	Zone A, B & C - 23 km, 27 km & 13 km	■ O&M (zones A, B & C) ■ Marshalling (WTGs and WTG foundations) ■ Offshore substation manufacturing
Port Okha	x	Zone G - 40 km	■ Limited - unless floating marshalling (zones G & H)

Table 47 - Gujarat major port summary

Port name	Vessel access restrictions	Distance to zones	Possible OW port type (ref. Section 3.2)
Kattupalli	√	Zone H - 310 km	■ WTG foundation manufacturing (GBS/steel) ■ Offshore substation manufacturing ■ Limited further application - vast distance to zones
Chennai	√	Zone H - 290 km	■ Limited application - vast distance to zones
Tuticorin	√	Zones A, B, C & D - 10 km, 63 km, 25 km & 51 km	■ O&M ■ Marshalling (WTGs and WTG foundations)

Table 48 - Tamil Nadu major port summary

Table 47 and Table 48 summarise the capability of the ports considered most suitable to generally facilitate offshore wind construction in Gujarat and Tamil Nadu. This was based on physical site visits and review of their state of readiness during late 2015.

As regards to the level of specific adaptation that may be required, and what form this might take, it would be un-economic to upgrade specific ports to allow them to accommodate each and every vessel, foundation, and turbine type currently available to the market.
For example, this would have a significant influence on the requirements for high and heavy storage areas. It would be recommended that site-specific assessments should be made on a project-by-project basis, at the earliest, when the Front End Engineering Design (FEED) studies have narrowed the range of turbine and foundation types under consideration, and most importantly when a clear view on the specific development areas and overall capacity of the offshore wind farms are known. At this stage, without these details, it is considered too early to provide reliable guidance on the specific port infrastructure upgrades that may be required.

An alternative would be to develop regional offshore wind construction hubs where the scope and range of possible projects are well defined at a national level and port facilities are upgraded to meet these needs. This would only be logical if there is perceived to be a firm enough commitment to the development of multiple offshore wind projects in the region and that such a port infrastructure investment will make a tangible return in the near future. This approach would have the advantage that it would reduce the level of development risks for owners and developers and decrease the perceived risk in their Financial Investment Decision.

4 DECOMMISSIONING

This section provides a high-level introduction to the processes and operations likely to be implemented when decommissioning an offshore wind farm at the end of its 20 to 25 year design life. Given the embryonic nature of the offshore wind industry limited decommissioning has taken place to date other than a handful of metrological masts, see Figure 134.

The base case assumption is that the wind farm will be decommissioned using similar procedures to those used in construction, only in reverse order. This will involve the use of:

- two large WTIVs, one to dismantle the turbines and towers, and the other to cut and remove the foundation (for example TP and Monopile or Jacket)
- a DP cable vessel to remove the array cables

In addition, a DP Construction Support Vessel (CSV) will be used to prepare the foundations for cutting, for example cutting the array cables, removing internal seabed material in the pile down to at least the required cutting level, and removal of any secondary steelwork and electrical equipment within the TPs that would obstruct the installation of the main tracked water jet cutting tool.

Some of the lift sequences may be different from those during construction, because decommissioning tolerances and sensitivity are generally less critical in terms of damage to components; care will be needed however to ensure safe operations at all times, and also to protect any equipment such as turbines which may be considered for re-use/re-sale depending on their operational condition. All lifting operations will need to be engineered and the relevant structural integrity checks carried out.

It is likely that the site work in India might need to be carried out over a period of two seasons, with vessels moving off site over the intervening monsoon months. In the year prior to the first season on site, there will be significant engineering and project management including: site surveying, EIA updates and stakeholder consultations, development of bespoke water jet cutting rigs, tooling, lifting and handling equipment and sea fastenings, and also setting up the operational site and the scrapping site.

If the site had an OSS it would be assumed that it would be available to continue to supply power to the turbines as needed throughout decommissioning of the turbines and foundations. If there was no OSS or no available power source, then it would be necessary to fit a large number of turbines with temporary power supplies for things such as navigational aids, control and yaw systems, braking, periodic rotor jacking and rotation, nacelle temperature & humidity control, lighting, lifting gear and power tools for the early preparation stages of turbine decommissioning.

In summary decommissioning an offshore windfarm is no small task and might cost anything between 60 and 80% of the installation CapEx. In Europe almost all offshore projects require a detailed decommissioning study during the early project development.

Source: DBB Jak-up

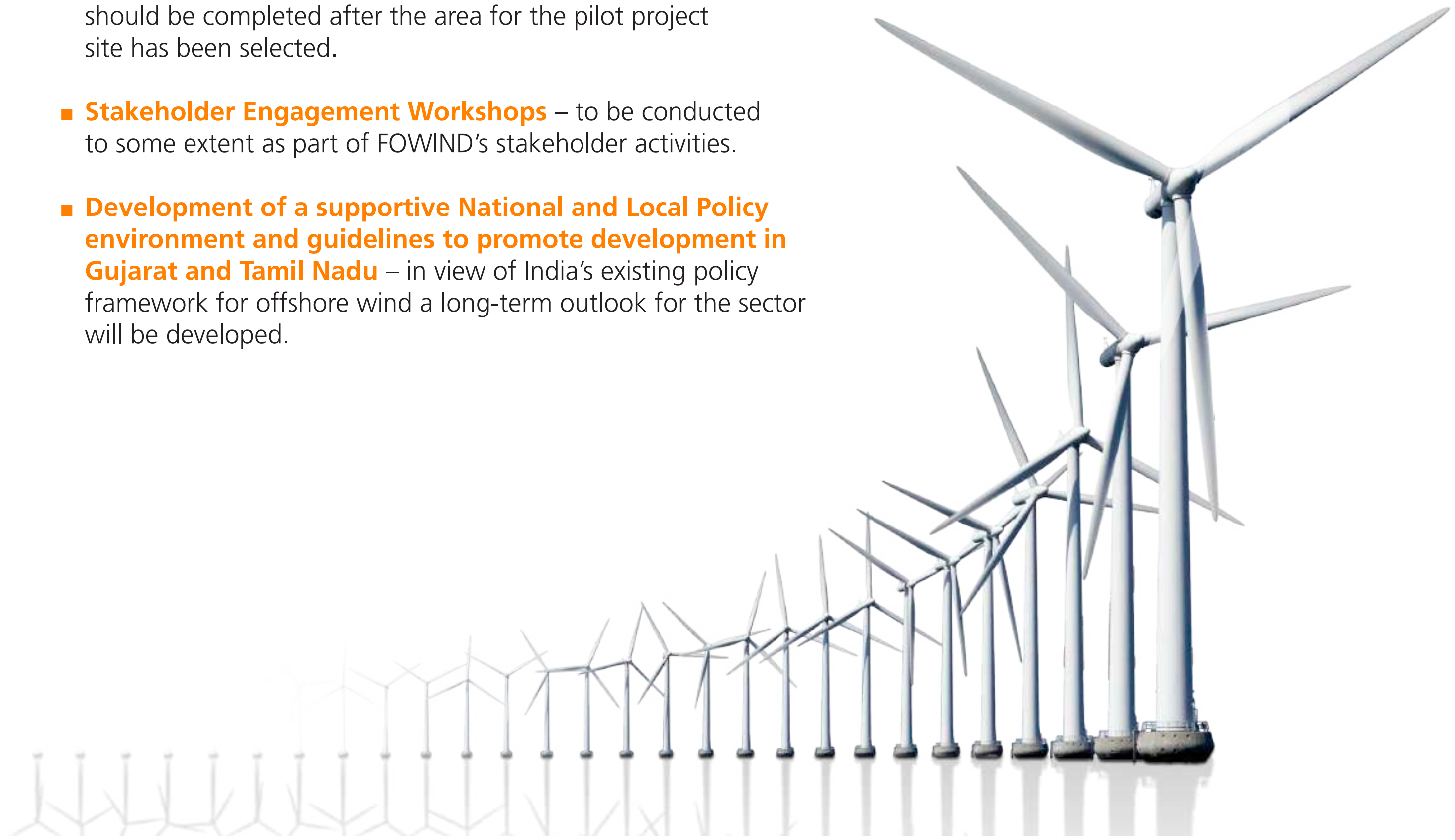
Source: DBB Jak-up

Figure 134 - DBB Jack-up decommissioning operations, removal of offshore masts (left) and associated monopiles (right) on Horns Rev 1 and Horns Rev 2 in Denmark

5 RECOMMENDATIONS FOR ONGOING WORK

The Consortium would recommend the following activities to support the feasibility and development of offshore wind in Gujarat and Tamil Nadu. It is highlighted were these recommendations will in part be undertaken through the ongoing FOWIND project work scope:

- **On-site wind measurement campaign** – later stages of the FOWIND project an offshore LiDAR wind measurement campaign is scheduled to help mitigate this risk; limited area coverage.
- **Full Feasibility Study** – Pilot Project Site Selection, Preliminary Engineering and cost modelling; to be included within the FOWIND full-feasibility study.
- **Extreme wind speed studies considering typhoon risk** – to be conducted to some extent in the FOWIND full-feasibility study.
- **Gathering further constraint data, metocean data and ground related data (Geophysical and Geotechnical)** – to be conducted to some extent in the FOWIND full-feasibility study.
- **Logistics and Infrastructure Study** – an updated and more detailed investigation should be completed after the area for the pilot project site has been selected.
- **Grid Connection and Transmission Study** – to be included within the FOWIND Grid Connection Study.
- **Preliminary Environmental and Social Impact Study (ESIA)** – an updated and more detailed investigation should be completed after the area for the pilot project site has been selected.
- **Stakeholder Engagement Workshops** – to be conducted to some extent as part of FOWIND's stakeholder activities.
- **Development of a supportive National and Local Policy environment and guidelines to promote development in Gujarat and Tamil Nadu** – in view of India's existing policy framework for offshore wind a long-term outlook for the sector will be developed.



6 APPENDIX A - PORT MAPS

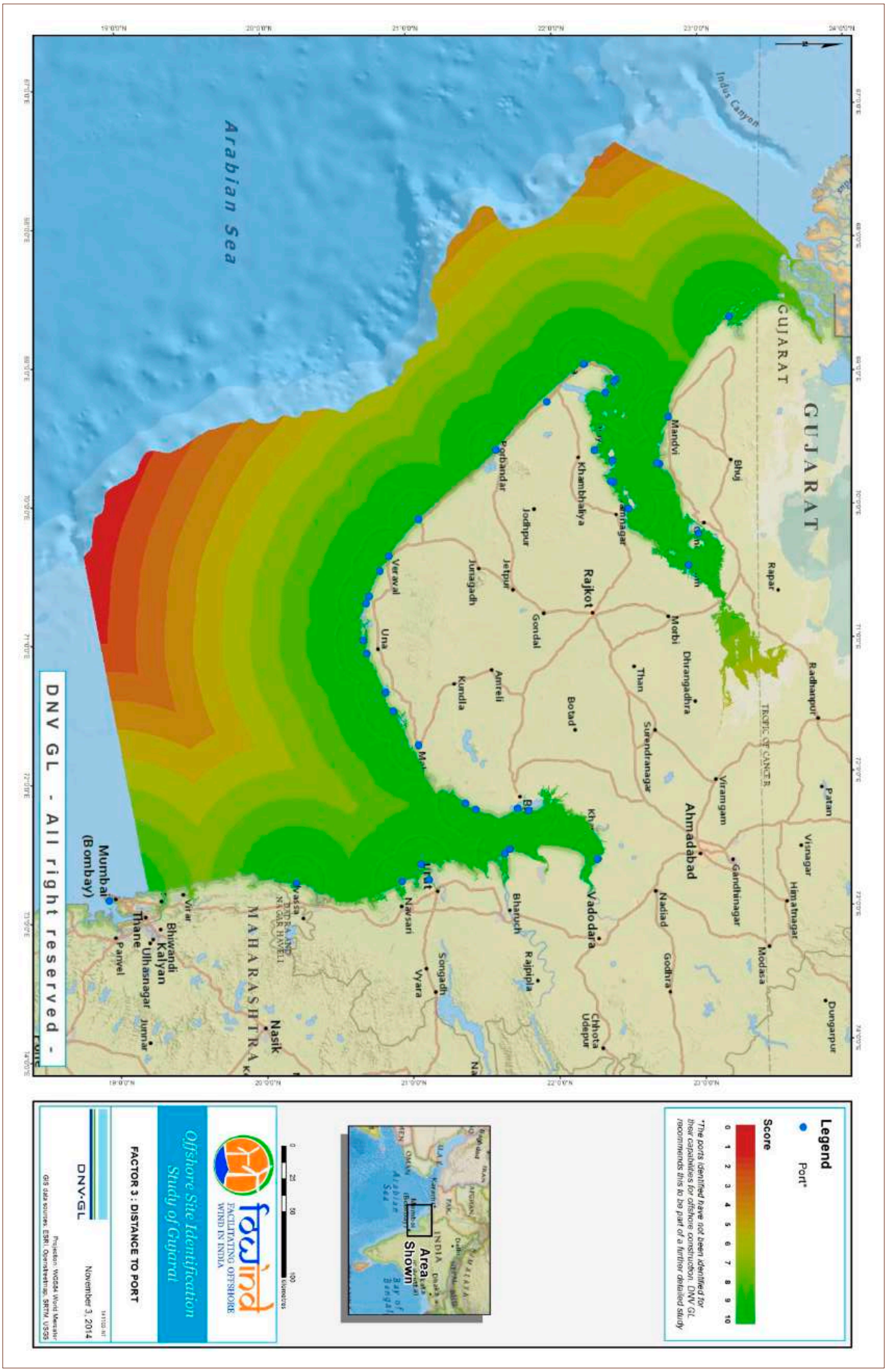


Figure 97 (from page 86) - Ports in Gujarat

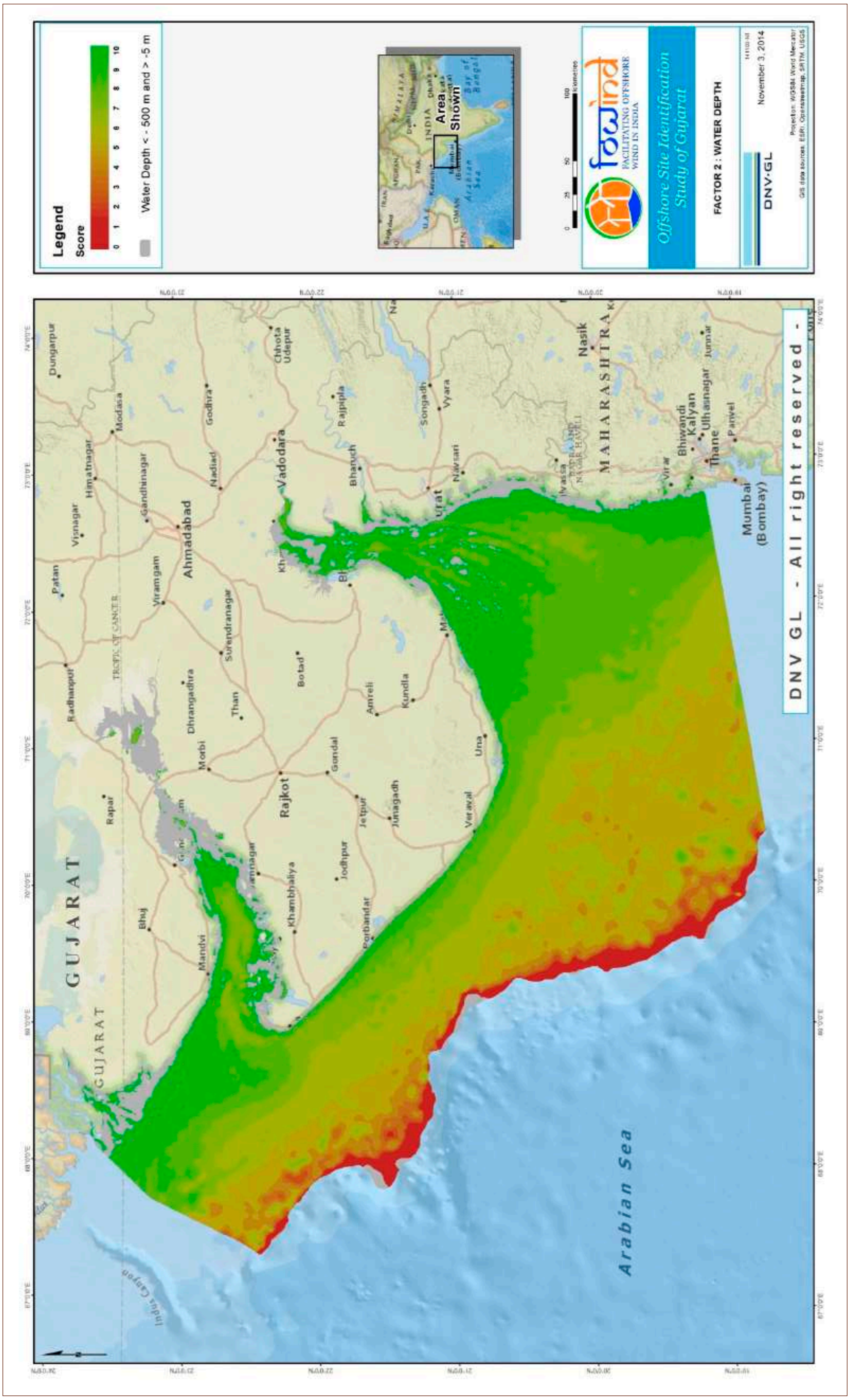


Figure 97a (supporting information) - Water depth in Gujarat

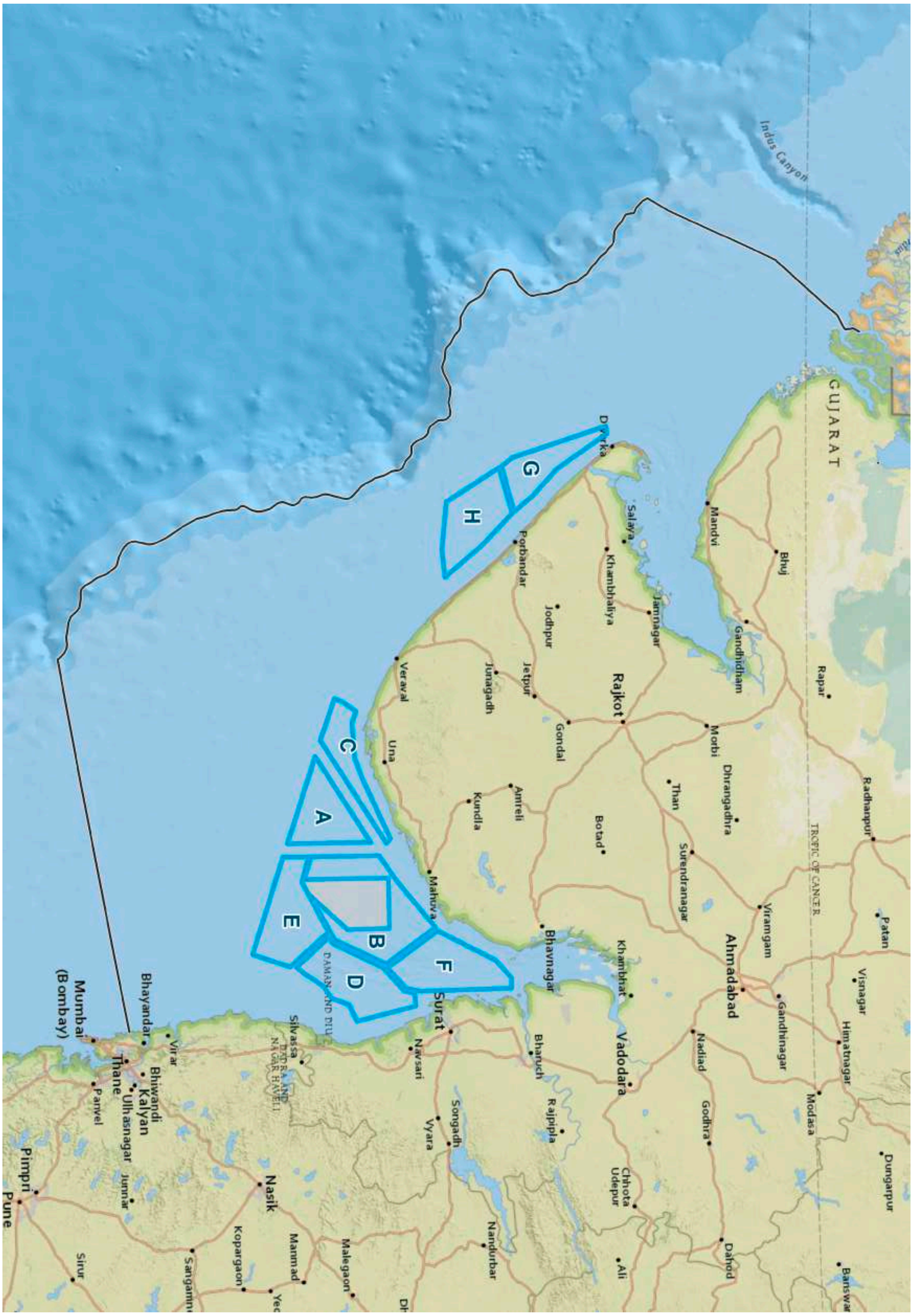


Figure 98 (from page 86) - Offshore potential ports in Gujarat

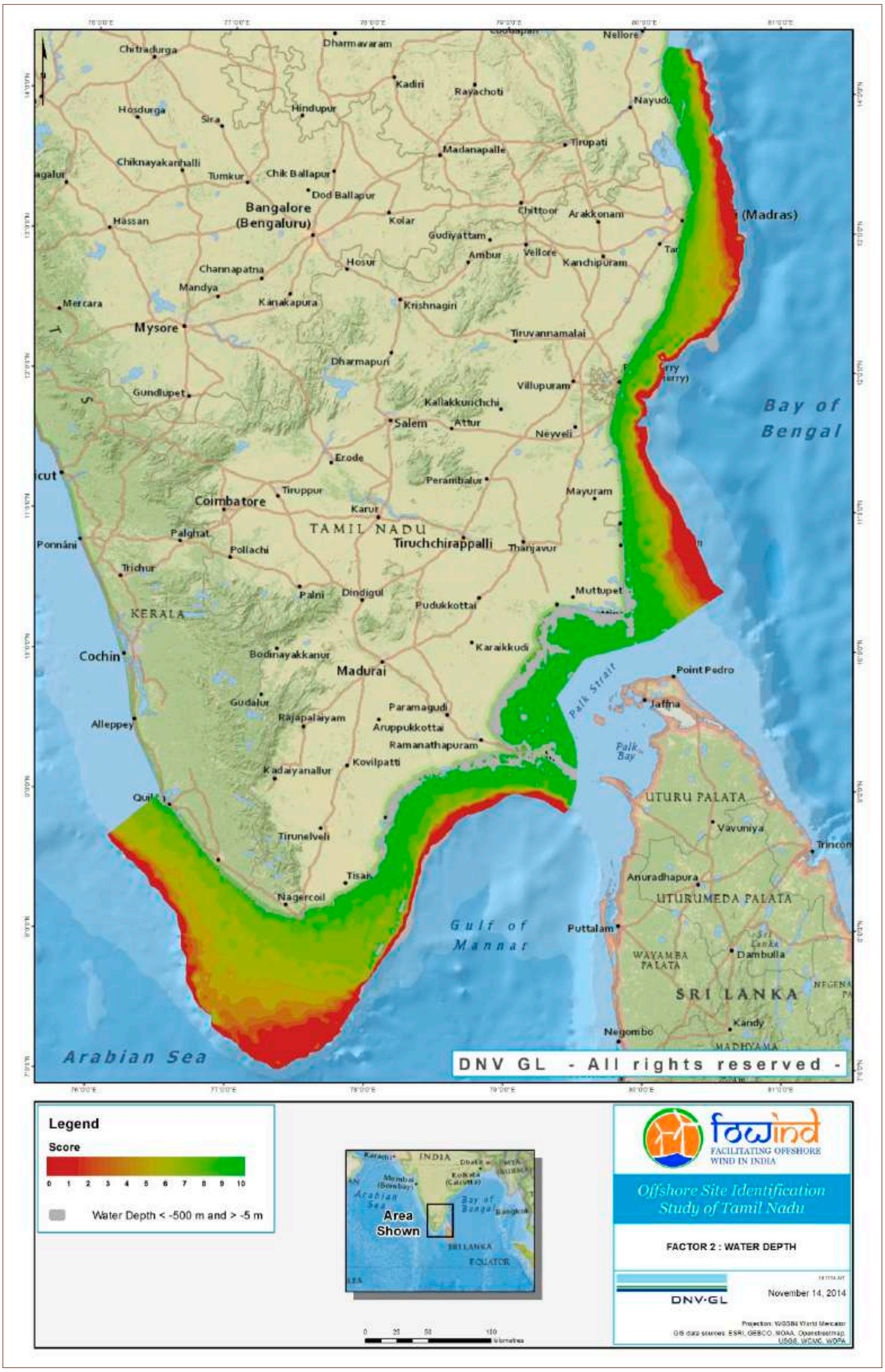


Figure 101a (supporting information) - Water depth in Tamil Nadu

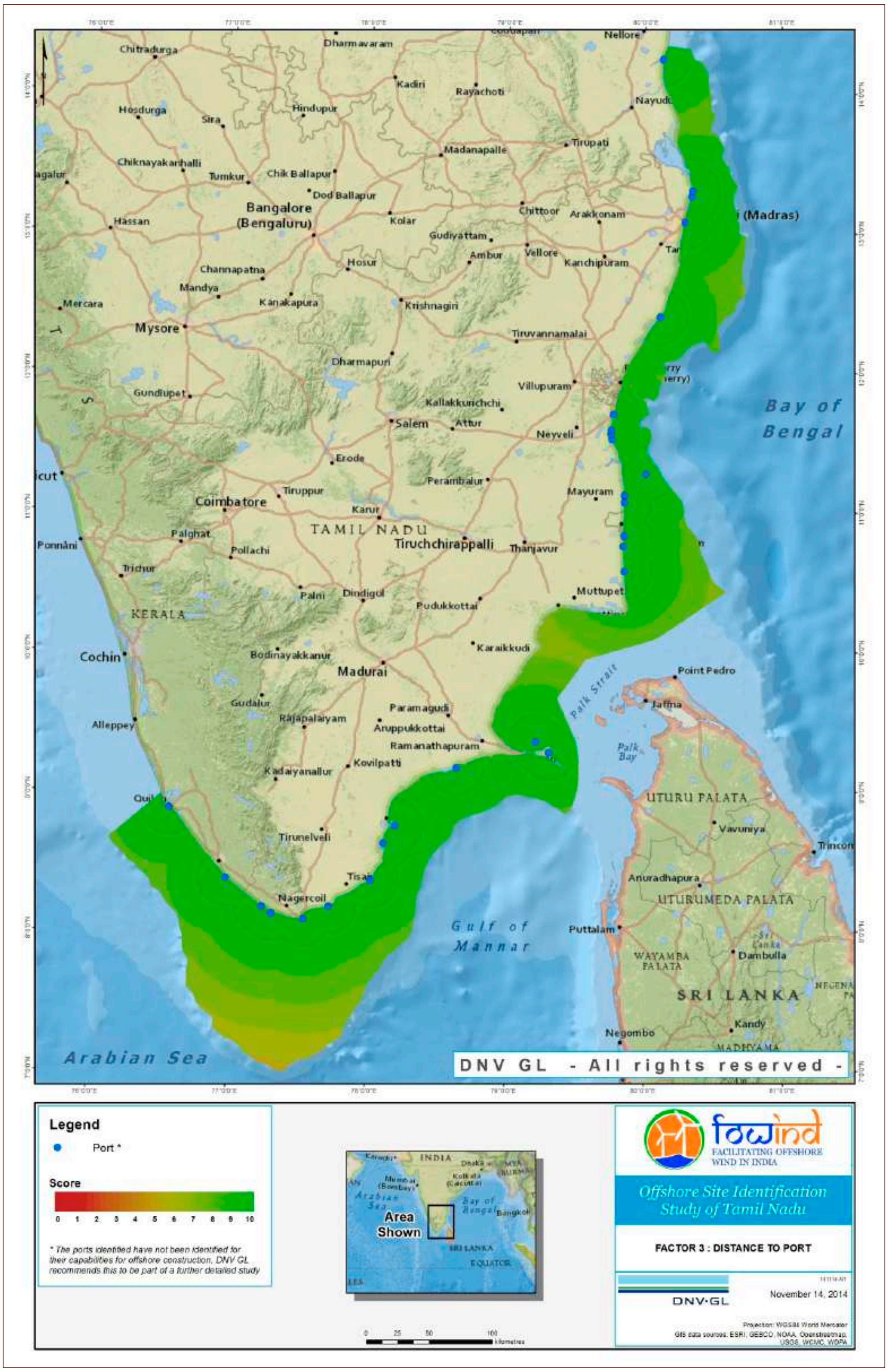


Figure 101 (from page 87) - Ports in Tamil Nadu

Figure 102 (from page 88) - Offshore potential ports in Tamil Nadu

PROJECT PARTNERS

Global Wind Energy Council (Brussels, Belgium) is the international trade association for the wind power industry. The members of GWEC represent over 1,500 companies, organisations and institutions in more than 70 countries.
www. gwec.net

Center for Study of Science, Technology and Policy (Bangalore, India) is one of the largest think tanks in South Asia; its vision is to enrich the nation with technology-enabled policy options for equitable growth.
www.cstep.in

DNV GL (Arnhem, the Netherlands) is the world's largest provider of independent renewable energy advice. The recognised authority in onshore wind energy, DNV GL is also at the forefront of the offshore wind, wave, tidal and solar sectors.
www.dnvgl.com

Gujarat Power Corporation Limited (Gandhinagar, India) has been playing the role of developer and catalyser in the energy sector in the state of Gujarat. GPCL is increasing its involvement in power projects in the renewables sector, as the State of Gujarat is concerned about the issues of pollution and global warming.
www.gpclindia.com

World Institute of Sustainable Energy (Pune, India) is a not-for-profit institute committed to the cause of promoting sustainable energy and sustainable development , with specific emphasis on issues related to renewable energy, energy security, and climate change.
www.wisein.org

KNOWLEDGE PARTNER

National Institute of Wind Energy (NIWE) will support FOWIND efforts towards preliminary feasibility assessments for potential offshore wind project development in the states of Gujarat & Tamil Nadu - with a special focus on wind resource validation. NIWE is an autonomous R&D institution under the Ministry of New and Renewable Energy, Government of India, established to serve as a technical focal point for orderly development of Wind Power deployment in India.
www.niwe.res.in

The **European Union (EU)** is a unique economic and political partnership between 28 European countries. In 1957, the signature of the Treaties of Rome marked the will of the six funding countries to create a common economic space. Since then, first the Community and then the European Union has continued to enlarge and welcome new countries as members. The Union has developed into a huge single market with the euro as its common currency.

What began as a purely economic union has evolved into an organisation spanning all areas, from development aid to environmental policy. Thanks to the abolition of border controls between EU countries, it is now possible for people to travel freely within most of the EU. It has also become much easier to live and work in another EU country.

The five main institutions of the European Union are the European Parliament, the Council of Ministers, the European Commission, the Court of Justice and the Court of Auditors. The European Union is a major player in international cooperation and development aid. It is also the world's largest humanitarian aid donor. The primary aim of the EU's own development policy, agreed in November 2000, is the eradication of poverty.

http://europa.eu/

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