Offshore Wind Port Infrastructure Study for India

An assessment of existing ports to serve the installation and O&M of offshore wind projects in Gujarat and Tamil Nadu

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for Offshore Wind and Renewable Energy

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1. Foreword

India has set the ambitious target of 500 GW non-fossil fuel capacity by 2030. To help achieve this ambition, India has a goal of 30 GW offshore wind by 2030.

Owing to its long-track record of successfully developing offshore wind, Denmark is supporting India with the development of its offshore wind market. In 2021, India and Denmark launched a knowledge hub called the Centre of Excellence for Offshore Wind and Renewable Energy (COE). This is a formalized joint govt. – govt. initiative between India's Ministry of New & Renewable Energy (MNRE) and the Danish Energy Agency (DEA). MNRE is the Nodal Ministry, and the National Institute of Wind Energy (NIWE) is the Nodal Agency for the development of offshore wind in India. The COE´s operational work and enabling initiatives are organized under thematic areas, which include supply chain and port infrastructure.

Ports are essential enabling infrastructure supporting the delivery and operation of offshore wind projects. The Government of India (GoI) has an important role to ensure that the port infrastructure in India is suitable and established in a timely manner to support its ambitious offshore wind strategy. Existing infrastructure such as ports can influence the cost of early projects, and so to prevent costly delays to (or inefficiencies in) project construction, it is important to avoid bottlenecks in port availability. To build a port, or to undertake major upgrades, takes time, typically a minimum of two years. Timing can be highly dependent on permitting and in some cases can take significantly longer than two years. The GoI and port owners and operators should therefore plan for making any necessary port upgrades in good time.

Offshore wind projects have different port requirements at different stages in their lifecycle. Large ports are required during construction for component manufacture and assembly prior to installation. Smaller ports are required for operations and maintenance activities. Ports which are located close to project sites are beneficial as they reduce transit time and hence cost. Port investments also need to be future-proofed by being able to adapt to accommodate next generation technology, such as 15+ MW scale turbines that are likely to be installed between 2025 and 2030.

Other organisations and donors have previously looked at the subject of ports for offshore wind in India. In 2014, the four-year long FOWIND project commenced and was aimed at undertaking feasibility assessments of project zones off the coasts of both Gujarat and Tamil Nadu. As part of the project, a supply chain, port infrastructure and logistics assessment study was carried out in 2016. The study concluded that no single port in Gujarat and Tamil Nadu was suitable to facilitate all offshore wind construction activities without some level of adaptation or with the strategic use of multiple ports.

As part of the roadmap project commissioned by the World Bank Group (WBG), several ports were identified during a high-level desktop study as being suitable to support the proposed Demonstration Program as well as the pipeline of future projects towards 30 GW of offshore wind power. These ports were screened based on publicly available information on a number of criteria to pick the most suitable candidates.

Building on this high level port assessment work that has already been carried out, this report aims to provide a more updated and detailed assessment of the most suitable ports identified off the coasts of Tamil Nadu and Gujarat, and highlight what upgrades, adaptations and expansions the ports require to deliver the first offshore wind projects. The report also aims to provide recommendations for port development to deliver on India's longer-term offshore wind goals, bearing in mind that new, larger, state of the art turbine technology will be coming on to the market.

On top of the desktop study, the DEA and COWI teams put a high focus and a considerable effort on planning and executing interviews and port visits. The intention of having interviews with industry was to align and affirm COWI's own assessments and projections on port infrastructure requirements and to gain relevant insight from different leading industry experts and stakeholders on offshore wind ports. The intention was to use their knowledge about international best practices into what it takes to have a port fit for purpose for offshore wind activities in India. The various interviews were held with utilities, wind turbine and foundation designers/ manufactures (OEM), EPCI contractors (responsible for engineering, procurement, construction, and installation). Together with DEA a Q&A (question and answer) catalogue with detailed questions was developed for the interviews to be able to deep dive into criteria that was important for the different interviewees and company types in terms of port selection.

In addition to the interviews with industry, port visits and interviews with the port owners/ representatives were scheduled to better understand their point of views and planning, when it comes to e.g., existing infrastructure, planned and/ or possible port extension, possibility of infrastructure upgrades.

Finally, COWI also liaised with the World Bank Group in terms of their port assessment (see above) to take this information into account as well.

The results and conclusions of these interviews and port visits were used to validate and reflect on the assessments from the desktop study and to build the study on a solid foundation, founded on the market needs for offshore wind ports in India.

2. Executive summary

This Offshore Wind Port Infrastructure Study for India assesses the viability of existing ports in the regions of Gujarat and Tamil Nadu Offshore Wind Zones (OWZs) to support India's offshore wind development, also using state of the art 15+ MW wind turbine generator technology.

Brief Summary of Work

The work carried out during the course of this study is summarised as follows:

1. Benchmark: starting with a projection of key port infrastructure criteria including: distance to Offshore Wind Farm (OWF), channel depths, clearances, berth length and depth, and other critical factors. Through interviews and feedback with experienced professionals from recognized Offshore Wind (OW) industry leaders, this benchmark was evaluated, and minor adjustments made as necessary.

2. Identification of candidate ports: Through a screening process of potential ports along the coasts of Tamil Nadu and Gujarat two installation ports for each OWZ are identified.

3. A detailed assessment of each identified port was then prepared for each port. This assessment included review of existing master plans, site visits and on-site interviews to collect sufficient information. This assessment results in concept level design and cost estimates to develop an OW terminal within each port in accordance with the benchmark.

4. A brief study of the development of marshalling (installation) terminals was performed which discusses various ownership and development models (Developer Driven vs. OW Cluster models) for Ports as well as financing and economic development.

Benchmark

The study establishes baseline criteria of critical port infrastructure necessary for installation of offshore wind WTGs (Wind Turbine Generators) as well as Operation & Maintenance (O&M) activities. This benchmark key location and harbour properties for construction and installation is summarised as:

Property	Unit	Acceptable	Recommended
Distance to OWF	[km]	<400	<200
Harbour entrance width	[m]	160	0.8-1 LOA (LOA = length overall)
Channel depth	[m]	9	12.5
Access channel width	[m]	200	200
Presence of lock/gate	[y/n]	Not Acceptable	
Vertical clearance	[m]	Unrestricted	
Turning circle	[m]	240	300

A summary of key berth and yard properties for installation ports was also developed.

Property	Unit	Acceptable	Recommended
Berth length	[m]	200	400-500
Depth at berth	[m]	8	12
UDL load capacity (UDL = uniform distributed load)	[kN/m^2]	75	100-150
Yard area	[ha]	20-25	30-40

Identification and Assessment of Candidate Ports

To address the gap between the existing port infrastructure and the necessary improvements identified in the established baseline criteria high-level conceptual development alternatives were proposed for each port with accompanying rough-order-of-magnitude cost data.

Tuticorin Port

With a relatively close proximity to the Tamil Nadu OWZ, Tuticorin Port was found to make a very ideal location for establishment of an OW terminal. Although the master plan currently does not feature any area dedicated for development of an OW terminal, it is clear from discussions with the V.O. Chidambaranar Port Authority that there was both interest on their part and flexibility in the master plan to accommodate OW terminal development.

An analysis of the port identified multiple development models to establish an OW terminal. These models can be combined over time to fit the expected growth in demand for OW development in the adjacent Tamil Nadu OWZ. As an example, an analysis of one model (Alternative 2A) was made and high-level concept level scope, cost and schedule data developed.

Tuticorin Port Model (Alternative 2A)	
Improvements:	Extensive dredging, construction of concrete grid-connected-pile supported quay and berths, and seabed strengthening for WTIV jack up support.
Berth length:	900 m
Yard area:	50 ha
Cost:	961 INR Crore/117 Mill USD
Duration:	30 months

Vizhinjam Port

Vizhinjam Port located to the north-west of the Tamil Nadu OWZ is located adjacent in Kerala State and is currently under development. The port has good connectivity to highways and the master plan features a proposed rail connection as well. It is noted that the master plan for

Vizhinjam Port currently does not consider development of an OW terminal; however, in meetings with the port potential concepts for development were discussed and are identified herein.

Of particular interest was the model identified as "Alternative 3", which utilizes the port's existing plans for phased development to the advantage of developing an OW terminal. This could be achieved by building the next phase of pile supported quay deck to handle the significantly higher loading capacity needed for OW and omitting the final paving. As the container yard grows over time due to increased demand, the OW terminal could, over time, also be pushed further south. As the development is already planned for the container terminal development, an OW terminal would only require relatively minor additions of a strengthened quay structure and likely seabed strengthening for Wind Turbine Installation Vessel (WTIV) jack up operations at the berth.

A detailed analysis of the most ideal model (Alternative 3) was prepared and includes:

Vizhinjam Port Model (Alternative 3)	
Improvements:	Extensive dredging, construction of concrete grid-connected-pile supported quay and berths, and seabed strengthening for WTIV jack up support.
Berth length:	450 m
Yard area:	18 ha
Cost:	732 INR Crore/89 Mill USD
Duration:	21 months

Hazira Port

Hazira Port located in Gujarat east of the Gujarat OWZ is a multi-use port that is operated in conjunction with Adani Group Gujarat Maritime Board and Shell. It is noted that the master plan for Hazira Port currently does not consider development of an OW terminal, but a model was developed for the purpose of this study.

Hazira Port Model	
Improvements:	Extensive dredging, construction of concrete grid-connected-pile supported quay and berths, and seabed strengthening for WTIV jack up support.
Berth length:	600 m
Yard area:	35 ha
Cost:	760 INR Crore/92 Mill USD
Duration:	24 months

Pipavav Port

Pipavav Port located directly adjacent to the Gujarat OWZ, is a multi-use port and follows the public-private-partnership model. The port master plan currently does not consider development of an OW terminal, but the port administration welcomed the idea when discussed and explored potential concepts.

The model for OW development used for this study considers redevelopment of an existing coal berth (Berth1) that is expected to be closed down in the coming years with ultimate redevelopment as a container berth.

Pipavav Port Model	
Improvements:	Minor dredging, construction of concrete grid-connected-pile supported quay and berth, and seabed strengthening for WTIV jack up support.
Berth length:	330 m
Yard area:	28 ha
Cost:	622 INR Crore/75 Mill USD
Duration:	21 months

Operations and Maintenance

A summary of key location and harbour properties for CTV based O&M ports was developed

Property	Unit	Acceptable	Recommended
Distance to OWF	**[km]**	<100	<50
Depth at channel (entrance) at MLLW	**[m]**	4+	6+
Harbour entrance width	**[m]**	15+	50
Presence of lock/gate	**[y/n]**	Tolerable	Preferable No
Vertical clearance	**[m]**	15+	>20
Turning circle	**[m]**	40	60-75
Depth at berth	**[m]**	4+	6+
Adjacent area	**[ha]**	0.5	0.75-1.5

Multiple O&M ports were identified for both the Tamil Nadu and Gujarat OWZs. For Tamil Nadu OWZ both Kudankulam and Muttom are viable options with respect to distance, sheltered area, ease of navigation, water depth and yard area.

For Gujarat OWZ, Pipavav is a viable option due to its close proximity and since it presents enough water depth and easy access for vessels, as well as a sheltered area (which is not present at the other locations), local industry, and hence more likely access to qualified workforce.

Development of Marshalling Terminals

For development of OW ports adjacent to the Gujarat and Tamil Nadu OWZs, the idea is raised of adopting the so-called "Developer driven model" for the initial offshore wind projects. The so-called "Cluster model" has many interesting features and benefits and could be a potential model to consider as the build-out rate increases together with firm investor confidence.

Concluding Analysis

This study concludes that the identified candidate ports fulfil basic navigation and access criteria to support installation of turbine components and foundations. While they are well adapted to handle their current operations, each of the identified candidate ports lack readily available key infrastructure such as berths and yards which that have the physical capacity necessary for the marshalling of WTG turbine components. Due to the nature of existing berth structures (concrete decks suspended on piles), properties and occupancy rates, repurposing or upgrade is not considered feasible. Instead, development of a purpose-built terminal is proposed for each of the locations, which is aligned with existing port masterplan. Depending on the location, development time is around two years, not including planning, design and consenting (for some locations, Environmental Impact Assessment (EIA) is already done for development congruent with proposal). This applies to both short term and long-term pipeline of offshore wind development, most of which is identified in the Tamil Nadu region and potentially at more than one location.

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6. Abbreviations

[AACE]	Association for the Advancement of Cost Engineering
[AHPPL]	Adani Hazira Port Private Limited
[AVPPL]	Adani Vizhinjam Port Private Limited
[CAPEX]	Capital expenditure
[CD]	Chart Datum
[CJ]	Coal Jetty
[CTV]	Crew transfer Vessel
[DEA]	Danish Energy Agency
[DKK]	Danish Kroner
[DL]	Datum Level
[EIA]	Environmental Impact Assessment
[EPCI]	Engineering, Procurement, Construction, Installation
[FOW]	Floating offshore wind
[GBS]	Gravity Based Structure
[GMB]	Gujarat Maritime Board
[GPPL]	Gujarat Pipavav Port Limited
[ha]	Hectare
[HAT]	Highest astronomical tide
[HLV]	Heavy Lift Vessel
[LAT]	Lowest astronomical tide
[LOA]	Length overall
[LNG]	Liquid Natural Gas
[MLLW]	Mean Lower Low Water
[NCB]	North Coal Berth

[OEM]	Original Equipment Manufacturer
[OJ]	Oil Jetty
[OPEX]	Operational expenditure
[OW]	Offshore Wind
[OWF]	Offshore wind farm(s)
[OWT]	Offshore Wind Terminal
[OWZ]	Offshore Wind Zone
[RE]	Renewable Energy
[RoRo]	Roll On – Roll Off
[RTG]	Rubber tired gantry
[SOLAS]	International Convention for the Safety of Life at Sea
[SOV]	Service operation vessel(s)
[SPMT]	Self-propelled modular transporter
[STS]	Shore-to-Ship container cranes
[TOC]	Terminal Operating Company
[UDL]	Uniform distributed load
[VISL]	Vizhinjam International Seaport
[VOCPA]	V.O. Chidambaranar Port Authority
[WTG]	Wind Turbine Generator
[WTIV]	Wind turbine installation vessel

7. Introduction

In 2015 the Government of India announced the National Offshore Wind Energy Policy for the development of offshore wind power in the country. Following this policy announcement, India's offshore wind potential has been extensively investigated, initially under FOWIND (2014-2018) and the further under FOWPI (2015-2019) and most recently under Danish energy Agency (DEA) supported Marine Spatial Planning project (2022). These studies identified several main development areas along the west coast and southern tip of India with a special focus along the coasts of Tamil Nadu and Gujarat.

In 2018, Ministry of New and Renewable Energy (MNRE) announced a target to develop 30 GW of offshore wind by 2030. In June 2022, MNRE followed up on this commitment and released a strategy paper outlining the road map for auctioning 37 GW of offshore wind projects in India. This strategy paper identified offshore wind development sites along the coast of Southern Tamil Nadu and Gujarat and outlines auctioning trajectories under three distinct models.

A key component of offshore wind development is the establishment of necessary port infrastructure in the vicinity of the targeted offshore wind farm designed to support the installation and construction of the growing sizes of the latest generation of offshore WTGs (wind turbine generators) and their components. Outside of a handful of northern European ports that have developed infrastructure specifically to support offshore wind, there are at present very few ports world-wide, which have the capability of supporting the installation of offshore wind development.

This study investigates existing port and terminal infrastructure, around the identified offshore wind sites in the coastal regions of Tamil Nadu and Gujarat with respect to the specific needs of offshore wind and identifies two ports in each region that are best suited to support offshore wind installation. The identified ports are then analysed against a benchmark developed with input from offshore wind industry experts to establish the necessary infrastructure improvements with a rough order of magnitude cost.

7.1. Previous Work

The conclusions from the FOWIND and FOWPI studies as well as recently concluded Marine Spatial Planning Study (DEA, 2022) related to port infrastructure are summarized below:

- No facilities have been established to serve in offshore wind construction and installation without significant upgrades to existing port infrastructure;
- Early consultation with port authorities is recommended to facilitate the establishment of offshore wind related facilities;
- The most promising ports in Gujarat are Hazira and Pipavav;

- The most promising port in Tamil Nadu is Tuticorin. Ports north of Palk Strait (such as Chennai port) will have to overcome large distances (>1000 Kms) to serve the planned offshore wind farms and therefore are not suitable to support offshore wind development;

- Smaller ports in those two regions can also be suitable for O&M (Operations and Maintenance) activities.

7.2. Objective and scope of the work

This study follows the above-mentioned previous studies with a focus on development of existing ports to support offshore wind development in the regions of Gujarat and Tamil Nadu. It should be noted that this study is not intended to be an update of these studies, but instead is intended to build upon these studies where the scope of their interest ends.

The main objectives of this study include:

- Provide a detailed assessment of viable ports to serve offshore wind projects located off the coasts of Gujarat and Tamil Nadu against a pre-defined set of baseline criteria for both construction ports (including preassembly, staging, marshalling of turbine components) and O&M ports. The assessment will consider both short-term suitability for the first offshore wind projects and long-term requirements for a large future pipeline of offshore wind projects in India and adopting state of the art 15+ MW offshore wind turbine technology.

- Identify and assess the possibilities for upgrade/development of port facilities to accommodate offshore wind construction in India.

The conclusions in this report are aimed at indicating the scale of upgrades (including timeline and costs) and can serve as a starting point for future, more detailed, studies, or be transferred to similar ports.

The scope of this study includes:

1. Establishment of pre-defined baseline criteria for construction and O&M ports;

2. Identification and rough screening of potential ports off the Tamil Nadu and Gujarat coasts with shortlisting of best port candidates;

3. Detailed ports assessment using both desk-based studies and site visits;

4. Overview of the development and financing models for upgrading existing ports to serve offshore wind development.

5. Concluding analysis and recommendations.

The study begins with a high-level survey of ports in the regions of Tamil Nadu and Gujarat where an initial screening is performed and looks at the feasibility and viability of each of the ports. This then results in the shortlisting of two ports potentially suitable for construction / installation in each region followed by a gap analysis for each of these identified ports from which “roadmaps” with potential infrastructure improvements are then developed.

7.3. Basis

MNRE’s offshore wind strategy (2022) announced ambitious goals to auction 37 GW of offshore wind projects in Indian Waters by 2030. The first auction for 4 GW of offshore wind in Tamil Nadu OWZ is expected in Q4 2022. 1 GW of offshore wind is anticipated to be auctioned in Gujarat OWZ in 2023-24, followed by 32 GW of projects auctioned in Tamil Nadu and Gujarat OWZs through to 2030 at a pace of 4-5 GW/annum.

Cost information provided herein is based on industry standard practice for cost estimating and falls between Concept Screening level (Class 5) and Study/Feasibility level (Class 4) as defined by AACE International. An assumed exchange rate of 1 million USD equals 8.3 crore INR (As of October 2022) is used for development of all cost data provided herein.

This analysis does not represent a study of the technical feasibility of building any port structures.

7.4. Offshore wind zones

Figure 1 and Figure 2 illustrate the identified offshore wind zones off the coasts of Gujarat and Tamil Nadu. These zones were first identified under FOWIND study, in consultation with National Institute of Wind Energy (NIWE), based on a high-level multi-criteria approach involving assessment of various parameters such as wind resource, bathymetry etc.

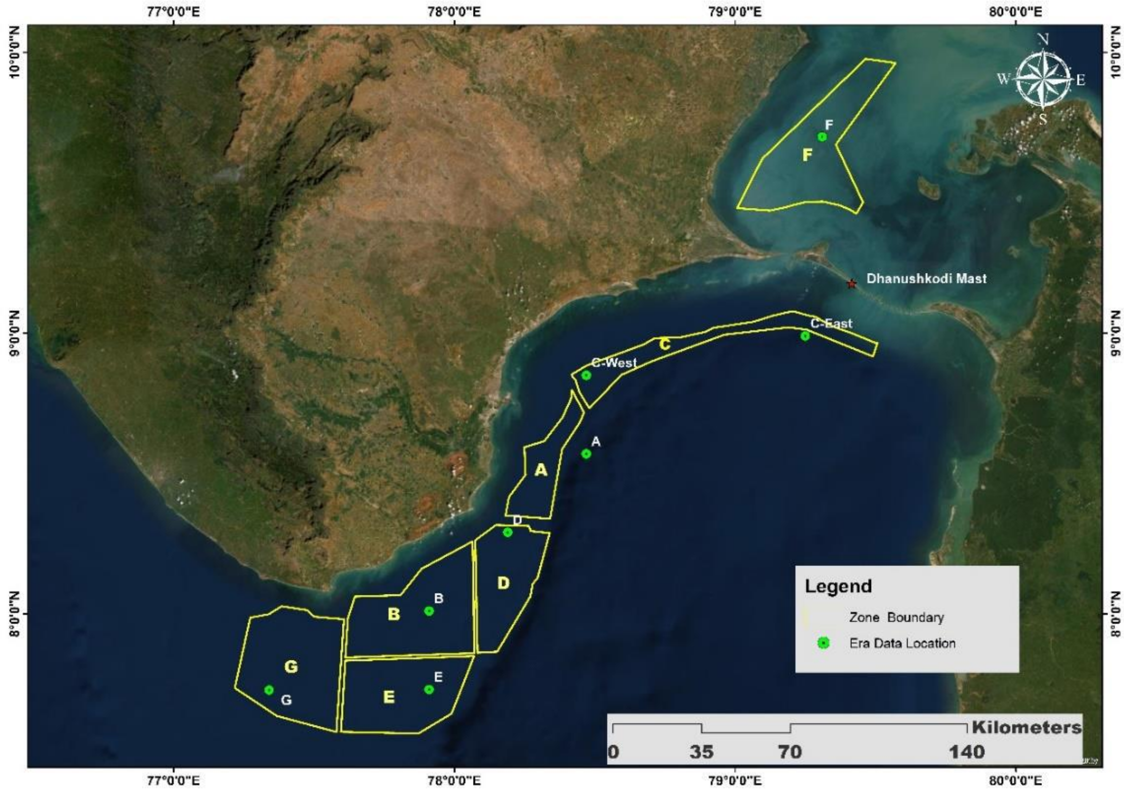

Figure 1: Offshore wind Zones off the coast of Tamil Nadu.

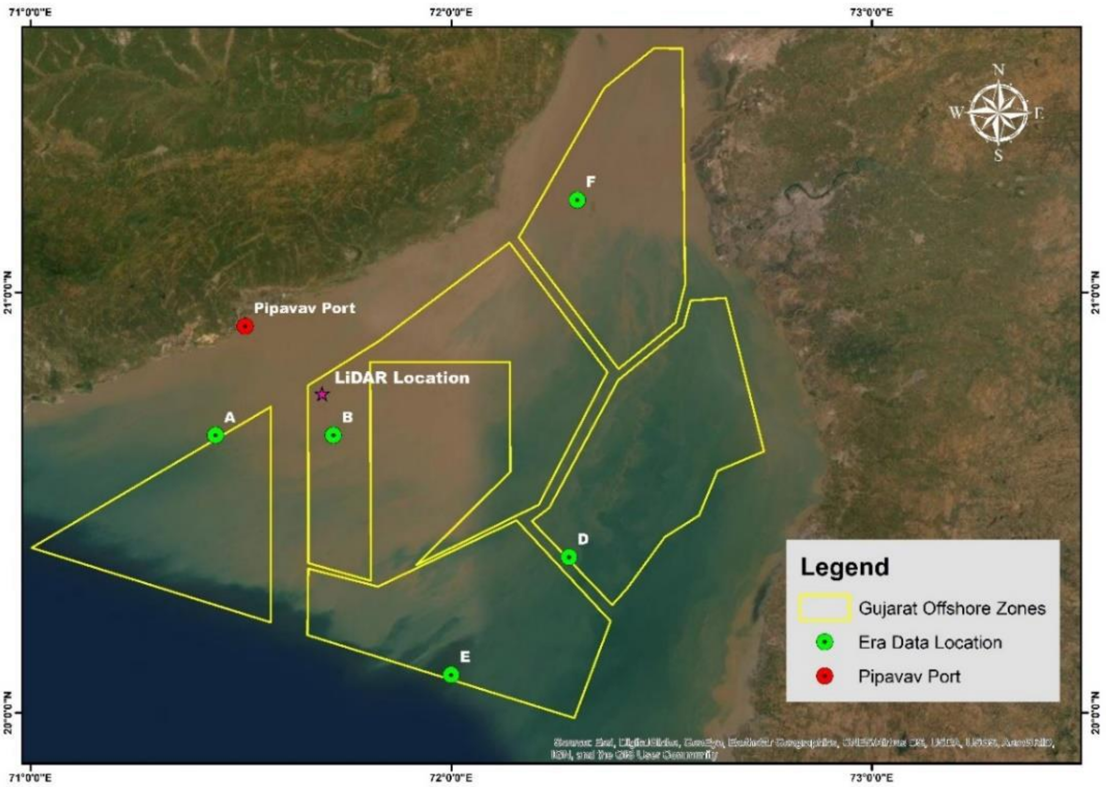

Figure 2: Offshore wind Zones off the coast of Gujarat.

The distance between a home construction port and an identified offshore wind farm installation site (OWF) is a key factor in the analyses carried out in this study. The acceptable distances used as inputs to this study are taken from the previous studies (FOWPI, FOWIND and Marine Spatial Planning) as well as COWI's professional judgement. This study refers to these areas as Offshore Wind Zones (OWZ).

7.5. A typical Offshore Wind Farm

Offshore wind energy, or colloquially "offshore wind" (OW), is a form of electricity generated by wind turbines that have been installed in the sea. These could be fixed foundation and floating installations. Turbines are typically grouped into arrays which form an offshore wind farm (OWF).

This study refers to many parts of OWF, so a familiarity with these terms will allow a reader to gain the most from this report. An offshore wind farm typically consists of several components schematically shown in Figure 3 and Figure 4.

Turbines are typically connected to each other by inter-array cables in strings of six to ten turbines. Historically, inter-array cable voltage has been 33 kV, but more recent offshore wind projects have been adopting a 66 kV inter-array system.

The inter-array cables lead into the offshore substation (or offshore transformer platform) where the electrical power is "stepped up" to its export voltage. The export cable connects the offshore substation to the onshore substation. At the onshore substation, the power is transformed and conditioned such that it can be integrated into the existing electrical grid.

Offshore wind farms can have any number of wind turbines, depending on the size of location. Commercial-scale projects typically start at 200 MW. The world's current largest OWF, Hornsea 1, commissioned in 2020, has 174 turbines of 7 MW for a total of 1.2 GW installed capacity. OW turbines have steadily increased in size over the previous 20 years. In current projects turbines are between 6 MW and 9.5 MW while projects in the pipeline are planned with turbines of up to 15 MW. The next generation of 15+ MW turbine has been announced by major turbine manufacturers.

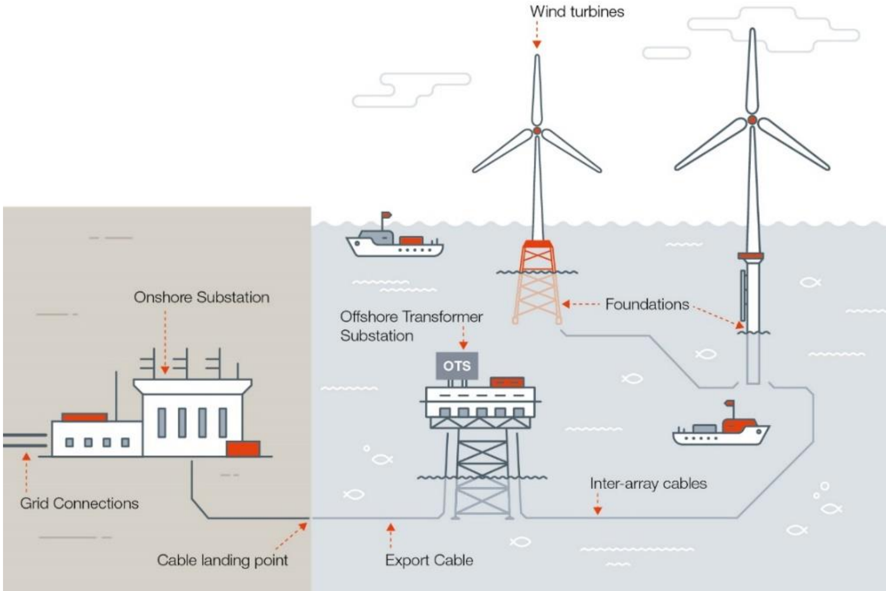

Figure 3: Elements of a typical offshore wind farm with fixed-bottom foundations.

Components of a typical OW turbine, mounted on a monopile foundation, are shown on Figure 4.

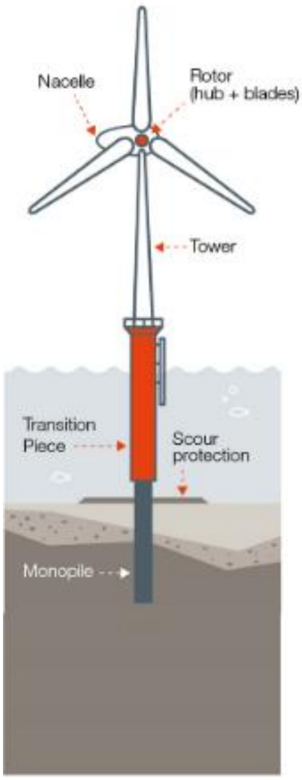

Figure 4: Components of a wind turbine

Wind turbines all consist of:

- Foundation – this study assumes monopile foundations with transition piece or jacket-type foundation;
- Tower
- Nacelle – where generator and drive train are housed;

Rotor assembly – including a hub with three blades. The turbine shown in Figure 4 is installed on a monopile foundation. Monopile foundations are the most common type of foundation and coupled with a transition piece which connects the turbine to the monopile; however, they are not suited for all soil conditions. Foundation types are typically governed by water depth and geotechnical conditions. Jacket foundations are more expensive to manufacture, but can be used in deeper water than monopiles, or in geotechnical conditions unsuitable for monopiles (e.g. too hard for driving or too soft to provide sufficient lateral support).

Gravity-based foundations can be made of lower-cost materials and often used in shallower waters where they are not driven into the seabed but simply rest on top. Tripod foundations look similar to a monopile foundation above the waterline but can be used in softer soils because the three legs provide additional stability. These foundation types are shown in Figure 5.

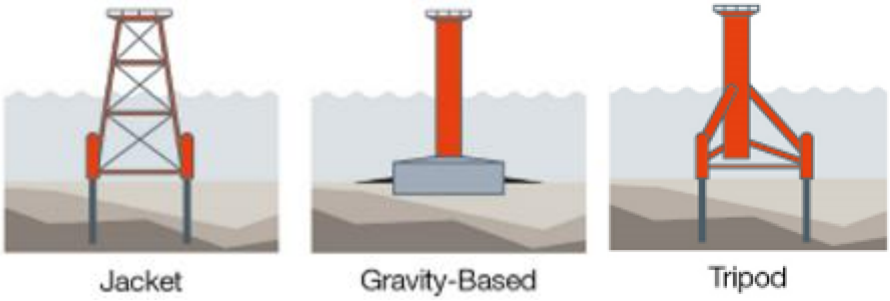

Figure 5: Other common foundation types

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8. Port-screening benchmark

Screening of port facilities was performed using a benchmark – a list of key port properties with defined thresholds. The screening is developed using the following approach:

Analysis of operations	List of properties is generated by analysing operations carried out during marshalling and installation. Draft threshold values are proposed based on typical vessels and onshore equipment requirements.
Previous OW projects	Review of previously prepared studies and including a non-comprehensive catalogue of European ports currently serving the OW industry. Draft threshold values are checked and compared against these example ports.
Market insight	As a part of this study interviews were conducted with industry experts from across the OW industry to gain their insight on Port activities related to OW, including manufacturing, loading/unloading, supply chain, navigation, etc. The focus of the interviews included their requirements but also their views on the future of trends in OW (particularly relating to 15+ MW turbines and the consequences for port infrastructure).

Due to the high-level nature of this study, this benchmark is intended to be used as a guide for development and expansion of existing ports and terminals to serve offshore wind and not as a rigid set of rules. It is prepared for specific objectives of this study and could be reconstructed and developed further depending on phase and focus of a specific project.

To help with understanding of port-related terms used in the remainder of the report, most relevant definitions are given in Appendix B.

Focus of the benchmark and the rest of the report is on bottom-fixed foundation installation. This type of OWF installation has a long track record of more than 30 years and has gone through many iterations and refinements leading to a level of standards expected within the industry. In contrast, floating offshore wind (FOW) is still in early stages of development without a track record of large commercial projects and is not part of the scope of this report.

8.1. Role of ports in offshore wind phases

The offshore wind farm supply chain is inseparable from port infrastructure and operations due to the very fact that access to the wind farm location must be facilitated by seafaring vessels. Moreover, as the offshore wind industry matures, the role of ports is continuously evolving. This role is shaped by markets which dynamically price the availability of facilities, vessels, components, weather windows and distances between different sites of interest.

Typical activities and functions that ports facilitate are shown in Table 1 grouped by phases in life cycle of an offshore wind farm. The focus of this study is on Phase 3, **Installation and Commissioning** and Phase 4, **Operation and Maintenance**. It is considered that port-related operations for these activities are not only necessary and a critical enabler in the construction of OWF but also must be in relative proximity to the site. Apart from that, requirements for the port infrastructure for the facilities that are servicing transhipment of turbine components are not more stringent than for the ports used in installation.

Phase	OWF Phase	Role of Port
1	Planning (including design, development and consenting)	Survey vessels, test areas, installation of wind measurement equipment
2	Manufacturing and procurement	Loading, unloading and storage of main components (turbine, foundations, cables, etc.) to/from production facilities; Fabrication of substation (foundation and topsides); Export, import and transhipment of components;
3	Installation	Pre-assembly and staging of turbines and foundations;
4	Operation and maintenance	Berthing of O&M vessels, hosting of spare parts storage and crew charter;
5	Decommissioning and disposal	Break-up and recycling

Table 1: OWF life cycle and role of ports.
Phases 3 and 4 are the focus of this study.

The role of ports in **manufacturing and procurement**, Phase 2, is related to the subject of ports, but is primarily a service to support the manufacturing side of the supply chain and therefore not a focus of this study; however, the topic is briefly discussed here.

Turbine component manufacturing facilities can either be located inland and use nearby ports for transhipment, or alternatively they can be located within the port itself. As WTG increase in generation capacity and physical size, the components are becoming increasingly more cumbersome for road transport and the ability to load them directly onto cargo (or installation) vessels can allow for a reduction in both time and cost.

Production phase differs from fabrication site to fabrication site and in the case of monopiles, research of existing fabrication plants indicates that a range of anywhere from 70 to 350 monopiles per year can be attained depending on the targeted market and investment. Due to the nature and complexity of construction of jacket-type foundations it is assumed that production will be less for the same level of investment in manufacturing capacity. It is also noted due to their size and weight, WTG foundation fabrication facilities (monopiles, transition pieces, jackets) are almost always located adjacent to waterways and ports to facilitate the use of waterborne transport due to the size and weight of completed elements. The same steel fabricators often also produce substation foundations and topsides.

Export cables, which connect the offshore substation to the onshore substation, and array cables, which connect individual WTGs to the offshore substation, are usually directly transported in cable installation vessels from the manufacturing site to the offshore wind farm for installation. Although relatively shorter distances for the shipment of export and array cables from manufacturing site to the OWF can provide a minor reduction in the overall development costs of an OWF, it is expected that the significant investment required for developing new specialized cable manufacturing facilities directly in the region will greatly outweigh any potential savings on shipping costs.

8.2. Port usage in installation of bottom-fixed turbines

8.2.1. Logistics

Pre-assembled turbine components (blades, nacelles, tower) are transported to a staging port (also known as a marshalling or installation port[1]) which is a key link in a bottom-fixed turbine OWF installation. A typical OW terminal can be divided into four zones, each with a distinct function.

Unloading and loading area

- Receipt of main turbine components (such as nacelles, blades, tower sections), inspection securing and storage;
- Receipt of secondary components (fixtures, electric components, etc.), inspection and storage (in buildings if weather sensitive);
- Frames from the pre-assembly area are loaded.

[1] Terms "staging ports" and "installation ports" are used interchangeably in the document

Storage area

- Where WTG components are prepared, and empty transport frames are stored;
- Set in a certain layout to serve the preferred distribution of WTG components based on a specific pick approach;
- It can also accommodate washing activities;
- Sub-assembly of secondary components (in building);
- Warehouse and office buildings also located in this area.

Pre-assembly area

- Where towers are prepared before loadout onto WTIV. Towers can be fully pre-assembled or partially (final assembly on WTIV) if the apron does not meet the load bearing requirements;
- Nacelle preparation for load-out;
- Blade preparation for load-out;
- Quality control walk-down and hand-over documentation;
- Pre-commissioning, where systems are verified for functional operability to achieve readiness for the commissioning (and shorten the duration of the process in offshore environment).

Loadout area

- Load-out (loading components onto the installation vessel
- A diagrammatical layout for an installation port is shown in Figure 6 and an example of Esbjerg Port is shown in Figure 7. The functions of Zones 3 and 4 are often merged where berth space is limited; however, scheduling of supply vessels in Zone 1 must be carefully coordinated such that it does not interfere with critical load-out operations in Zone 4. Although the process flow remains the same, the layout of the respective zones changes on a project-to-project basis.

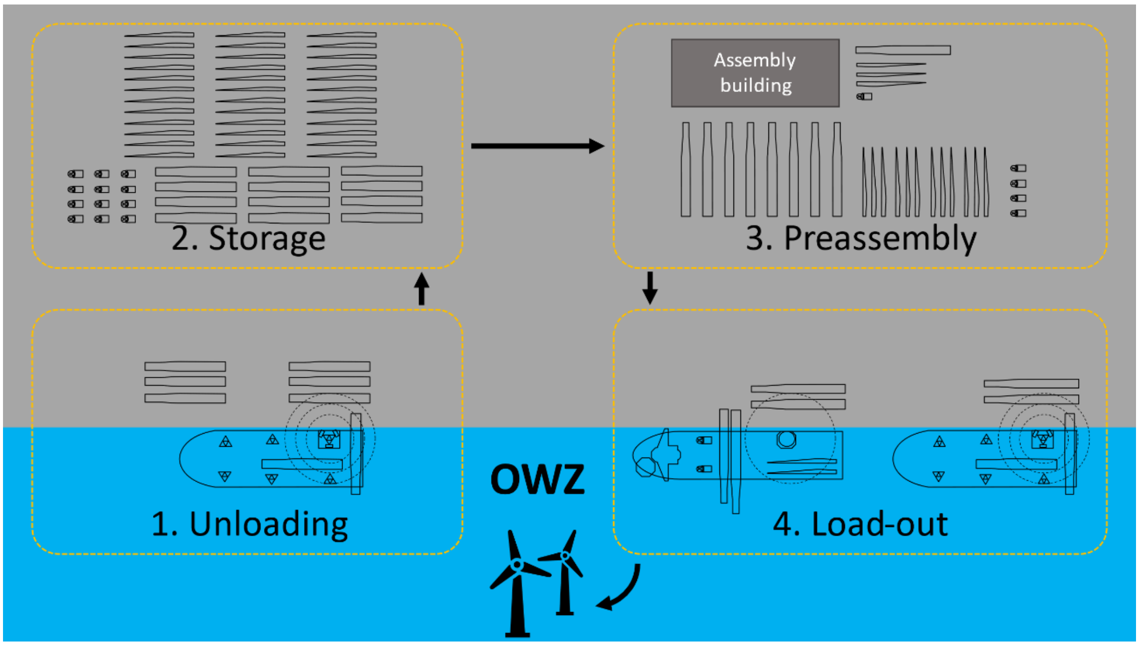

Figure 6: Diagrammatical layout for an installation port

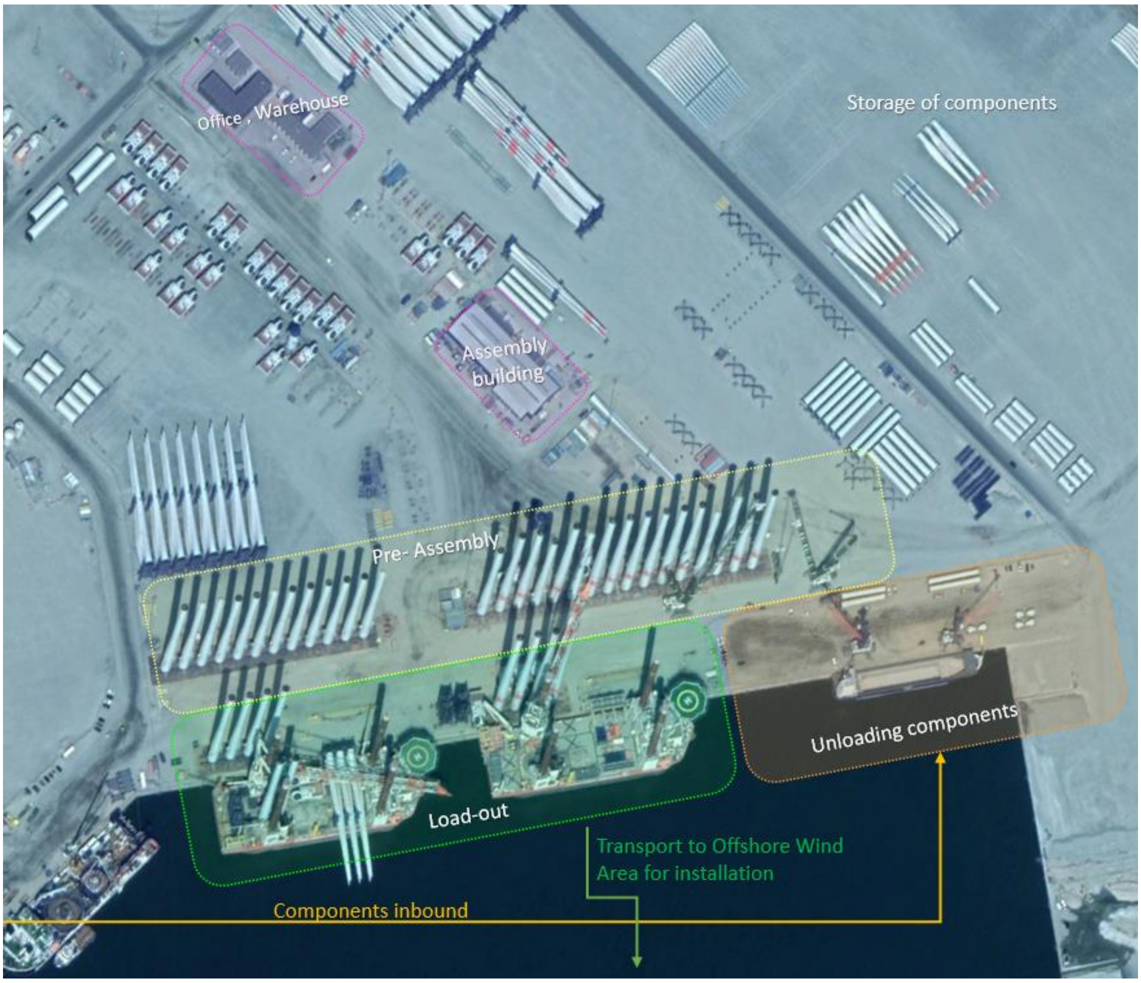

Figure 7: Typical layout for an installation port. (Esbjerg Port)

Installation of turbines is carried out by specialized jack-up vessels called wind turbine installation vessels (WTIV) (see Section 8.2.3). Due to the significant demand and cost of these highly specialized vessels, both in terms of capital investment and operational expense, charter of these vessels is more costly than ordinary cargo vessels and their availability can be limited which is why the staging process is an intensive one. Port facilities are often located and planned as to minimize charter time of WTIV. The choice of vessels used to install foundations depends on their type.

A typical process of sourcing and installation of components in OWF is shown in Figure 8.

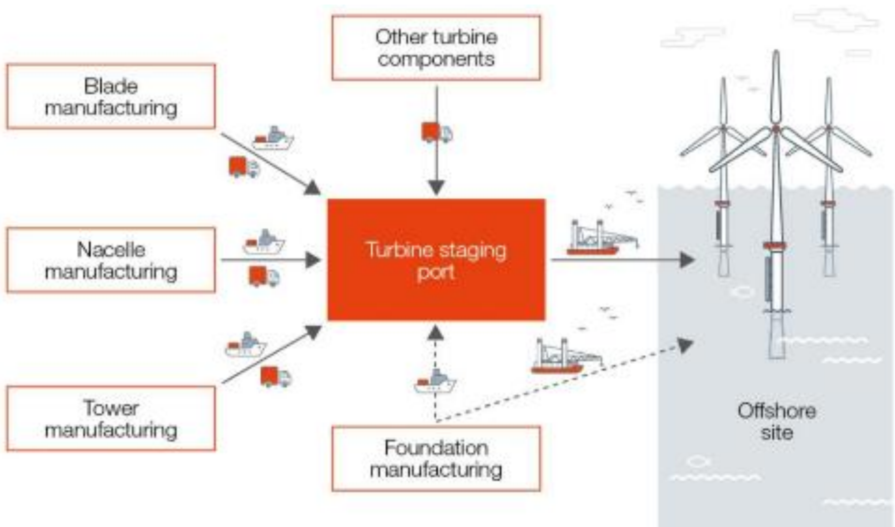

Figure 8: Typical process of sourcing and installation of components in OWF.

Transition pieces and foundations can be completely finalized and fitted out in the fabrication facility needing only to be unloaded from vessels at the staging port (if used). Otherwise, secondary steel works and fabrication can be completed in the staging port.

8.2.2. Components storage and handling

A starting point to estimate space and load requirements for the apron and yard should be the properties of the components that are handled in a staging port. Component size and weight can vary with producer as well as the assembly and storage process.

Foundations - Monopile foundation loadout activities using SPMT can be challenging in macrotidal environments where the required barge height cannot be kept within a safe limit. In these cases, a combination of using SMPT and large ring cranes can be a solution to reduce downtime. SMPTs also require more clearance at quay and can significantly reduce storage area.

Embankments and steel or concrete racks are typically used for storage of monopiles in the yard to allow the standoff for the SPMT to enter below the monopile and lift it. Loadout can be done by SPMT or crane; however, loads imposed by cranes are often much higher than those imposed by SPMT and in some cases pose a limit for foundation size to be handled at port.

Transition Pieces - Transition pieces are generally stored vertically within a 10 m x 10 m area to allow access all-around. Jacket structures are typically stored standing. Transport is generally done by SPMT.

Towers - Tower sections typically arrive prewired. However, tower internal platforms must be pre-assembled in a sheltered facility at the port to protect sensitive power electronics and other electrical equipment. Completed internal platforms must be stored and sheltered, either in the assembly facility or other location, until they are lifted into place inside the towers and secured. Properly covered and secured tower sections can be stored securely outdoors for later load-out.

Turbines - Turbine components are kept in an open-storage yard away from the quay. Each component has a storage & transport frame to facilitate manipulation and lifting. Components and frames are stored on supports which are selected based on load bearing and settlement limitations.

Blades - Blades can be stored in multiple levels using stacking frames.

Ground preparation

During storage, ground settlement is generally limited to 5 cm and allowable inclinations up to approximately 3% may be permissible. This however depends on different factors such as channelling of the rainwater runoff and maximal slope for operation of SPMT vehicles.

In reality, settlements should be anticipated and their management should be built into either construction or operation, either of which can have different cost and schedule trade-offs. This is in particular relevant in cases that require soil reclamation, improvement or replacement.

The substation topside is generally transported directly from the manufacturing port to site. In some cases, foundation components are stored on barges at the installation port, not using any of the staging area. Main properties of general WTG and foundations for various turbine sizes are provided in Table 2 and Table 3 below. Note that components size and weight vary depending on project specific conditions (water depth, soil conditions) and on manufacturer.

Component	Property	Unit	10-12 MW	15 MW	20 MW*
Tower	Length	[m]	110	130-140	Up to 160
	Diameter	[m]	8	8-10	Up to 12
	Weight	[t]	600	700-1000	1000-1500
Nacelle	Weight	[t]	650	650-900	900-950
	LxWxH	[m]	22/10/12	28/12/12-30/14/14	Up to 30/17/17
Blade	Length	[m]	100	110-120	135-145
	Weight	[t]	50-60	65-70	>70

Table 2: Main properties of WTG components for various MW capacity.
**Figures provided for 20 MW WTG units are projections.*

Type	Property	Unit	10-12 MW	15 MW	20 MW*
Monopile	Length	[m]	50-80	Up to 120	120
	Diameter	[m]	5-7	Up to 12	Up to 15
	Weight	[t]	800-1200	Up to 2500	Up to 3500
Transition piece	Length	[m]	30	30-40	30-40
	Diameter	[m]	6-7	7-9	9-12
	Weight	[t]	40-500	500-1000	1000
Jacket	Weight	[t]	550	550-1000	1000
	LxWxH	[m]	20/20/50	20/20/50	20/20/50
Substation	Weight	[t]	1000-5000	1000-5000	1000-5000
	LxWxH	[m]	34/27/24	34/27/24	34/27/24
GBS	Weight	[t]	5000	5000-6000	>6000
	Diameter Base	[m]	30	30-35	>35

Table 3: Main properties of bottom-fixed foundations for various MW capacity.
**Figures provided for 20 MW WTG units are projections.*

There are no requirements for fixed cranes for installation base ports. This is primarily because loadout is usually carried out by a high-capacity crane mounted on the WTIV. The WTIV is not sensitive to tide variations. In some cases where there is not enough load bearing capacity at quay side, the tower can be pre-assembled as:

- Two tower sections with only Section 1 and 2 pre-assembled and the last section loaded out separately
- No pre-assembly and all sections loaded out separately

Storage area can be estimated by multiplying the area taken by one turbine by the number of turbines required to be stored at port. Additional space for warehouse and offices must also be considered. Example is given in Table 4 but should be noted that there are several factors that influence the area. Component sizes differ from one manufacture to another, and density of storage can have an influence as well. Blades can be stacked up which greatly affects the resulting area. Furthermore, depending on the location and the installation strategy used, the number of staged components at the port can cover part or the entire project.

Component	Property	Unit	10MW WTG	15MW WTG
Towers	Area*	[m^2]	1060	1400
Nacelle	Area*	[m^2]	230	335
Blades	Area*	[m^2]	775 (1 to 3 rack)	930 (1 to 3 rack)
WTG	Area*	[m^2]	3620 / 2070**	4525 / 2665**
OWF Size		[MW]	1000	
No. WTG		[-]	100	67
No. WTG at port		[-]	50-100	35 - 67
Area required		**[ha]**	20 - 50	

***stacked blades*

Table 4: Example of required storage area estimation

The example above presents the area required for storing all WTG components at port. This is not required in all projects. It is usually the pace of the installation which determines the required WTG components buffer. If WTG components are expected to be imported from Europe it is recommended to that a great number of components are stored at the installation port prior commencement of installation in order to reduce the risk of delays..

Table 5 provides an overview of typical surface (ground) loading of the various components and activities that are usually found in OWTs. Figure 9 illustrates typical storage, handling and transport methods employed at these OWTs.

Activity	Equipment	Estimated load	Methods to reduce load
Load in WTG components	SPMT/Ramp Crawler cranes Mobile cranes (Blades)	10 t/m² when unloaded/transported by SPMT (load under vehicle axles) 30 t/m² when unload using heavy crane (load under crane tracks)	Layer of crushed stone or gravel Crane mats or crane foundation
Loadout of WTG components	WTIV Crane/ HLV crane	No load to the apron	
Load in / Loadout of MP	SPMT Crawler crane	10-12 t/m² (load under vehicle axles) 25-60 t/m² (load under crane tracks)	Layer of crushed stone or gravel Crane mats or crane foundation
	Vessel crane/ HLV crane	No load to the apron	
Transport & Load in / Loadout of TP	Crawler crane	20-30 t/m² (load under crane tracks)	Layer of crushed stone or gravel Crane mats or crane foundation
	SPMT	10 t/m² (load under vehicle axles)	
	Vessel crane	No load to the apron	
WTG Components transport	SPMT	10t/m² (load under vehicle axles)	Layer of crushed stone or gravel
Assembly of towers	Crawler crane	Crane+T1 section up to 30 t/m² (load under crane tracks)	Crane mats Foundations
Nacelle storage	Concrete blocks Crane mats	Varies depending on layout, global spreading, lifting equipment…	Crane mats Embankments
Tower sections storage			
Blades storage	Supports / frames		
Monopile storage	Concrete/steel pads or gravel		
TP storage	frames/saddles Concrete blocks		

Table 5: Activities, equipment and estimated loads at OW installation port
Based on 10-15 MW WTG, Images are given in Appendix (Section 15.2).

WTG Components storage, handling and transport examples

Foundation components storage, handling and transport examples

(projectcargojournal, 2022) (rechargenews, 2022) (energyprojectstechnology, 2022) (shirejournal, 2022) (windpowernl, 2022) (windpowerengineering, 2022)

Figure 9: Examples of storage, handling and transport WTGs and foundation components.

8.2.3. Vessel portfolio

This section provides an overview of typical vessels that call at staging ports. A given vessel's size and manoeuvrability will dictate the port navigational requirements. Examples of the vessels discussed herein, and their dimensions are provided in Table 6.

Turbine components are transported by multi-cargo transporters and open deck carriers. Some multi-cargo transporters have also been converted to serve exclusively the transport of blades or nacelles. They can be equipped with a lifting bow to allow RoRo (roll-on/ roll-off) loading process.

Roll-on/roll-off ships are cargo ships designed to carry wheeled cargo, such as cars, motorcycles, trucks, semi-trailer trucks, buses, trailers, and railroad cars, that are driven on and off the ship on their own wheels or using a platform vehicle, such as a self-propelled modular transporter. This is in contrast to lift-on/lift-off (LoLo) vessels, which use a crane to load and unload cargo. RORO vessels have either built-in or shore-based ramps or ferry slips that allow the cargo to be efficiently rolled on and off the vessel when in port.

Wind turbine components (tower, nacelle, and blades) are generally installed using WTIVs, that are specifically designed for offshore wind installations and have the capability to jack the vessel off the seabed and lift the entire vessel out of the water. Jack-up vessels are required due to the large hub-heights of turbines and provide the stability and control required during heavy lift activities at hub height with tight tolerances. Additionally, jack-up WTIVs can be used for installation of foundations as well.

To load components, the WTIV is required to jack-up adjacent to the load-out quay. This minimizes movement and potential damage to components during lifting and sea-fastening and is one of the governing factors that need to be accounted for in qualifying a port for staging. In the past, this was solved by prescribing a minimal standoff from the quay and estimating penetration of the spuds into the seabed. However, increase in component sizes has resulted in limiting the crane reach and the preference is now to ensure that vessels can jack-up without standoff. This can be ensured by various methods of seabed strengthening.

With offshore wind projects being developed all around the globe, different constrains (such as vertical clearances and soil conditions) have led to the development of alternative loadout processes and installation methods.

Heerema Marine Contractors has developed a method of assembling and installing XXL wind turbines on a floating dynamically positioned vessel (tested by using the crane vessel Sleipnir). The method will be used for the OWF Arcadis Ost1 in the Baltic Sea. The company will deploy the vessel Thialf for the project, which will be able to sail through the Storebaelt Bridge.

Feeder barges and WTIV method will be used for Empire Wind project in the U.S. This solution is said to be less weather dependent and efficient, reducing port requirements in terms of draft and vertical clearances.

Vessel Type	Name	LOA [m]	B [m]	Draft [m]	Comment
WTG Components transport					
Multi-cargo vessel	M/V Pacifica	138.5	21.0	8.0	Geared to 300t
Offshore component transporter	Rotra Vente	141.0	20.0	6.5	Ro-ro bow and flush deck
Open deck carrier	M/S Meri	105.5	18.8	4.7	1660m^2 deck area
Feeder vessel concept	Designed by Ampelmann	103.5	23.8	5.5	20 crew+12 passenger; 2.5m Hs
Foundation components transport & installation					
Heavy lift vessel	Seaway Yudin	183.3	36	5.5-8.9	2500t main crane; 2560m^2
Crane vessel	Svanen	102.8	74.6	4.5	5705t capacity
Semi-sub	GPO Grace	225	48	10.6	183x48m free deck
Semi-sub	MV. Sun Shine	168.5	40	7.08	134 x 44 m deck space
Jack up vessel	Aeolus	139.4	44.5	10.1	3775m^2 deck area
Wind Turbine Installation Vessels					
WTIV (jack up)	Pacific Orca	160.9	49.0	6.0	1200t@31m crane
WTIV (jack up)	Voltaire	169.3	60.0	7.5	3000t crane Deadweight for jacking 14000t
New generation of installation vessels for large scale OWF					
FDP Vessel	Thialf	201.6	88.4	11.9	14200t capacity
Semi-sub crane Vessel	Sleipnir	220	102	12	20000t capacity
WTIV	Orion	216.5	49.0	11.0	5000t@35m crane Also XXL MP and Jacket installation
WTIV (jack up)	Atlas-A	155.4	57.4	6.5	@14000t deadweight

Note: Vessel draft given is for fully loaded condition. Draft may be reduced when vessel is not fully loaded.
Table 6: Typical vessels that call at OW installation ports

Monopile foundations are transported long distances by deck-carriers or semisubmersible vessels. For short trips barges can be used.

WTG Components transport

1-Multi cargo vessel
2-Offshore component transporter
3-Open deck carrier
4-Feeder vessel

Foundation components transport & installation

1-Heavy lift vessel
2-Crane vessel
3-Semi Sub vessel
4-Jack up vessel

Wind Turbine Installation Vessels

1-FDP vessel
2-Semi sub crane vessel
3-Jack up vessel
4-Jack up vessel

Figure 10: Typical vessels that call at OW installation ports.

Other vessels which are involved in construction activities are:

- Transport barges
- Cable installation vessels
- Platform supply vessels
- Tugboats
- Safety vessel / Standby ERRV
- Multi-purpose project vessel

These vessels are typically smaller, and therefore their dimensions are not the driving factors for port requirements.

8.2.4. Distance to site

COWI has analysed the distances between major OWF and their installation ports as shown in Figure 11.

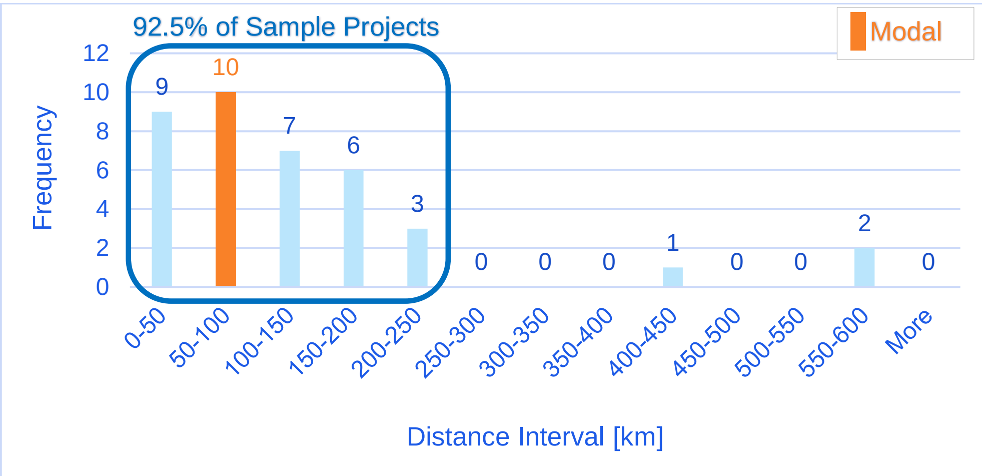

Figure 11: Distances between OWF and installation port facilities.
(frequency in number of wind farms)

Based on the sample of 40 OWF installations, including all European projects (2015-2021), modal distance interval is 50-100 km with great majority of projects, 37 out of 40, being less than 250 km. However, some outliers, such as Northwind (Belgium) and Westernmost Rough (England), where installation was carried out from Esbjerg despite a distance of nearly 600 km, shows that other factors can take precedence, for example tidal restrictions. Acceptable sailing distance is usually determined on a case-by-case basis by the project developer, who must consider overall program including CAPEX and installation campaign duration.

8.2.5. Other factors

In addition to the properties discussed above, various other considerations could play a role in port planning with OW services in mind.

Quality of land-based traffic connections. Good road connections are a key requirement if supply chain is dependent on the transport of components from hinterland. This criterion tends to be fulfilled by default in all major cargo port centres. It is not commonly seen that freight trains are used for transport of components to installation bases.

Proximity to other modes of transport. For example, airports, could also be an advantage if crew rotation is planned out of the installation base.

Exclusive availability of berth for components load-out activities. As they are on the critical path of the installation schedule.

Local Economic Ecosystem. Offshore wind developments typically drive the local economy in and around the installation port(s) that support them by job creation. In major European OW ports, there is an entire economic ecosystem of specialized business present and providing services required by developers, OEMs, vessel operators, etc. These include but are not limited to stevedoring, mission-equipment fabrication, fuelling, transportation and lodging of staff and personnel, repair of vessels, training facilities, etc.

8.3. Port usage in O&M of bottom-fixed turbines

8.3.1. O&M strategy and requirements

OWF in operation require regular inspection and maintenance to minimize downtime and maximize generation of electricity. These activities include:

- Management of the asset: remote monitoring, environmental monitoring, administration etc.
- Preventive maintenance: routine inspections, change of lubrication oils and regular replacement of wear parts.
- Corrective maintenance: repair or replacement of failed or damaged components.
- The O&M strategy differs from one operator to the next aiming to find optimal intersection of access to the asset and onshore support:
- Access to the asset: transit time and time in which a turbine can be reached by O&M personnel.
- Onshore support: availability of parts and services taking part in maintenance or repair.

O&M base ports can be at an entirely different location from the installation ports, as their main requirement is to be within relatively close proximity to the OWF and as infrastructure requirements are less demanding compared to installation.

O&M strategy can roughly be split in two groups:

- Shore-based: where personnel and spare parts are located in the port and shuttled to the OWF.
- Offshore based: where personnel and parts are located on a fixed or floating accommodation base.

Due to the projected OWF sites being relatively close to shore, only the shore-based access will be assumed.

8.3.2. Vessel portfolio

Crew Transfer Vessels (CTV) are small vessels limited to return trips within a single day. In all cases, workboats are limited to a 12-passenger capacity to maintain the classification of non-conventional vessels according to SOLAS (vessels not engaged on international voyages). These boats are usually aluminium (or fiberglass) catamaran designs, with overall lengths ranging from 14 m to 26 m.

With distances of OWF between 40 km to 90 km, the use of CTV can be supplemented by helicopters (examples: Horns Rev 1, Alpha Ventus, DanTysk, Sandbank, Greater Gabbard). Helicopters are used for out-of-schedule maintenance, to minimize down-time or in cases when sea-state does not allow transfer by CTVs.

SOVs are larger vessels that include accommodation, workshops and spare part storage. They can spend weeks at sea and usually return to port only to restock, refuel and exchange crew. A unique feature of these vessels is the ability to allow personnel to "walk to work" where gyro-stabilized gangways give safe access to turbines even in high wave conditions, up to 3 m. With use of SOVs, the distance between an O&M base and OWF can increase to 150 km.

Vessel Type	Name	LOA [m]	B [m]	Draft [m]	Comment
CTV	Damen FCS 2610	26.3	10.3	2.4	100 m^2 deck area, 12 personnel
CTV	Ribcraft CRC Voyager	15.0	3.6	0.7	1500 kg payload, 12 personnel
SOV	Ulstein SX 175	88	18	6.4	350 m^2 deck area, 60-90 personnel

Table 7: Typical vessels that call at OW O&M ports

Examples of the O&M vessels discussed herein and their dimensions are provided in Table 7 and Table 8.

Vessel Type	Crew Transfer Vessel - CTV
	
Vessel Type	**Service Operation Vessel - SOV**
	

Table 8: Images of typical vessels that call at OW O&M ports

8.3.3. Distance to site

COWI has analysed the distances between major OWF and their O&M port. The results are shown in Figure 12, below.

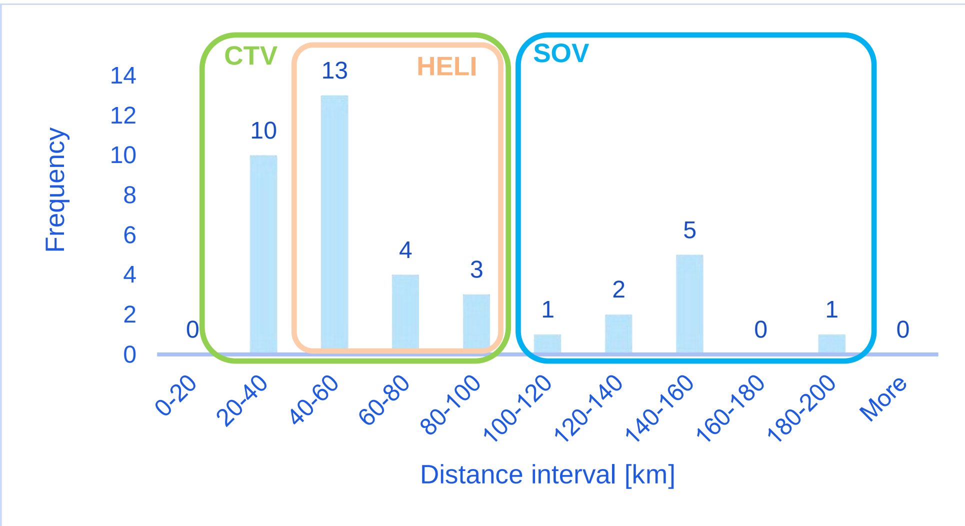

Figure 12: Distances between OWF and installation port facilities.

The analysis shows that OWF that use CTV vessels are generally at a distance to the O&M base between 20 km and 80 km. Those that use SOV vessels group between 120 km and 180 km.

Helicopter support is generally used for distances between 40 km to 90 km and can also be present for longer distances providing service for medical emergencies.

8.4. Derived benchmark for installation ports

The following benchmark for installation ports also assumes that the port can be used for staging of foundations (transition pieces, monopiles, jackets) although it does not cover some specific features typical for such use. For ports where marshalling of both foundations and WTG components will occur concurrently it is expected that the area requirement will be higher due to the need to avoid scheduling conflicts. The general case in Europe is that OWF installations using two different ports often occurs due to distances but some projects, such as Arcadis Ost 1, use the same port.

The benchmark presents two thresholds:

- An acceptable value which covers minimal required properties for current WTG and up to 15 MW WTG (Assuming 1 GW OWFs)
- A recommended value to cover 15 MW WTGs and future trends (Assuming 1 GW OWFs)

Harbour and location properties are derived based on expected vessels calling at port and are considered as “need-to-have” properties, (See *One way channel

Table 9). As such these would be the properties used for coarse screening as it is considered that location that does not meet these criteria cannot serve the purpose. Construction works associated with deepening existing ports or construction of new ones (including dredging, reclamation and breakwater) requires longer-term planning due to permitting (EIA in particular) and other factors.

Depth at the entrance, in the channel or along the fairway should allow access to all vessels at all tides, also assuming increase in size of future vessels. If a harbour can only be accessed and departed at high tides, this adds additional constraint to a critical activity, which is the efficient charter of installation vessels. Depth at navigation channel is assessed as 1.15 x D (D = vessel draught). Depth at berth is assumed as vessel draught plus an additional meter.

Entrance width should be sufficient to allow easy navigation in a range of weather conditions. According to recommendations, harbour entrance (breakwater gap) should be 0.8 – 1 x LOA, (C.A.Thoresen, 2018) but depending on conditions and manoeuvrability, smaller entrances could be navigable, subject to a more detailed investigation. It should also be acknowledged that WTIV are carrying blades stacked across the deck (length of 120 m for 15 MW WTG). Therefore, to the structures such as lighthouses should be checked. If there is a restricted **approach channel** leading to the harbour, the width (full depth) is calculated as (1.6 – 2 B + 2xB).

Locks can be tolerated only in port facilities that are intended to support fabrication of foundations as foundations can be transported on barges and generally do not hang over the beam of the vessel. Locks are not acceptable for installation ports if jack up WTIV is considered.

Turning circle is generally calculated as 2x LOA; however, under favourable conditions (i.e. for manoeuvrable vessels) can be reduced to 1.25x LOA.

All the above properties are vessel dependent. Acceptable and recommended values have been set by using vessel portfolio values in Table 6.

It is strongly recommended that the **vertical clearance** is unrestricted. Such restrictions can come in from of bridges, utility lines or airstrip landing corridors, for example. Both pre-assembled towers and retracted jack-up legs can extend 100 meters above the deck of the vessel and presence of any overhead obstacles, even above that height should, be carefully analysed before accepted.

Property	Unit	Acceptable	Recommended
Distance to OWF	[km]	<400	<200
Harbour entrance width	[m]	160	0.8-1LOA
Channel depth	[m]	9	12.5
Access channel width	[m]	200*	200*
Presence of lock/gate	[y/n]	Not Acceptable	
Vertical clearance	[m]	Unrestricted	
Turning circle	[m]	240	300

**One way channel*

Table 9: Summary of key location and harbour properties for installation port

Berth and yard properties are derived based on analysis of operations (berth, quay and yard). These have been compared to the case-studies of major European ports servicing installation of OW and insight from interviews done for this study with industry professionals.

Table 10 should be used in evaluating existing terminals (within port basin) or planning of new one. It is unlikely that a berth and yard would fulfil these criteria unless they are already built for the purpose.

Berth length is a function of the number and length of vessels expected to simultaneously use the berth. It is assumed that the berth is marginal (quay parallel to shoreline) to allow unconstrained access between apron and the yard. There should be sufficient space for simultaneous mooring of two vessels as this will allow necessary flexibility in scheduling the inbound and outbound transport. It is also recommended to allow for an additional berth to be reserved for a second WTIV during a load-out.

Based on LOAs provided in previous Note: Vessel draft given is for fully loaded condition. Draft may be reduced when vessel is not fully loaded.

Table 6, recommendation for the length of berth equal to 1.25 X LOA (C.A.Thoresen, 2018). The terminal should be designed as a multi-purpose terminal to allow flexibility of use and maximize income from other usage in-between OW installation cycles.

In addition, a multi-purpose terminal allows for monopiles, jackets or transition pieces which are shipped from fabrication yards elsewhere to be stored as well as to allow foundation staging if needed. To address this provision of a heavy load Ro-Ro ramp could add additional flexibility as well.

Load capacity of areas depends heavily on use and type of transport. High load allowance does not need to be present throughout and there are several examples where general, or container cargo quays have been adapted for storage or load-out. In case of suspended decks (e.g., pile supported), this can be achieved using custom-built load spreaders to transfer the loads directly to the piles rather than the deck structure itself. With embedded wall quays, construction of a dedicated load relief platform on driven piles can efficiently take the loads away from the wall itself and directly onto the bearing stratum below. Certifying (or strengthening) existing quays for these types of operations and cargo must be done from case to case and with keen awareness of minimizing cost and logistical constraints while maximizing utility.

In general, having an overall general UDL of 75 kN/m^2 (7.65 t/m^2) is deemed enough to allow both transport and storage of elements such as nacelles, blades and tower segments and 100-150 kN/m^2 (10.2–15.3 t/m^2) for unhindered running of all components using SPMT (including monopiles and transition pieces) and staging of transition pieces on the quay side in close proximity. SIF terminal at Port of Rotterdam and Port of Hull feature a 100 kN/m^2 (10.2 t/m^2) UDL adjacent to their berth space.

Some operations require a higher UDL allowance. Tower foundation packs or heavy load areas where elements are erected and pre-commissioned require bearing capacity of 150-300 kN/m^2. It is often standard practice and more economical to limit this to a dedicated area. This also applies for other similar uses such as heavy load pads for crawler cranes or cradle foundations for monopiles. The same recommendations apply for yards. If the load is not affecting the quay, or other retaining wall structures, for example at the back of the suspended pile wharf, providing high load areas is less costly. If the fill is already compacted, a well compacted gravel top layer, typically up to 1 m, should be sufficient to achieve uniform distribution of loads and avoid further settlements.

It is worth stressing the importance that UDL in this case is uniformly distributed load over the entire, or larger, area. Loads under the crane tracks are typically much higher, however, act over limited (and dedicated) area. Point loads are generally assessed at later project stages and are not considered as part of this high-level study. It should be noted that it is possible to accommodate special areas for high point loading, such as crane pads and similar, by adding structural reinforcement to existing pile supported quay structures or constructing pads that can distribute the higher point loads over structures with less bearing capacity.

A strengthened seabed is recommended to ensure that WTIV can jack-up immediately adjacent to the quay. This can be achieved through different strengthening methods, such as but not limited to:

- Stone bedding to distribute the load from spud cans;
- Rigid inclusions;
- Soil improvement;
- Lateral confinement.

In general, seabed strengthening is constructed for a particular vessel size and may not fit the envelope of all WTIV dimensions, potentially increasing loads on some of the jack up legs. It is recommended to utilize seabed strengthening for an area which could serve multiple vessels.

An alternative would be to verify that the leg penetration is not compromising quay stability and that a safe distance to the quay is not hindering loading process. However, this option should be carefully considered and avoided for quays that are intensively used for installation.

Also, with sufficiently competent seabed, jacking-up can be possible without strengthening or penetration. Seabed inclination should also be limited to 10% which is achievable for most of the jack-up vessels.

It should be emphasized that the benchmark is based on the installation method using a jack-up WTIV that makes multiple return trips between the OWT port and the OWF site to pick up the components. Installation using these vessels has proven to be the most efficient and is most commonly used. However, other methods are possible as well, where components are transported to site using feeder vessels while a jack-up barge is stationary at the site. In Europe, ports around the North Sea (or Baltic) have evolved simultaneously with the industry in pursuit of cost reduction fueled by a continuous project pipeline. This could be different in countries that are yet to kick-off its OW projects and could warrant consideration of different installation methods.

The major cost-driver for the installation of WTGs is expected to be the loadout process speed. When calculating minimal berth length properties, it is assumed that only one vessel can be moored. Having two WTIVs at port is becoming more common to reduce the duration of installation campaigns, especially for OWF over 1 GW capacity.

Property	Unit	Acceptable	Recommended
Berth length	[m]	200	400-500*
Depth at berth	[m]	8	12
UDL load capacity	[kN/m^2]	75	100-150
Seabed	[y/n]	**	
Yard area	[ha]	20-25	30-40

** Value for accommodating 2 vessels at terminal (cargo vessel & WTIV or 2 x WTIV)*
*** Read description in paragraphs above*
Table 10: Summary of key berth and yard properties for installation port

Benchmarks, like the one provided above, represent a limited set of most salient properties of a port / terminal needed for hosting OWF staging installation operations. As such, it could be used as a starting point when planning a new facility.

8.5. Generic installation terminal footprint

Based on recommended properties, a generic installation terminal footprint is shown in Figure 13. Apart from key properties, it also shows some of common areas and features typically found at a such facility.

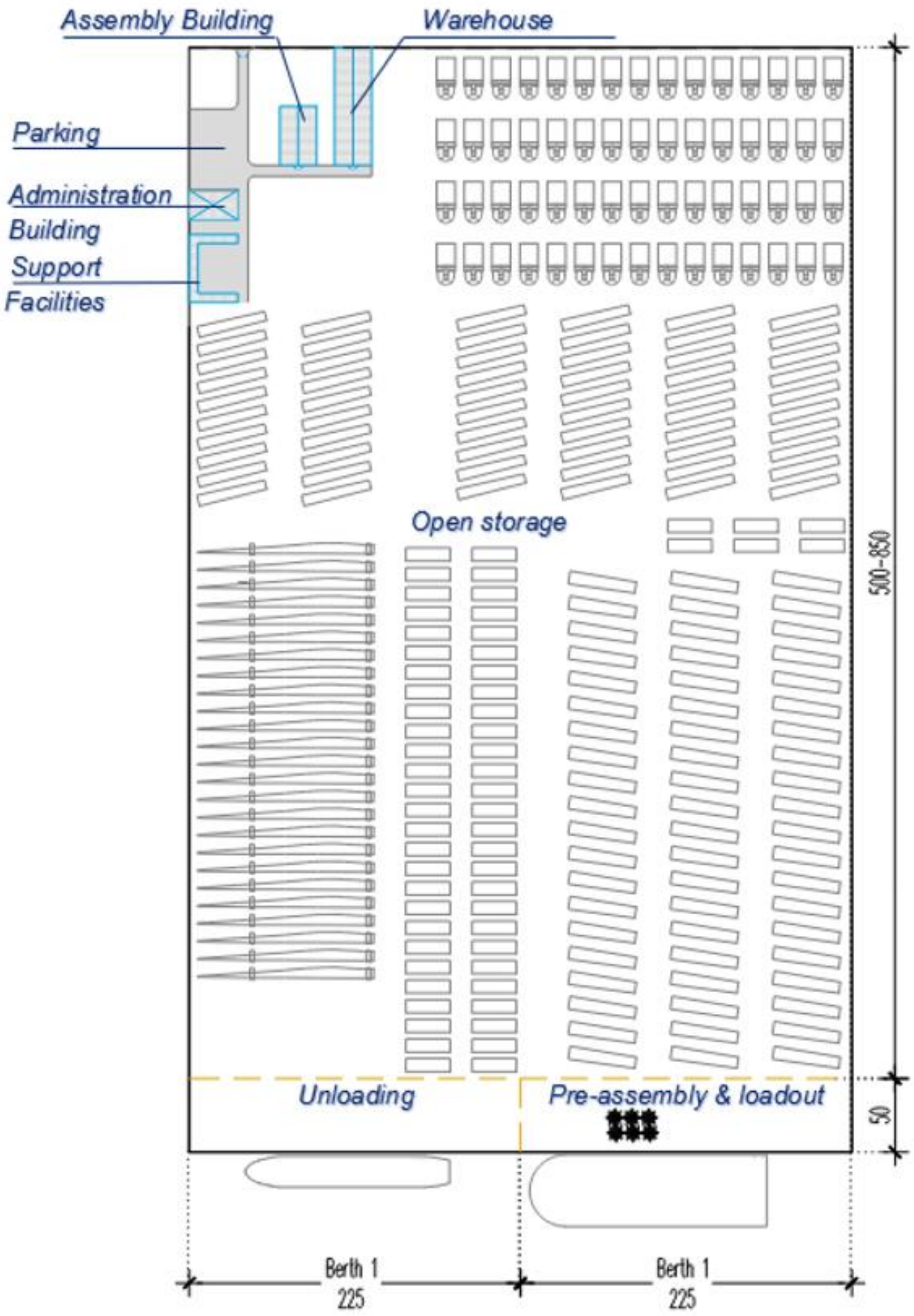

Figure 13: OW terminal – indicative masterplan. (measurements in meters)

Unloading zone	The unloading area is a 50m wide apron behind a 225m long berth. The unloading zone allows the possibility to have more smaller vessels (such as feeder barges) moored simultaneously. The unloading area can also be used for load-out as it fulfills the same bearing capacity criteria.

	Cargo is unloaded using the vessel's own cranes or by crawler cranes in the port. *Berth length:* *225m, min. water depth -12.00* *Area:* *225 X 50m = 11,250 m2*
Pre-assembly / load-out zone	The pre-assembly and load-out areas are intended primarily for berthing of WTIV and rapid loading of installation-ready components. Due to the high charter cost of WTIV, its installation rate acts as a driver of the pre-assembly process. The load-out area is fitted with two sets of foundations for assembly and pre-commissioning of towers. Towers are assembled in two halves on the outer foundation pack and moved to the quay. Foundations are assembled full height and pre-commissioned. From there, they are loaded fully assembled by WTIV's on-board crane. Other components (blades, nacelles, etc.) arrive by SPMT from open storage and are loaded on deck using the WTIV's crane. The WTIV is jacked-up in front of the quay to achieve full crane capacity and eliminate movement. *Berth length:* *225m, min. water depth -12.00* *Area:* *225 X 50m = 11,250 m^2*
Open storage zone	This is a laydown area for turbine components (tower sections, nacelles, blades, rotors, hubs, empty transport frames). The exact layout will depend on the organization of component handling (such as random pick, first-in-first-out, first-in-last-out). As explained before, the size can depend on the overall logistic strategy and several other factors. Transportation of components within the OWT is done using SPMT or trailers (for blades). *Area:* *≈225,000 – 382,500 m^2*
Warehouse	The warehouse is an uninsulated hall that is used for storage of smaller components, tools, spare parts and consumables. It should be equipped with racks and pallet stacking areas. *Area:* *80 X 25 m = 2000 m^2*
Assembly building	The assembly building an insulated and air-conditioned hall which serves the pre-assembly and storage of electrical components such as power and transformer units. *Area:* *40 X 25 m = 1000 m^2*

Administration building	The administration building, also insulated and air-conditioned, should provide enough space to host staff belonging to all principal stakeholders: - Terminal operator - Developer - OEM - Marine contractor *Area:* *800 m²*
Support facilities	Facilities to support working crews from different stakeholders are needed. Support facilities can also be executed as office and accommodation container units. Facilities should include offices, locker room and welfare facilities. *Area:* *2000 m²*
Parking	A parking area with 80 spaces for small vehicles. *Area:* *2000 m²*

It is assumed that installation rate of the WTIV is 3-4 days per turbine, including load-out, transport and reasonable downtime due to weather (Lacal-Arántegui, 2018).

An indicative throughput of the OWT would be 60 turbines over a period of 3-4 months, assuming that two WTIVs are working simultaneously. Moreover, with the vessel installation rate driving the installation schedule, a realistic installation rate of 3.5 turbines per week could be achieved.

On the lower end of the range shown for the laydown area, components would be stored more densely, and the area would be sufficient for 2-3 months of installation. On the other end, the number of stored components could suffice for an entire installation campaign which would be a preferred logistic strategy of some OEM’s and developers to ensure that potential delays do not create knock-on effects.

8.6. Derived benchmark for O&M ports

For operations based on the use of CTVs, requirements for O&M ports are far less demanding than those for installation bases. Assuming vessels with a LOA of 15-30 m, a basic set of port parameters for CTVs is given in Table 11. Benchmark properties for SOV are not included as it is assumed that any major port (including those selected for installation) will be able to accommodate these vessels and that the maximum recommended travel distance can range up to 200 km.

As the loads for equipment and spare parts are not considerable, existing quays can typically function as berths for service vessels. This might not be the case though, in the case of historic quays or those that are in state of significant deterioration. In the case of CTV, access to the vessels is often very difficult from fixed berths due to the low freeboard and deck height or in the case of large tidal variations. In such cases, it is quite common to provide a dedicated pontoon berth suitable for smaller vessels (see Pontoons highlighted within orange dashed area.

Figure 14). Such pontoon berth arrangements often include facilities for fuelling, potable water, holding tank pump-out, shore-side power, firefighting, electrical outlets, and lighting. All associated tank storage, pumps and substation infrastructure is typically located onshore adjacent to the dock. Fixed cranes located adjacent to and sometimes on the pontoon arrangement and/or mobile cranes provide lifting capacity for provisioning, loading, and unloading of work vessels.

An O&M facility should have available area adjacent to the berth for onshore facilities such as offices, storage, accommodation, and workshop(s). In addition to the above listed location and infrastructure properties, one of the key requirements for O&M bases is local availability of qualified workforce and hinterlands that can support activities.

Based on European experience, a building at the port of at least 300 m^2 is needed for storage of spare parts and a small workshop. Spare parts and consumables that need to be stored for O&M activity could include items such as tools, hardware, fasteners, cables, and lubricants, necessary for both scheduled and unscheduled maintenance of the wind farm and substation(s). The workshop should facilitate planned and unplanned maintenance and repair activity of minor components.

A staff office is usually established at the port and should include facilities for incidental office work and staff/crew support facilities including showers, changing rooms, laundry and drying for wet work clothes. It is not expected that required number of CTVs and facilities will vary much from 10-15 MW to 20+ MW WTGs as well as for different OWF sizes. The main expected difference will be the crew requirements.

New strategies in terms of O&M for some ports is shifting and serving multiple OWFs in around 200km radius by using a variety of means (CTV, SOV, helicopter) and the service providers winning these contracts by providing access to relevant services in or around the port.

Property	Unit	Acceptable	Recommended
Distance to OWF	[km]	<100	<50
Depth at channel (entrance) at MLLW	[m]	4+	6+
Harbour entrance width	[m]	15+	50
Presence of lock/gate	[y/n]	Tolerable	Preferable No
Vertical clearance	[m]	15+	>20
Turning circle	[m]	40	60-75
Depth at berth	[m]	4+	6+
Adjacent area	[ha]	0.5	0.75-1.5

Table 11: Summary of key location and harbour properties for CTV based O&M ports

8.6.1. Other O&M activities

Smaller WTIVs are often used for maintenance operations where WTGs may require replacement of minor components. It is deemed that 5-10 ha should provide plenty of space for generator replacement or single blade replacement. Port navigational requirements will depend on selected WTIV and can be estimated as per Section 8.4.

Pontoons highlighted within orange dashed area.
Figure 14: Ørsted's O&M base at Vlissingen.

9. Port screening and gap analysis

The ports selected as candidates to support the installation of the two OWF are shown on Figure 15 for the Tamil Nadu region and Figure 16 for the Gujarat region. The ports were selected based on previous studies and due to their relative vicinity to the OW zones.

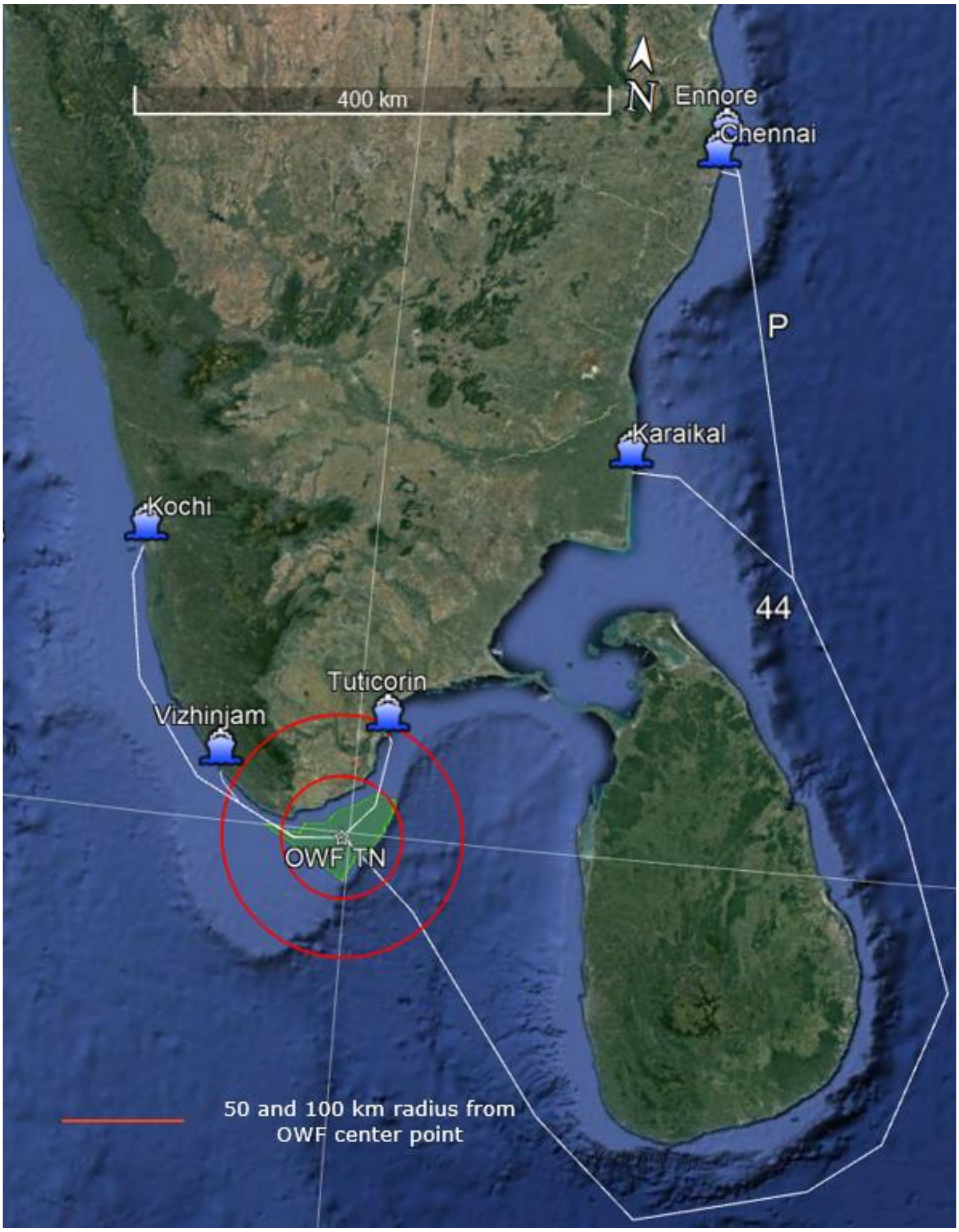

Figure 15: Candidates to support the installation of OWF at Tamil Nadu

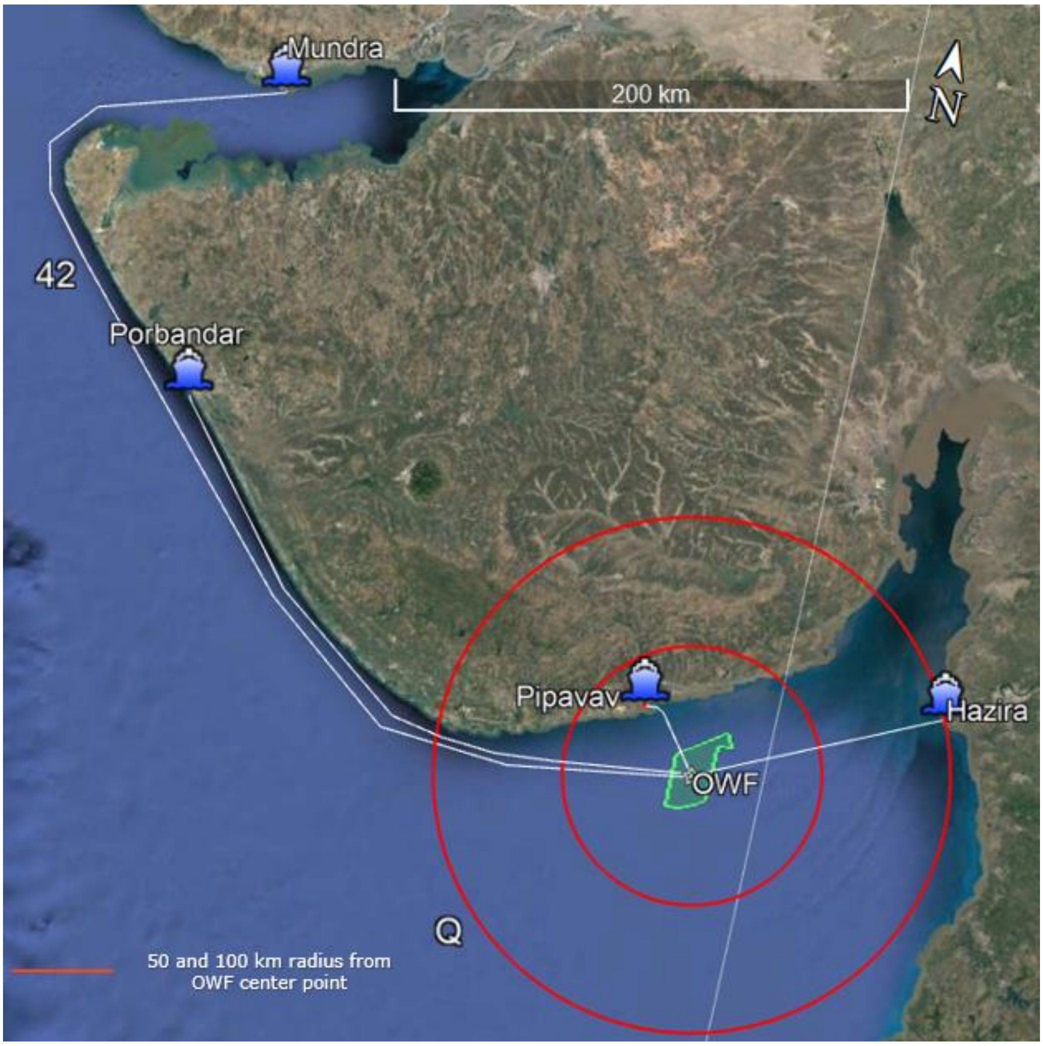

Figure 16: Candidates to support the installation of OWF along Gujarat coastline.

Following the gap analysis of port properties and possibilities for upgrade and future development, two ports per region for which to prepare a roadmap are selected in Chapter 4.

9.1. Methodology

Ports screening was accomplished in two separate phases:

Phase 1 comprises a coarse screening using the harbour and location properties as eliminating criteria. The result of Phase 1 is identification of two “shortlisted” ports in each region.

Phase 2 comprises a detailed analysis of the two selected ports for each region.

A gap analysis was performed to determine the suitability of each shortlisted (or candidate) port (or its selected facilities) to serve as staging (marshalling) terminal for bottom-fixed turbines. The role of ports in OW and the reasoning behind such focus in this study is provided in Section 8.2.

These ports differ in size, operating model, stage of development and potential for further development. Because of this, it is difficult to produce a relevant screening tool and enable comparison.

The gap analysis is primarily based on port properties described in the benchmark provided in Section 8. The analysis is intentionally qualitative rather than quantitative, meaning that the parameters have not been assigned a score nor weight. Rather, a simple "traffic light" system was used to designate whether a certain parameter falls within or outside the criteria. See Table 12.

Light code	Description
Red	Does not meet the minimally acceptable criteria
Yellow	Between recommended and minimum acceptable values
Green	Currently meets the recommended values

Table 12: Traffic light system applied in gap analysis

Port properties which are considered have been fine-tuned to match the sample size and the nature of the screening as explained in the sections below.

9.2. Phase 1 coarse screening

The information used for ports screening was obtained from:

- Previous studies conducted by COWI.
- Official port web pages and publicly available studies.
- Nautical charts (in electronic format) and Google Earth measurements/images.

9.2.1. Tamil Nadu OWZs

Main properties considered for the gap analysis and values for the screened ports are presented in Table 13.

It is noted that the Distance to OWF property quickly distinguishes viable candidate ports from those that are not. As it can be seen in Figure 15, all ports located north of Sri Lanka present excessive distances to the OWF and are automatically eliminated from the selection.

Port	Tuticorin Port	Chennai Port	Ennore Port	Karaikal Port	Vizhinjam Port	Kochi DP World Terminal
Properties	Est. value	Est. value	Est. value	Est. value	Est. value	Est. value
Distance to OWF	100-120 km	>1000 km	>1000 km	500-700 km	125 km	350 km
Depth at channel entrance	15 m	18.6-19.2 m	16.0 m	14.5-15.5 m	18.0-20.0 m	16.5 m
Harbour entrance width	150 m	240-410 m	250 m	150-200 m	300-400 m	300 m
Presence of lock/gate	Not present	Not present	Not present	Not present	Not present	Not present
Vertical clearance	No restriction	No restriction	No restriction	No restriction	No restriction	No restriction
Berth length	140-370 m	130-380 m	240-260 m	220-360 m	400 m x 5	600
Depth at berth	9.3-14.2 m	8.5-16.5 m	16-18.5 m	11-15.5 m	16 m	16.5 m
Yard area	55-870 ha	70 – 240 ha	1100 ha	240 ha	96 ha	40 ha

Table 13: Port screening for Tamil Nadu OWF areas

Advantages and disadvantages of the three candidate ports are presented in Table 14.

Port	Advantages	Disadvantages
Tuticorin Port	• Meets most of the key requirements. • General cargo terminals already present in port as well as coal berths without fixed loaders. • Presents sufficient yard area to serve initial project. • Ambitious expansion plans that could come online to satisfy long term development of OW.	• Breakwater gap seems narrow for WTIV carrying longer blades across the deck. Confirm viability of the port and planned breakwater gap widening. • If not possible, an option would be feeder model or expansion. • All berths have an occupancy greater than 50%. • Sufficient area to serve various projects if needed but requires transit between areas (Approx. 1.5km).
Vizhinjam Port	• Meets all requirements in terms of navigation, distance, and yard. • Offers a very versatile plan able to accommodate any scope of operations.	• Port currently under construction. Completion date is unknown. • Port planned as container terminal. • Unknown estimated capacity when finished.
Kochi DP World Terminal	• Meets most of the key requirements.	• Container terminal seems to have high occupancy and might not be able to accommodate OW activities. • Would require dredging if expansion needed. • Distance to OWF is way higher than for the two other ports. • Located in a channel with a lot of traffic.

Table 14: Advantages and disadvantages of screened ports for Tamil Nadu OWZ.

Considering the points given in Table 14, the two ports which present better conditions to serve as installation ports are:

Tuticorin Port. The port checks off all location and access criteria if the breakwater gap is sufficiently wide to accommodate WTIV carrying blades across the deck. The port may require upgrades and expansion of the berths.

Vizhinjam Port. The port is currently in construction and expected occupancy is unknown and may not be ready to serve the initial projects in the desired time frame. However, the port may be able to serve the planned OWF development goal of 30 GW if a dedicated berth and hinterlands can be developed.

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9.2.2. Gujarat Coast OWZs

Main properties considered for the gap analysis and values for the screened ports are presented in Table 15.

Port	Hazira Port	Pipavav Port	Porbandar Port	Mundra Port
Properties	Est. value	Est. value	Est. value	Est. value
Distance to OWF	90-110 km	30-40 km	270 km	470 km
Depth at channel entrance	15.0 m	14.5 m	12.5-13.7 m	17.5 m
Harbour entrance width	470 m	350 m	1000 m	500 m
Presence of lock/gate	Not present	Not present	Not present	Not present
Vertical clearance	No restriction	No restriction	No restriction	No restriction
Berth length	720 m	340-735 m	101-385 m	2000 m
Depth at berth	13-14 m	12-14.5 m	3.0-9.8 m	11.0-14.0 m
Yard area	>35 hectares	630 hectares	24 hectares	~160 hectares

Table 15: Port screening for Gujarat coast OWF areas

Advantages and disadvantages of the candidate ports are presented in Table 16.

Port	Advantages	Disadvantages
Hazira Port	• Meets most of the key requirements in terms of navigation. • Has brownfield areas which could be converted into new terminal or yard area within port footprint (less permits and reduced time for upgrades expected).	• Petrochemical industry in port might impose safety restrictions which could undermine terminal development towards western side. • Terminal development towards east side may require a more complicated quay layout.
Pipavav Port	• Meets all requirements in terms of navigation and distance. • Plenty of space for setting a new yard area. • Has already presented interest in OW Industry.	• Currently does not present adequate berth layout to serve loadout activities. • Quay access bridges are 10m wide. • May require major upgrades to set a loadout area in existing terminals and using part of the container terminal. • May require major dredging if new terminal needs are to be developed.
Porbandar Port	• Good conditions for navigation and load capacity. • Expansion plans include hinterland areas which present enough space for storage of WTG components.	• Does not present sufficient depth at berth to accommodate high end vessels. • Loadout area is reduced. • Transit between loadout area and storage area along breakwater.
Mundra Port	• Presents good navigation and berth conditions. • Enough space for setting a new yard area if required.	• Container terminal might have 100% occupancy and not ready to be used which would imply construction of new terminal. • Located almost 500km from OWF.

Table 16: Advantages and disadvantages of screened ports for Gujarat OWZ

Considering the points given in Table 16, the two ports which present better conditions to serve as installation ports are:

- Hazira Port. The port is ready to serve the initial OW projects if container terminal can be shared. The port presents sufficient area for expansion without major interventions.
- Pipavav Port. The port is located very close to OWF. The port requires upgrades which could be major but has already shown interest in participating in OW Industry.
- The selected ports agree with the conclusions from the FOWIND study.

10. Detailed port analysis

The ports that have been outlined as best candidates based on the gap analysis are analysed in more detail. An analysis has been prepared based on an expanded desktop study, site visits and documents received from relevant authorities.

For each candidate port, available berths are checked for capability to serve OW installation with presently available facilities. Depending on the findings, a high-level terminal planning exercise is presented to show a functioning terminal for OW installation. Where relevant, conceptual level plans have been prepared with an assessment of costs and schedule to complete the suggested improvements.

Cost information provided herein is based on industry standard practice for cost estimating and falls between Concept Screening level (Class 5) and Study/Feasibility level (Class 4) as defined by AACE International. This gives an accuracy range of ±50%. An assumed exchange rate of 1 million USD equals 8.3 crore INR (As of October 2022) is used for development of all cost data provided herein.

10.1. Tuticorin Port (V.O. Chidambaranar Port)

V.O. Chidambaranar Port, referred to herein as Tuticorin Port, is located in the Gulf of Mannar in the south-eastern coast of India, with Sri Lanka on the southeast and the Indian subcontinent to the north and west, see Figure 17. The port is well sheltered from storms and cyclonic winds by a rubble mound breakwater and is operational throughout the year. The port authority, V.O. Chidambaranar Port Authority (VOCPA), is constituted by the Central Government and controlled by the Ministry of Ports, Shipping and Waterways. The main port activities are import of general dry and breakbulk cargo (fertilizer, finished raw materials) and export of dry cargo, general breakbulk cargo, and liquid-bulk cargo.

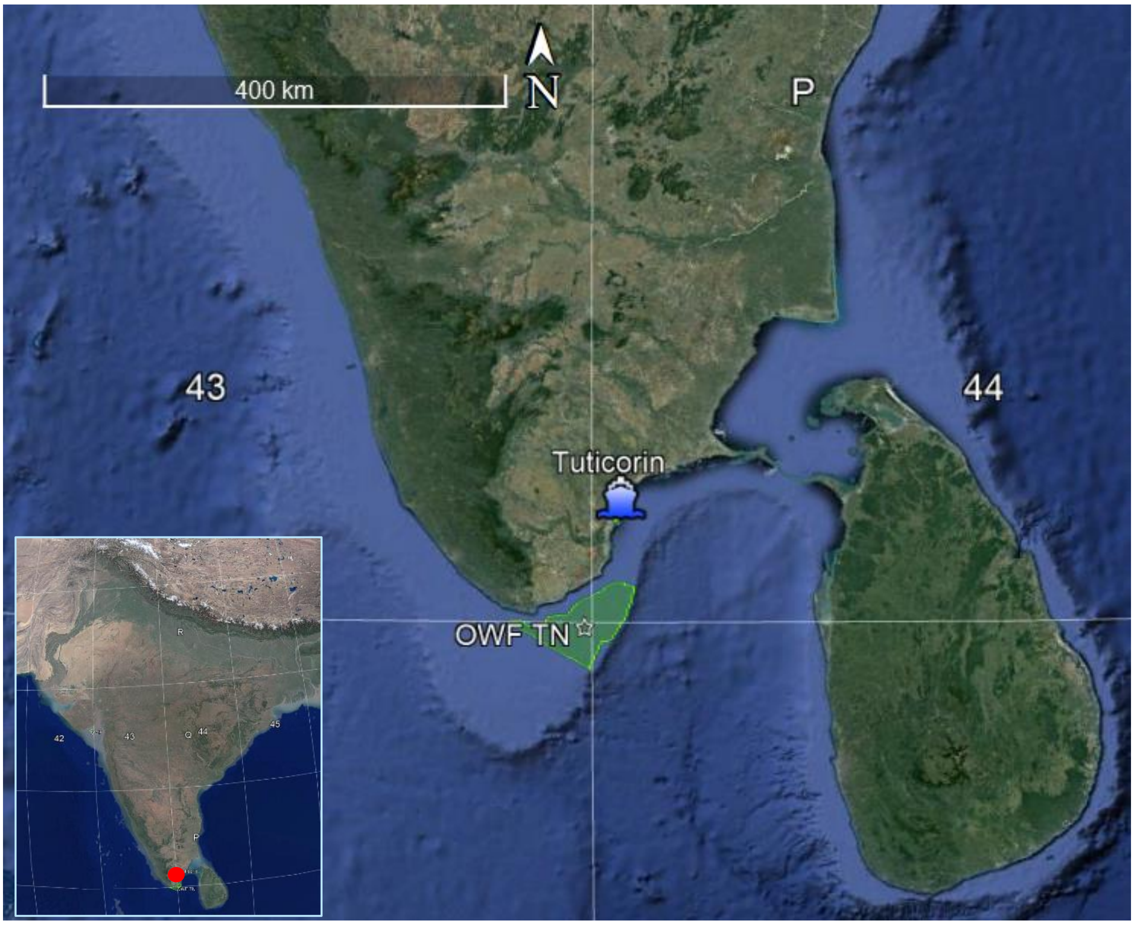

Figure 17: Port of Tuticorin location

10.1.1. Navigational characteristics

The navigational characteristics are presented in Table 22..

.Property	Unit	Value
Distance to OWF	[km]	100-120
Harbour entrance width	[m]	153[2]
Access channel width	[m]	230
Presence of lock/gate	[y/n]	No
Harbour basin depth CD	[m]	~ -10.5 to -14.5[3]
Channel depth	[m]	14.7[3]
Vertical clearance	[m]	Unrestricted
Turning circle diameter	[m]	488
Turning circle water depth CD	[m]	-14.5
Tidal range	[m]	~1
Lowest Low Water Level (LLWL)	[m]	+0.11
Mean Sea Level (MSL)	[m]	+0.64
Highest High-Water Level (HHWL)	[m]	+1.26

Table 17: Tuticorin Port – Navigational characteristics.

10.1.2. Infrastructure access

Infrastructure access to port is presented in Table 18.

Infrastructure	Value
Road access	NH 45; NH 7; VOC Road (SH 200) –major road
Railway access	Presently a single track (broad gauge) line from Milavattan Railway
Close Airports	Tuticorin Airport

Table 18: Tuticorin Port – infrastructure access

10.1.3. Existing terminals, berths and yards

Port layout is presented in Figure 18. Berths use and characteristics are given in **Fejl! Henvisningskilde ikke fundet.**. Yard properties are given in Table 19.

[2] Navigable width of harbour entrance is currently under expansion for up to ~ 230m and proposed to be completed by December 2022.
[3] Phase wise developments indicate that there are long term plans to deepen the harbour basin up to ~16m CD and the channel up to ~17.4m CD.

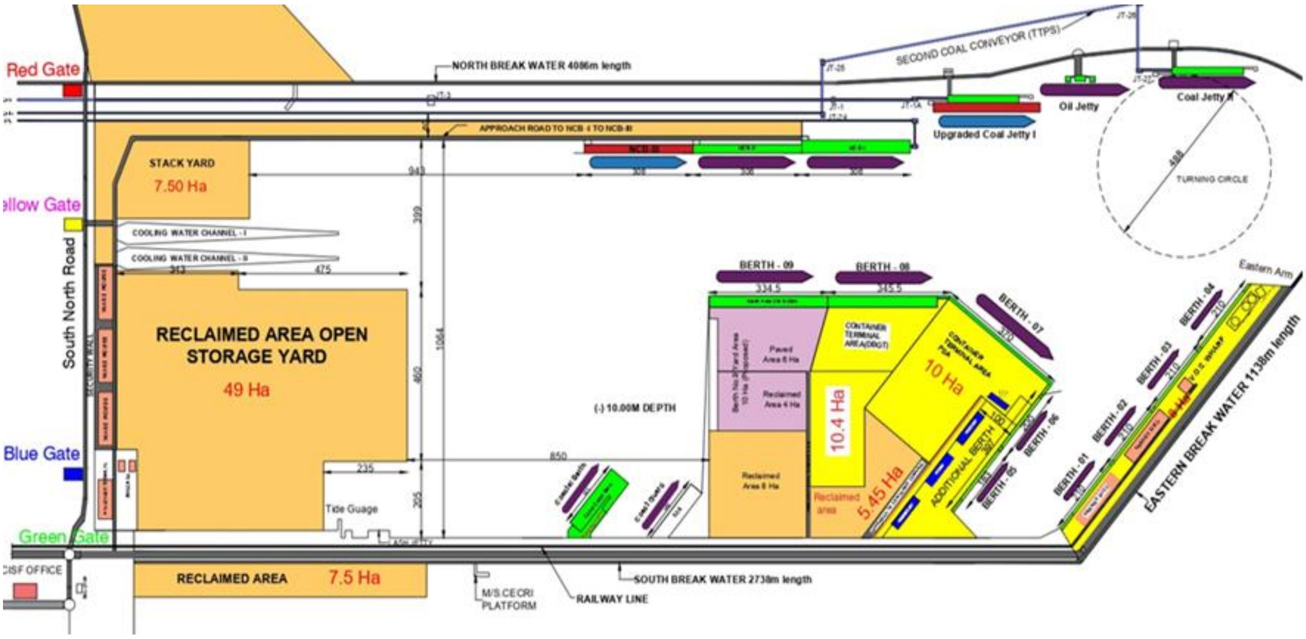

Figure 18: Tuticorin Port – Layout of existing harbour basin and terminals

Yard	Use	Area [ha]	Access	Capacity [t/m²]
No.1	Stack yard	7.5	Road	5
No.2	Reclaimed area open storage	49	Road	5
No.3	Reclaimed area	7.5	Road	5
No.4	Reclaimed area	6	Road	5
No.5	Reclaimed area	4	Road	5
No.6	Paved area	6	Sea	5
No.7	Container terminal	10.4	Sea	5
No.8	Container terminal	10	Sea	5
No.9	Reclaimed area	5.45	Road / Sea	5
No.10	Cargo area	8	Eastern break water	7.5

Table 19: Tuticorin Port – berth and yard characteristics
see Figure 19

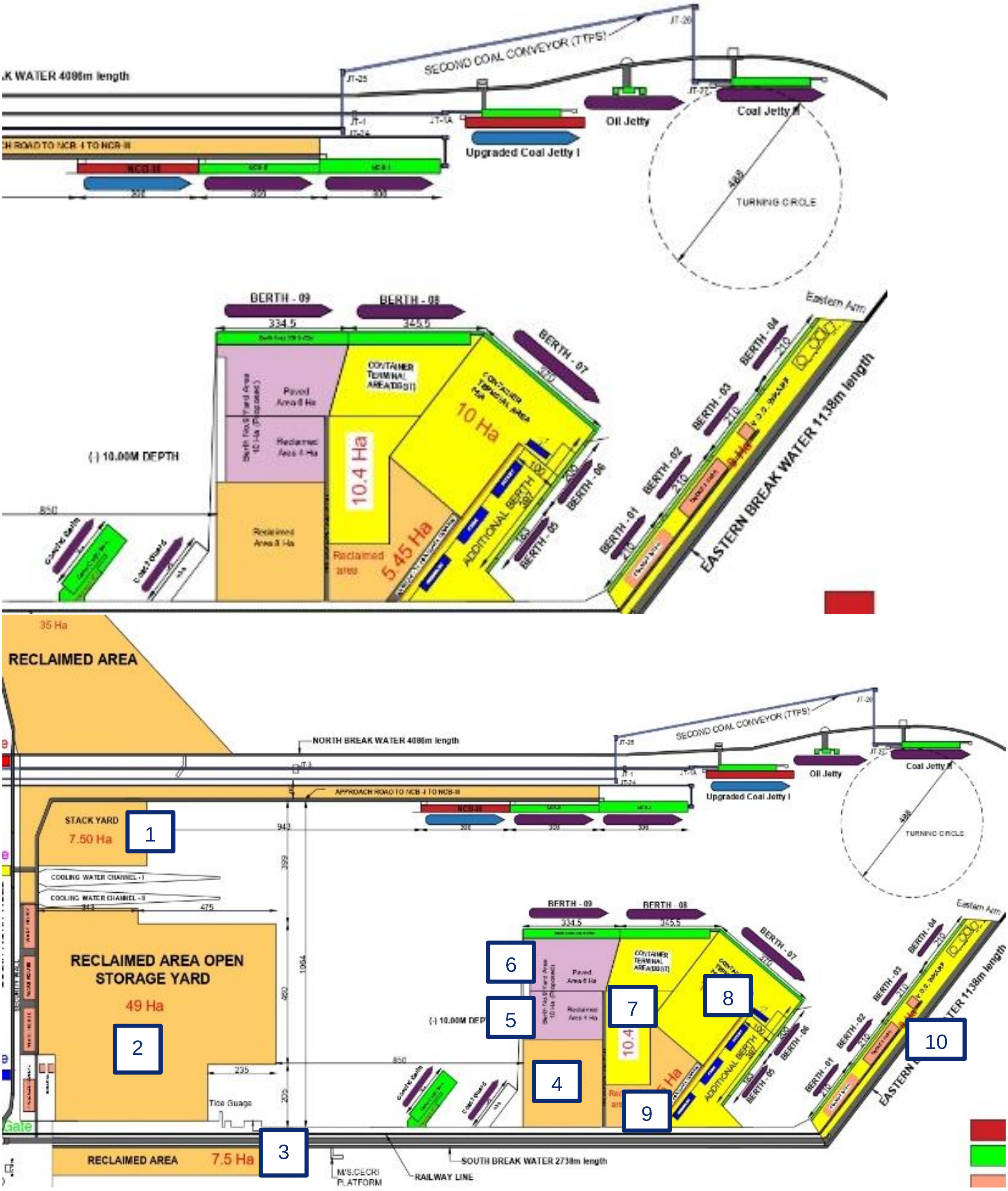

Figure 19: Tuticorin Port – Plan of existing berths and yards. Numbers given refer to yard areas as noted in Table 19.

Berth	Use	Structure Type	Length [m]	Depth [m]	Capacity [t/m²]
No.1	General cargo	Block wall[4]	168	9.3	7.5
No.2		Block wall	168	9.3	7.5
No.3	General cargo	Block wall	192	10.7	7.5
No.4		Block wall	192	10.7	7.5
No.5	Additional berths	Piled deck[5]	168	8.6	5
No.6		Piled deck	168	9.3	5
No.7	Container	Piled deck	370	11.7	5
No.8		Piled deck	345.5	14.2	5
No.9	General cargo	Piled deck	334.5	14.2	5
No.10	Construction materials	Piled deck	185	9.0	5
No.11	Thermal coal	Piled deck	306	14.0	5
No.12	Thermal coal (NTPL)	Piled deck	306	14.0	5
No.13	Thermal coal (TNEB-TANGEDCO)	Piled deck	185	12.8	5
No.14	Oil and gas	Piled deck	150	13.0	5
No.15	Thermal coal (TNEB-TANGEDCO)	Piled deck	318	13.0	5
No.16	Coast guard	Piled deck	145	5.0	5
No.17	Coast guard	Piled deck	145	5.0	5

Table 20: Tuticorin Port – Berths characteristics

[4] Block wall is a gravity-type quay wall that consists of plain concrete blocks stacked on top of each other. Blocks are typically 2-2.5m high and up to 10m long.

[5] Piled deck or suspended deck is an open berth structure where concrete plate on girders is supported by free-standing piles. Below the deck, there is usually a revetment (armoured slope) that leads from design basin depth to the level closer to the soffit of the deck at its back.

The waterfront is calm, with no record of cyclones. The operational tidal window is all day – 24 hours. A small patch of mangroves is located in the nearby creek; however, it is understood from discussion with the port authorities that this is not expected to present a constraint for environmental clearance. No rivers or streams outlet directly in the harbour, therefore no major siltation occurs in either the harbour basin nor the approach channel and hence, no major maintenance dredging is required. The general geotechnical conditions are characterized by hard rock, predominantly calcareous sandstone, which extend from 3-4 m below the ground surface to a depth of 15-20 m.

10.1.4. Tuticorin Port masterplan

The port authority has defined clear goals for the future development of the port of Tuticorin. The future development is shown in Figure 20, and can be divided in phases:

- **Phase I:** Conversion of Berth 9 into container berth & dredging at NCB-III to handle -14.20m CD draught vessels. In discussion with the port authorities, it was noted that this work is expected to begin in the immediate future and expected completion by 2024.
- **Phase II:** Conversion of Berths 1 through 4 maybe repurposed as Container Terminal and deepening the draught up to -15.50 m CD draught. The port authorities expect this work to be complete by 2027.
- **Phase III:** Additional two Container Terminals in the proposed Outer Harbour, of berthing length 1000m and dredge depth of -16m CD. The port authorities expect this work to be complete by 2027.
- **Phase IV:** Strengthening of Berths V & VI as General Cargo berth by deepening the draught up to -15.50m CD & Berth X as multipurpose berth with a dredge depth of -14.20m CD. The port authorities expect this work to be complete by 2027.

Port authorities have also indicated that they are currently planning to remove all coal storage from the existing coal storage yard at the north-west end of existing basin as part of Phase 1.

Regarding the expansion of the port with outer basin, it is understood that port authorities are already in discussion with potential partners for development as public-private partnership model.

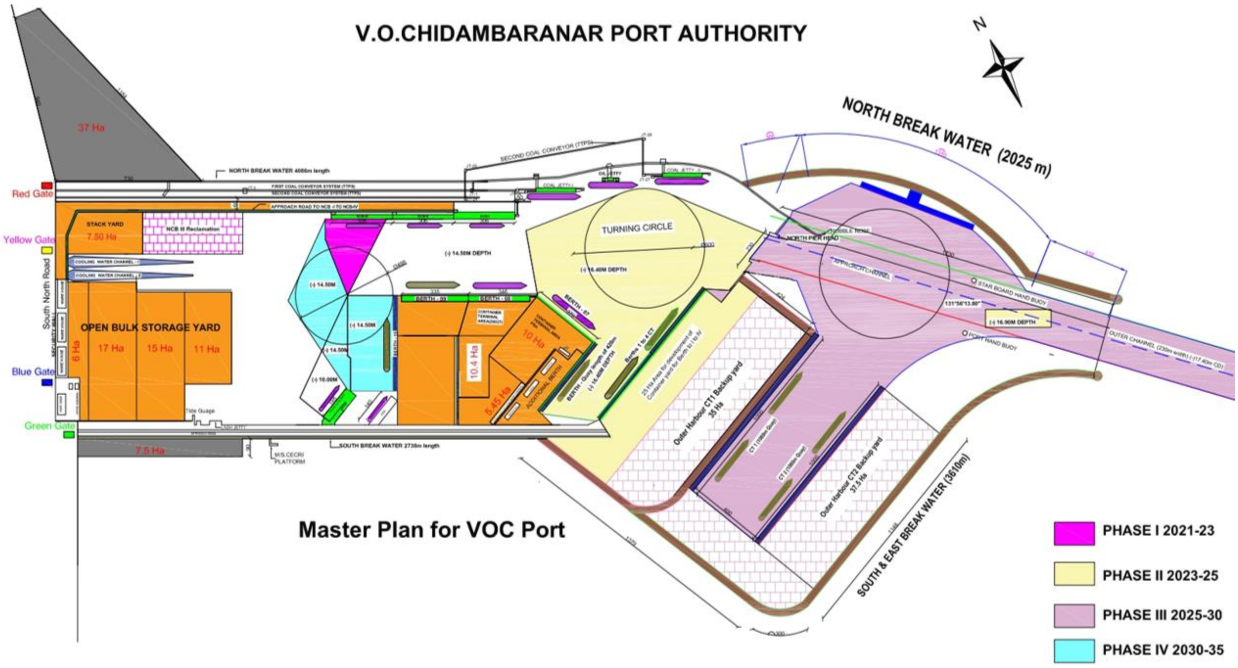

Figure 20: Tuticorin Port – Proposed development masterplan
Future development of both inner and out harbour shown.

10.1.5. Tuticorin Port suggested expansion for OW installation

From discussion with port authorities and review of the port masterplan it is clear that there are multiple opportunities to accommodate staging and installation of components in both short and long term. Although the port is already working with shipping of components for on-shore wind turbines, catering to OW is not a part of the current masterplan. However, discussion with port authorities indicate that it could easily be accommodated without hindering port's pursuit to expand current cargo operations. Three conceptual OW developments are presented here as alternatives to accomplish this.

10.1.6. Tuticorin Port conceptual OW expansion – Alternative 1

Figure 21 illustrates the possibility of developing the berths adjacent to Berth 9 (Berths 10,11). It was understood that the present coal operations carried out on Berth 9 will be phased out in one year and Berth 9 will continue to function as a container berth. Also, this is compatible with port development and would just assume pushing forward with Phases 3 and 4 of present plan for port expansion (see previous section).

Two new berths are developed along a present-day revetment with deepening of the basin to -12 m (or full depth envisioned by phase IV of masterplan). Yard is combined from the areas not currently occupied with container cargo. As the current level of operations on Berths 7 and 8 is 50% it stands to reason that the existing 20 ha container yard could be sufficient.

The available laydown area of 22 ha of this development alternative is on the smaller side; however, it could be further extended by storing blades offsite, for example at berths 1-4.

Figure 21: Tuticorin Port – OW Terminal Alternative 1
Future general cargo terminal suitable for OW installation adjacent to Berths 5-9

10.1.7. Tuticorin Port conceptual OW expansion – Alternative 2A

Figure 22 shows a similar alternative where an OW terminal is established at the place of existing coal yard. This is not entirely in line with existing port masterplan which does not assume dredging and creation of the berths at this corner. However, current masterplan does not consider OW and it is considered that outlining such solution here is not at odds with the masterplan but presents additional options that could also be recycled and applied at any expansion footprint as it is in essence a green field exercise with few constraints. On the other hand, it does not depend on construction of new breakwater and does not compete with other port operations.

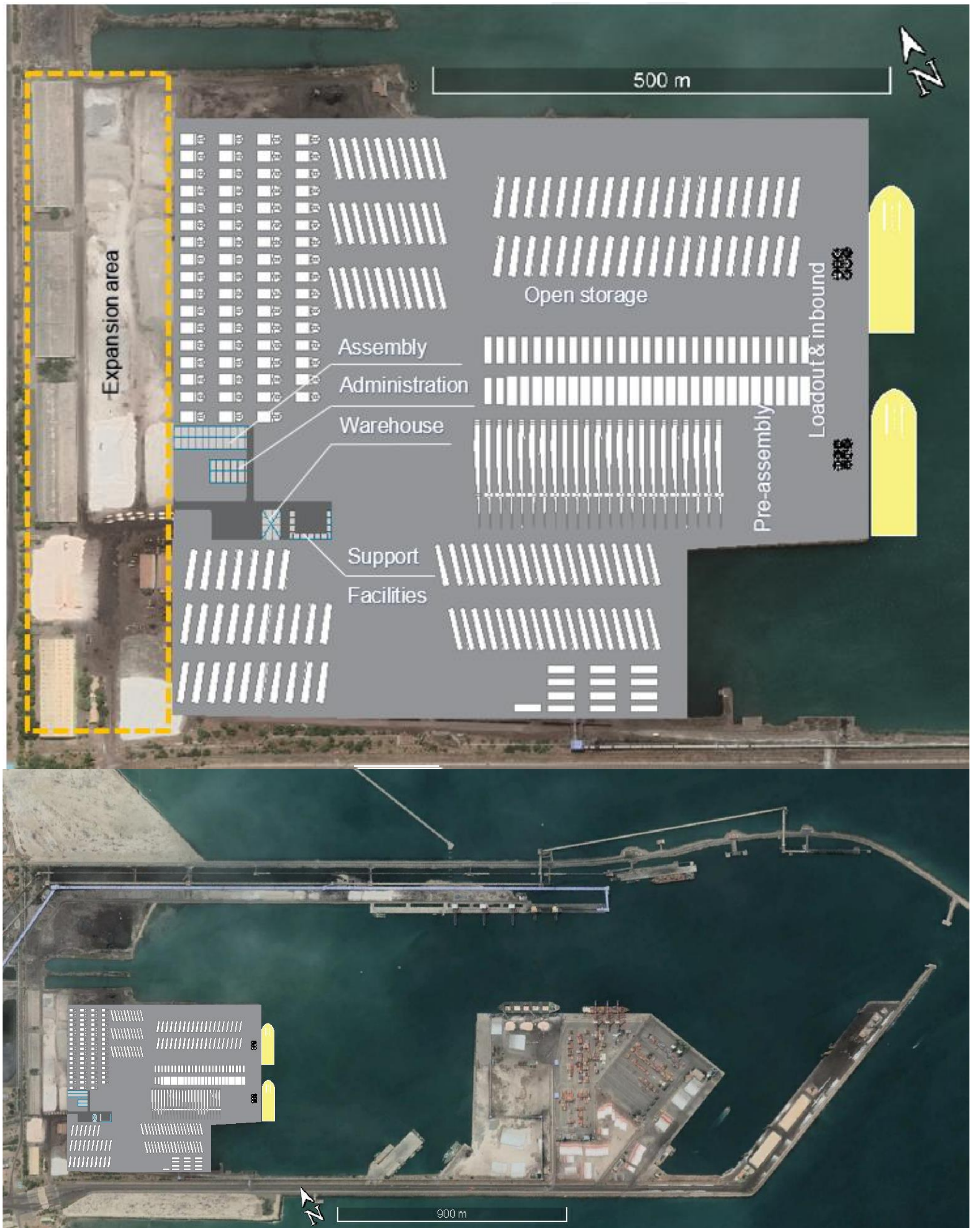

Figure 22: Tuticorin Port – OW Terminal Alternative 2A
Future general cargo terminal suitable for OW installation in place of current coal storage yard.

Benefit of such a terminal is that it allows for a larger laydown area, with sufficient size to stage all WTGs for a 1 GW project. Further reasons why this could be a more robust long-term option include:

- Area is not close to other competing port operations.
- Multiple berths, up to four, with a total berth length of approximately 900 m.
- Yard has a total potential area of 50 ha which allows for:
  - Phased development, where area in the back of the yard can be used for storage of other cargo.
  - Added versatility, where additional berth can be developed along the northern edge and Ro-Ro berth at the southern corner.
  - The possibility of simultaneous staging of foundations along with turbines. Although installation of foundations and turbines is sequential, due to long lead times and transport distances, contractors and OEMs can prefer to have these operations run partially parallel.
  - Multiple projects done by multiple developers / contractors. To avoid congestion between in-bound and out-bound loading operations, other berths (1-4) can be used for import of components such as blades and tower segments.

10.1.8. Tuticorin Port conceptual OW expansion – Alternative 2B

Another possible use of the terminal is the staging of foundations (jackets or monopiles and transition pieces). This stage precedes installation of turbines so it would be possible to use the terminal for both purposes for a single project.

If the same terminal should be considered for staging of the foundations, the yard area should be further expanded. Although it could be possible to complete foundation and turbine installation from the same yard, these operations can in reality often overlap. Also staging delivery and storage of both foundations and components takes time where in-bound and out-bound operations can easily run into a bottle neck and result in a delay of delivery. Also, staging of foundations requires cradles (with foundations) or soil embankments which, although can be temporary construction, will also take time to construct.

Figure 23 illustrates a larger terminal that can function as two independent terminals. Terminal on the left serves for staging turbines and terminal on the right for staging of foundations.

Figure 23: Tuticorin Port – OW Terminal Alternative 2B
Two separate terminals with 4 berths. Setup allows for easy adaptation of areas and use of berths depending on specific project and agreement with tenants – Tuticorin port

To meet India's offshore wind goals, most of which lies within the Tamil Nadu OWZ, multiple terminals with sizes as shown above (3-5) would operate year-round for approximately 6-7 years.

10.1.9. Tuticorin Port as an offshore wind hub

Finally, opportunities for the port to attract OW-related operations should also be seen with development of new breakwater and outer harbour, see Figure 20 and Figure 24. It is understood that gradual expansion of container cargo planned in phases 1 and 2 is designed as a segway for development of the new harbour in partnership with an established operator. Development of the outer basin will in time free up berths 1-9 and the yard in-between. Available areas and continuous pipeline in vicinity could spark development of Tuticorin as a hub for offshore wind which combines manufacture of components or foundations with multi-purpose terminals that could be used for export of components and installation.

Figure 24: Tuticorin Port – OW Terminal Vision
Inner harbour transformed to OW hub (doubling for project cargo, break bulk, etc) with outer harbour focused on container traffic – Tuticorin port.

Each of these high-level planning exercises described herein represents a potentially cumulative and overlapping steps that can be reconstituted in dialogue with prospective lessees.

10.1.10. Indicative assessment of construction

The purpose of this section is to give an indication of cost and length of development for the variant shown on Figure 22 (Alternative 2A). Construction works are described below in an approximate sequence of execution (shown by numbers) and illustrated with figrues (Figure 25 through Figure 27). It should be noted that comprehensive site investigation works (land and sea-bed) as well as other supporting studies and assessments would need to be carried out prior to design and construction. The descriptions are given only given as a high-level overview of major civil works.

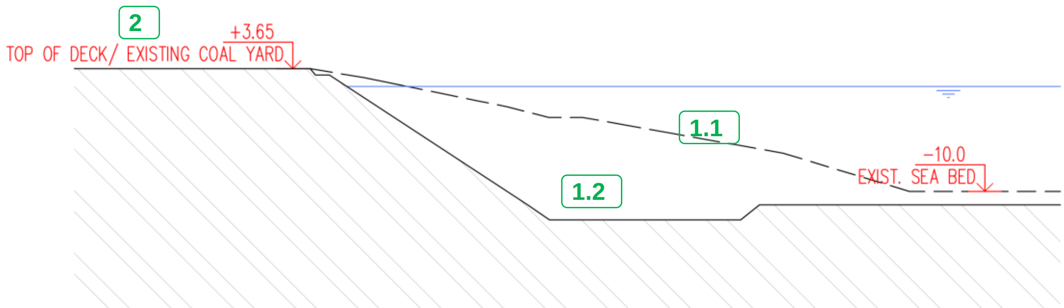

Figure 25: Tuticorin Port – Proposed sequence of works-1

[Steps 1.1-1.2] Dredging:

Dredging shall be carried out in the inner harbour to required depth of (-)12 m CD, for an area of approximately 35 ha in the basin of the existing coal stockyard. This gives an overall dredging volume of approximately 1.5 million m^3. Since the native soil is rocky in nature, cutter suction dredgers are likely to required.

At positions where jacking-up of WTIV is planned, a deeper trench is dug-out for forming of stone-beds that prevent the penetration of the foundation soil and to create a uniform and unyielding bearing surface for the jack-up WTIV vessels.

[Step 2] Yard:

The existing yard is already built to support coal stacking so significant reclamation or ground-improvement is not envisaged given that the native soil is rocky in nature. However, some levelling/ grading works may be required and some local strengthening in some specific areas may be required but is not envisaged to be significant.

The berth structure is planned along the eastern edge of the existing coal stockyard for a length of 460m as indicated in the Figure 22.

Considering the existing soil condition, which is predominantly hard rock strata, the berths shall comprise of bored cast-in situ concrete piles with beam connected concrete deck structures. The concrete piled berth should roughly correspond to approximately 5 m by 5 m grid size. [Step 3]

In order to maintain the dredge slope and the existing reclaimed back yard, the yard perimeter along the sea shall consist of suitable retaining structure, preferably in the form of rock revetment under the piled berth. Stone-beds are backfilled with rockfill and finished with a screed layer. Scour protection and revetment armour installed. [Steps 4.1-4.2]

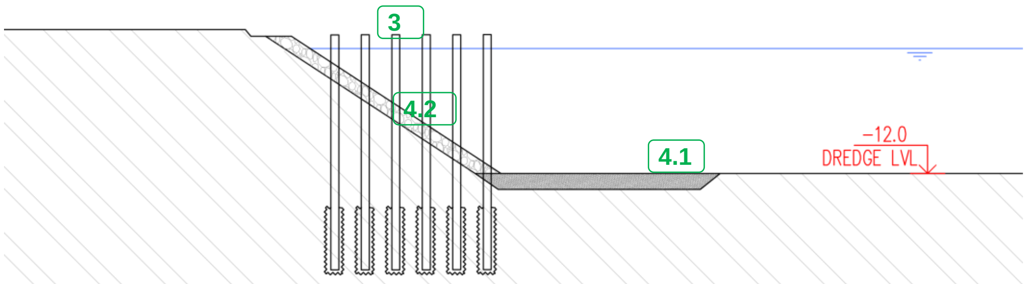

Figure 26: Tuticorin Port – Proposed sequence of works-2

The concrete deck structure shall comprise of in situ cross beams and longitudinal beams connected by deck slab element. The deck top shall be finished to the same level as the existing back up yard (+)3.65 m CD. Shallow founded transition plate is provided along the back edge of the concrete deck. [Steps 5 to 8]

- Quay furniture: (Assume no special aids to navigation etc are required)
  a) Fenders
  b) Cast iron bollards
  c) Safety ladders
  d) Rubbing strip for edge protection

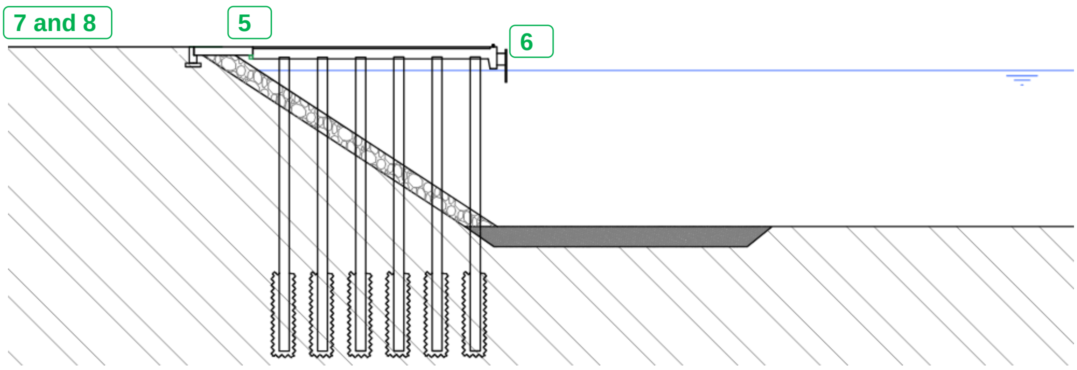

Figure 27: Tuticorin Port – Proposed sequence of works-3

- Buildings, fencing, gates, utilities, and internal roads
- Electrical works
- Cabling and substations
- Light masts are installed on pad foundations

10.1.11. Cost estimate

An indicative cost estimate is shown in Table 21. Costs have been calculated for the development according to the assumptions of various work descriptions given in section 10.1.10.

Construction	Cost [INR crore]	Cost [mill USD]
Dredging and shore protection	179	22
Grading and levelling of the existing back yard	9	1
Suspended deck construction	266	32
Quay furniture	8	1
Lighting and electrical works	6	1
Buildings, parking and fencing	14	2
Mobilization & demobilization (8%)	52	6
Engineering and project management (5%)	32	4
Total estimated for development new berth	**732**	**89**

Table 21: Tuticorin Port – Indicative cost estimate of OW terminal development
Note: Following works/items have not been included in cost estimate: drainage, sewage, water utilities, equipment and vessels.

10.1.12. Estimated duration

Indicative duration of the works is shown on Figure 28. The diagram only includes major works which form the critical path.

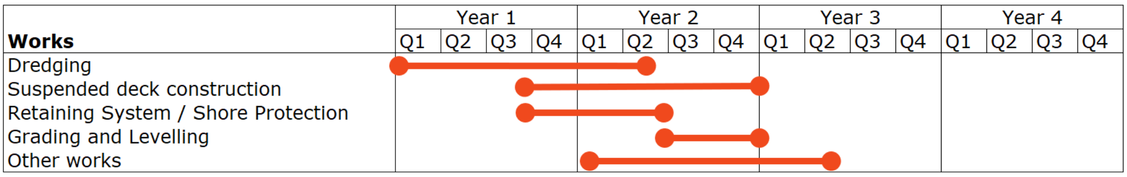

Figure 28: Tuticorin Port – Indicative duration of works

Rock dredging is anticipated to take around 18 months (based on the feedback from Port Authorities). This time may be both longer and shorter depending on the method used (underwater blasting or suction-cutter dredger). Construction of the pile supported quay deck is anticipated to require a duration of about 15 months and comprises of the following main stages; installation of piles, placement of rock revetment (retaining structure) and casting/construction of the reinforced concrete deck. With respect to the piling works and given the information that the port does not have any downtime due to cyclones, this period considers driving of piles inside predrilled rock strata and a minimum of two pile driving rigs will be mobilized simultaneously. Revetment placement would closely follow pile installation. Total construction for refitting of the terminal is expected to be around 30 months.

Grading and levelling works are minimal at the current yard with no significant reclamation or ground improvement required and the yard is assumed to be suitable to carry the higher stacking loads required to support OWF installation. Works have been assumed to be staggered with minimal delay to produced shortest time overall.

The indicative duration only represents purely production and construction times and does not consider time for engineering design, obtaining approvals from government authorities, tender and award of construction contracts, or delays due to vessel traffic and commercial operations.

10.2. Vizhinjam Port

Vizhinjam International Deepwater Multipurpose Seaport, herein referred as Vizhinjam Port is located at Vizhinjam (Lat 8° 22' N, Long 76° 57' E), in the state of Kerala, approximately 16 km south of the State Capital, Thiruvananthapuram, which falls in close proximity to the international East-West shipping route. See Figure 29. The port is being developed as transhipment port protected by rubble mound breakwater. The port is designed primarily to cater to the container transhipment business and is being developed in Public Private Partnership (PPP) model with the private partner – Adani Vizhinjam Port Private Limited (AVVPL) on a Design, Build, Finance, Operate and Transfer (DBFOT) basis.

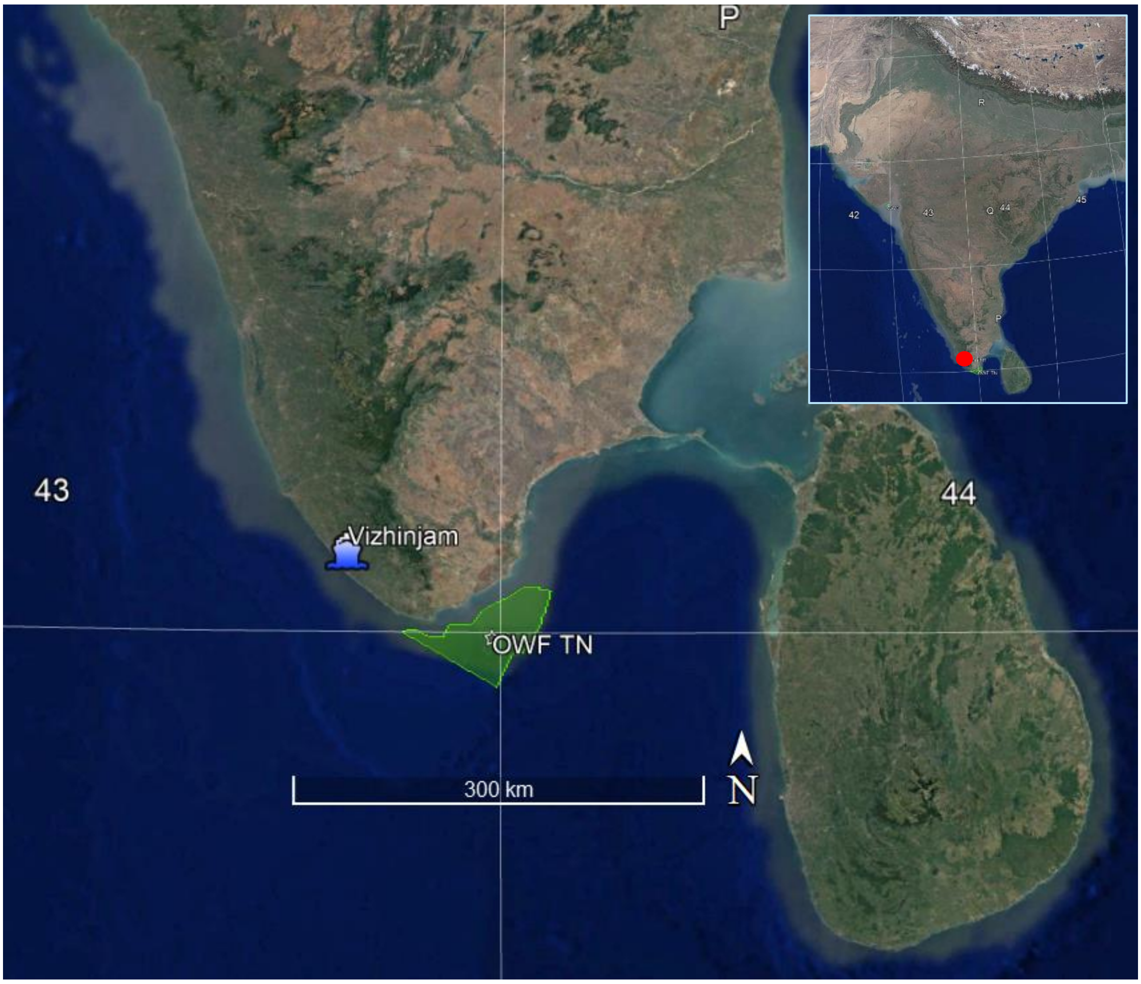

Figure 29: Vizhinjam Port location

10.2.1. Navigational characteristics

The navigational characteristics are presented in Table 22.

Property	Unit	Value
Distance to OWF	[km]	125
Harbour entrance width	[m]	300
Access channel width	[m]	400
Presence of lock/gate	[y/n]	No
Harbour basin depth	[mCD]	-18.4
Navigation channel depth	[mCD]	-20.8
Vertical clearance	[m]	Unrestricted
Turning circle diameter	[m]	700
HAT	[mCD]	+1.20
LAT	[mCD]	-0.10

Table 22: Vizhinjam Port – Navigational characteristics.

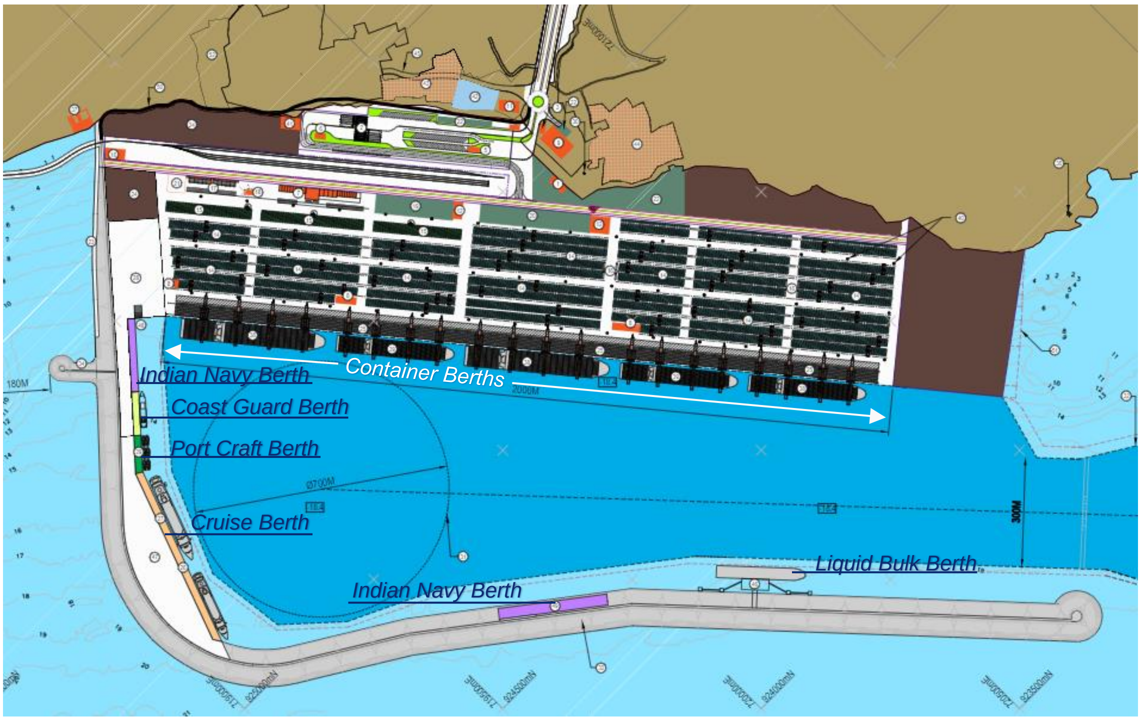

Figure 30: Vizhinjam Port – Proposed final buildout of port master plan Integrated Port Master Plan Report – Final, 2013

10.2.2. Infrastructure access

Infrastructure access to port is presented in Table 23.

Infrastructure	Value
Road access	4 lane port approach road connecting to NH-66
Railway access	Neyyatinkara and Trivandrum central
Close Airports	Trivandrum International Airport

Table 23: Vizhinjam Port – Infrastructure access

10.2.3. Projected terminals, berths, and yards

Vizhinjam Port is presented in Figure 30. The Port is planned to be developed in four phases having a total container berth length of 2,000 m consisting of 800 m in Phase 1, and an additional 400 m each in Phases 2 through 4. The construction of the port originally commenced in 2015 and was planned for completion by the year 2019; however, due to unforeseen circumstances a setback to the port's construction schedule has occurred resulting in the delay in procurement of suitable rock for breakwater construction. Out of the planned 3km long Breakwater, currently 1.4 km has been completed and the remaining portion is scheduled to be completed by the end of Year 2023.

Phases 1 and 2 are shown in Figure 31 and Figure 32 respectively. Per meetings with AVVPL it is understood that Phase 1 is currently scheduled for completion by the end of 2024.

Berths use and characteristics are provided in Table 24 and yard properties in Table 25, more detailed information can be found in "Integrated Port Master Plan Report – Final, 2013".

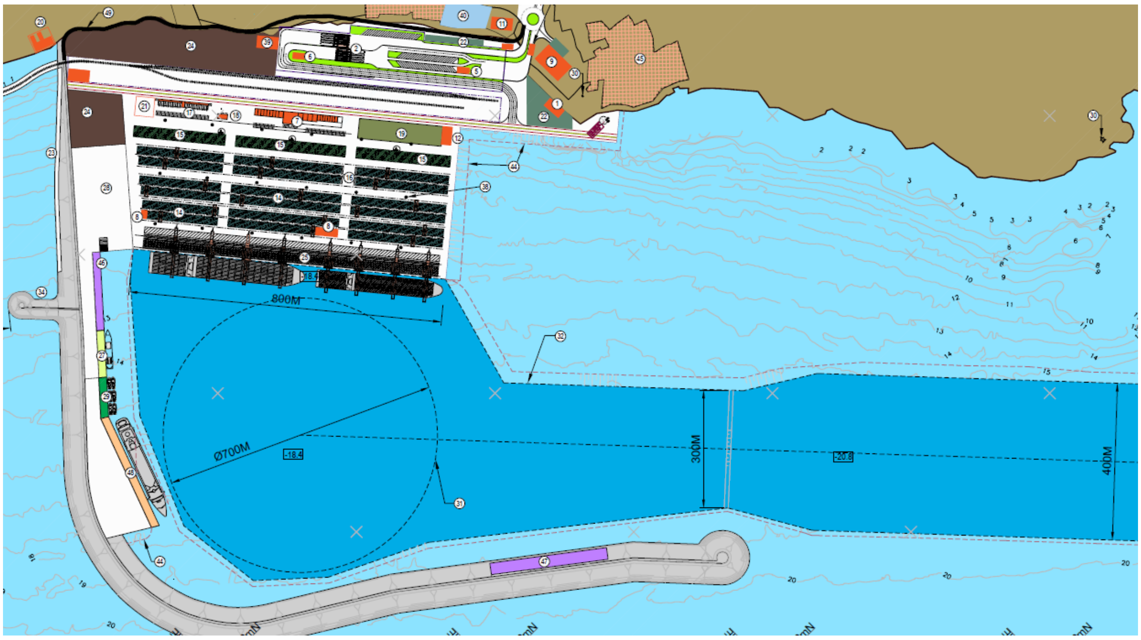

Figure 31: Vizhinjam Port – Phase-I layout
(Ref. Integrated Port Master Plan Report – Final, 2013)

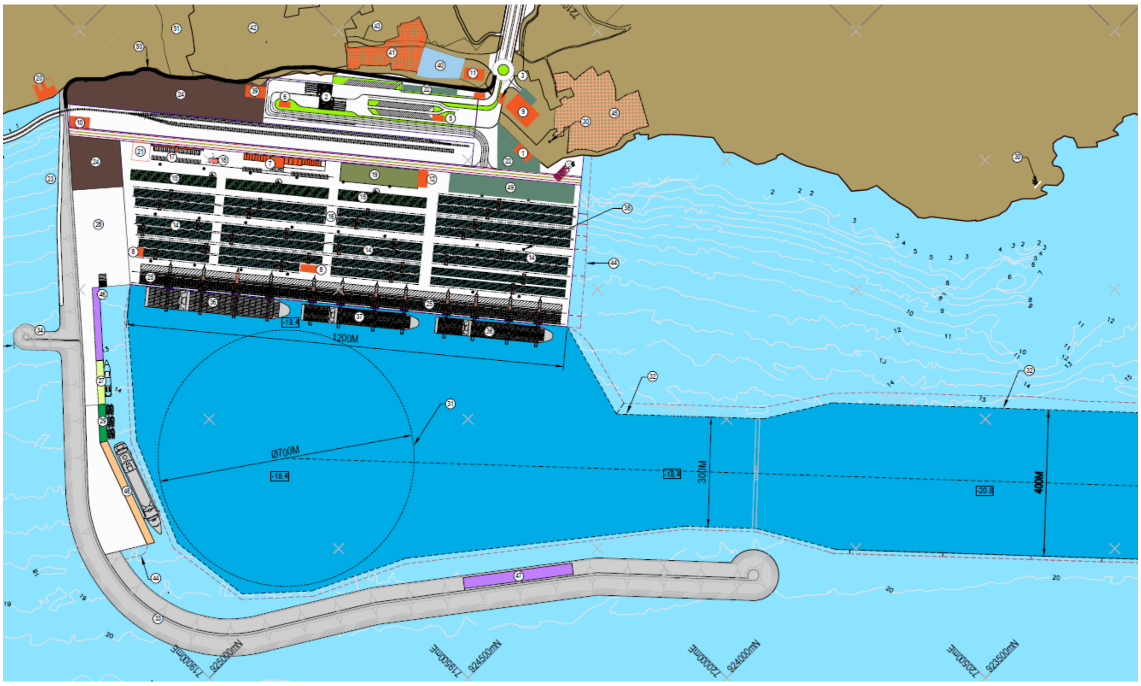

Figure 32: Vizhinjam Port – Phase-II layout
(Source: Integrated Port Master Plan Report – Final, 2013)

Berth	Use	Structure Type	Length [m]	Depth [m CD]	Capacity[6] [kN/m²]
No.1	Container	BCC piles with retaining wall and connecting deck structures	2000	18.4	50
No.2	Indian Navy	Unknown (as it is not yet planned)	200	13	50
No.3	Coast guard		120	14	50
No.4	Port craft		100	15	50
No.5	Cruise		300	17	50
No.6	Indian Navy		300	19	50
No.7	Cruise/ Mulitpurpose		300	18.4	50
No.8			200	18.4	50
No.9	Liquid		250	18	unknown

Table 24: Vizhinjam Port – Berths characteristics.
Refer to Figure 30. Note: that berths Nos. 2 through 8 were initially a part of the EIA; however, were not included in the final AVPPL Concession Agreement.

[6] To be confirmed by the port designer

Yard	Use	Area [ha]	Access	Capacity[4] [kN/m2]
No.1	Container storage	96	Sea	50
No.2	Approved reclamation for container storage	53	Sea	50
No.3	Recently acquired	20	Land	50

Table 25: Vizhinjam Port – Yard characteristics

Geotechnical conditions comprise: The top layer of the soil consists of loose to medium dense sand for about 5-8 m depth. The subsoil is predominantly silty clay/clayey silt only. There are no major traces of hard rock. However, there is presence of weathered rock for about 30-40 m deep below (-) 60 m CD.

10.2.4. Vizhinjam Port masterplan

Currently, the port is at the execution stage and scheduled to be commissioned by December 2024. The port is designed primarily to cater to the container transhipment business and will be competing with international ports like Colombo in Sri Lanka, Salalah in Oman and Singapore for Indian container transhipment traffic. The port is expected to have the berth occupancy of about 60% in the first Phase of the port.

The port master plan includes a proposed rail connection to local rail systems. The proximity of the planned railyard and connection allows for opportunities to handle future multipurpose/bulk cargo for landside transfer.

Further expansion east of rail yard and north of the gate could accommodate bunker fuel storage for bringing in the liquid petroleum products in the port by rail.

In addition to container and mixed cargo, one alternative development of the master plan proposes to construct a cruise terminal in the middle of the port.

10.2.5. Vizhinjam Port suggested OW port improvements

In meetings with AVPPL it was indicated that OW installation is currently not a part of the business plan; however, three alternatives for developing facilities of OW installations were discussed. See Figure 33.

Figure 33: Vizhinjam Port – Potential alternatives for developing OW berth in Vizhinjam port.

Alternative 1: The berths which were earlier proposed to be developed along the breakwater for navy purpose, could be used for OW installation. The approval is valid only for 300 m berth length. Any additional increase in the berth length would require EIA clearance.

This alternative is not considered suitable because of relatively small associated yard area. Due to the nature of onshore operations, the recommended way forward is having berths that are continuously connected to the yard.

Alternative 2: Considers the 800 m-long container terminal, which is currently being constructed. The developer is proposing that OW operations could be carried out from unoccupied berths of this terminal.

This would in theory be possible. However, feasibility cannot be readily estimated. Piles are already constructed for UDL of 50 kN/m2 and the completion of the deck is unknown. Such structure would have to be retrofitted to higher loads (see benchmark). Planning for this during the ongoing construction could be difficult and there is a chance that the structure would stand completed at the time when decisions mature. Also, suspended decks are difficult to retrofit for higher loads once constructed and partial demolition could be needed. Therefore, it is considered that detailed technical analysis associated with feasibility of such solution should be subject to future studies.

Alternative 3: The additional 400 m berth, which is currently planned for the development of Phase-II, could be adapted to the envelope of container operations and staging of WTG components.

For the purpose of this study, this option is considered as most realistic for the purpose of this study and is further developed below.

Proposal shown on Figure 34 also includes elements of Alternative 1 to maximize yard size.

It is assumed that new 450 m long berth is designed to be suitable to all requirements for both container and staging terminal. Apart from higher UDL allowance it also includes foundations for tower pre-assembly packs. On the other hand, it is expected that AVPPL would complete the full dredging to -18.4 m or at least design the structure so that the basin can be deepened later.

Associated yard of 18 ha is however smaller than recommended by the benchmark. However, container yard of the phase 1 could be upgraded for higher load requirements through soil improvement or left as designed for container loads and used for storage of lighter components such as tower segments and blades. If adjacent berths of container terminal are used for in-bound blades and tower components, it would reduce demand on purpose-built berths of the OW terminal which could then accommodate two installation vessels.

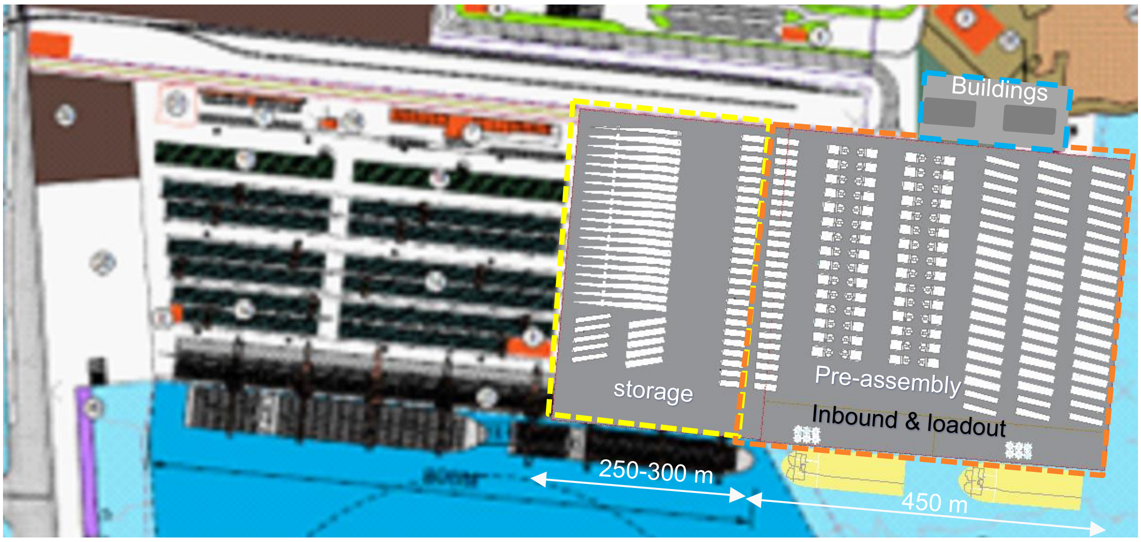

Figure 34: Vizhinjam Port – OW Terminal Alternative 3
Various options discussed for developing OW terminal. Orange dashed line represents exclusive OW Terminal. Yellow dashed line represents container terminal area used for temporary storage of lighter components.

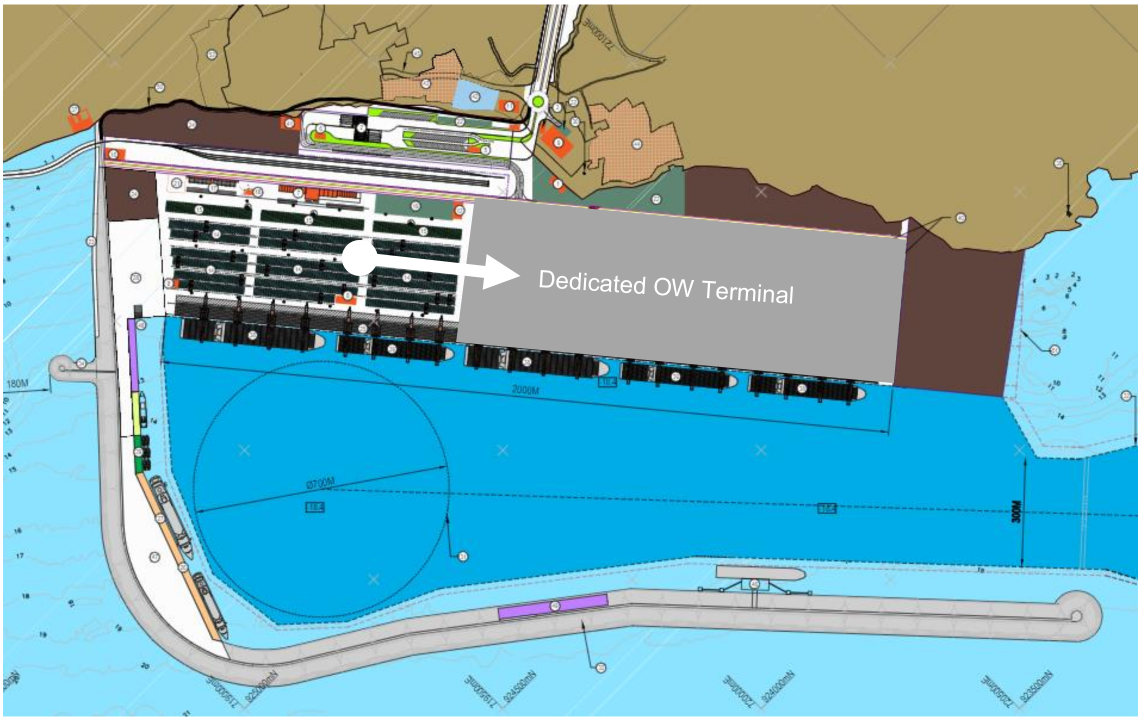

Figure 35: Vizhinjam Port – Future expansion possibilities

As container volume is expected to grow over time at Vizhinjam Port, the port master plan calls for expansion of the terminal in a south-easterly direction, such that beginning with the original Phase 1 development in the northwest, to Phase 2 and ultimately to Phase 3. Container operations would be consolidated on the northwest end while new OW staging facilities would be pushed south-eastwards, developing the port to its full extent. Because of the “envelope” development, there would be increased flexibility for use of areas and AVPPL could address both the primary cargo operations (container) but also compete in for OW installation given that the ambitious pipeline will most likely have several projects done in parallel (see Figure 35).

10.2.6. Indicative assessment of construction works

The purpose of this section is to give an indication of cost and length of development for the variant shown on Figure 34. It should be noted that comprehensive site investigation works (land and sea-bed) as well as other supporting studies and assessments would need to be carried out prior to design and construction.

Construction works are described below in an approximate sequence of execution (shown by numbers) and illustrated with figures. The detailed description of sequence of works including the miscellaneous items required for the berth structure such as quay furniture, buildings and electrical works shall remain the same as described in section 10.2.5 for all port developments. The below descriptions of works (shown in Figure 36 and Figure 37) highlight only the major civil works that exclusively pertain to the development of Vizhinjam port. It should be noted that most of these works have already been identified as part of Phase II development of the container terminal at Vizhinjam and will satisfy the OWF T&I requirements. In principle, only the berth structure needs to be designed for higher loads and maybe the ground improvement in the backup yard needs to be upgraded for the increased bearing capacity requirement.

- Dredging: As the port is planned to dredge the terminal for a final dredge depth of (-)18.4m CD, additional dredging to serve the offshore wind installation works is not envisaged. [Step 1]
- Breakwater: A very small extension (about 100m) is required for the breakwater, as compared to phase-1 length constructed, to shelter the proposed new berth. [Step 2]

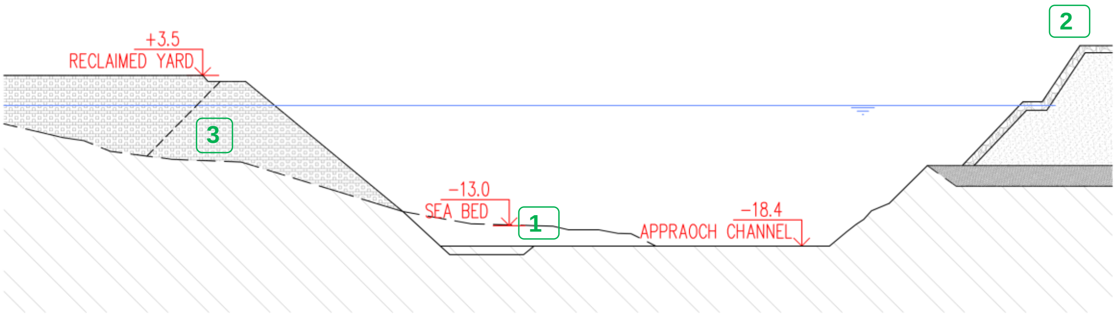

Figure 36: Vizhinjam port – Proposed sequence of works- 1

Yard [Step 3]: Yard area of approx. 450×400 m^2 is reclaimed to the designed level (assumed as ~(+)3.5 to (+)4.2m CD), which is computed for a volume of ~2.2million m^3. For the ground improvement additional loading requirements to be considered to satisfy both container and OWF needs.

The berth structure of 450m is planned, comprising of bored cast-in situ concrete piles. (approximately 5 m by 5 m grid size) with connecting concrete deck structures. This berth can be designed for higher loadings to satisfy both container and OWF requirements. The deck top shall be finished to (+)4.2m CD. [Step 4]

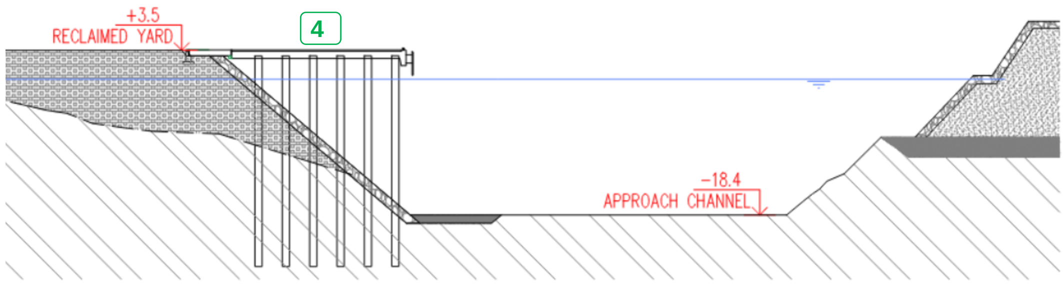

Figure 37: Vizhinjam port – Proposed sequence of works- 2

10.2.7. Cost estimate

An indicative cost estimate is shown in Table 26, which pertains to the requirement of developing the port to serve OW installation works. However, it should be noted that out of the total 88 million

USD estimated in Table 26, VISL has already planned for phase-II development works which is forecasted to share most of the benefits from the development for OW berth. It is envisaged that the additional cost to cater to OWF requirements is approximately 20 million USD which is already included in Table 26.

Construction	Cost [INR crore]	Cost [mill USD]
Dredging, reclamation and shore protection	179	22
Soil improvement	9	1
Suspended deck construction – for container terminal works	266	32
Additional cost for deck construction and associated works to suit OWF requirements	166	20
Quay furniture	8	1
Lighting and electrical works	6	1
Buildings, parking and fencing	14	2
Mobilization & demobilization (8%)	52	6
Engineering and project management (5%)	32	4
Total estimated for development new berth	**732**	**89**

Table 26: Vizhinjam Port – Indicative cost estimate of OW terminal development

Note: Following works/items have not been included in cost estimate: drainage, sewage, water utilities, equipment and vessels.

10.2.8. Estimated duration

Indicative duration of the works is shown on Figure 38 . The diagram only includes major works which form the critical path.

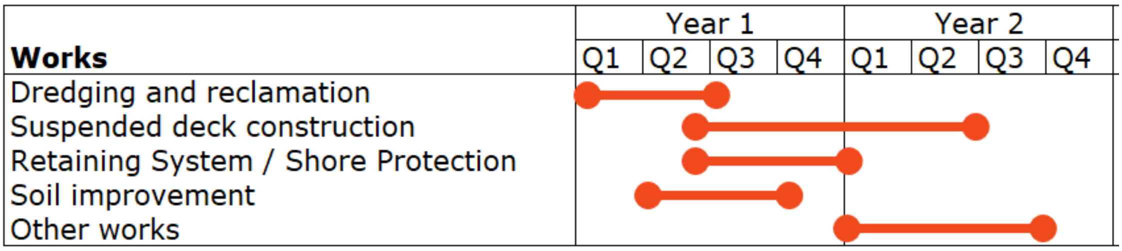

Figure 38: Vizhinjam Port – Indicative duration of works

Vizhinjam Port is at the execution stage and the Breakwater construction works are in progress, which is expected to be completed by the end of Year 2023. Currently, the installation of piles and erection of the beams connecting the piles for the Container Berth in Phase 1 have been completed as indicated in Figure 33 and Phase 1 of the port, as shown in Figure 31, is scheduled to be completed by December 2024.

With respect to the piling works and given the information that the port does not have any downtime due to cyclones, this period considers driving of piles using minimum of two sets of piling equipment being mobilized simultaneously.

Works have been assumed to be staggered with minimal delay to produced shortest time overall. Total construction for refitting the terminal is expected to be around 21 months.

The indicative duration only represents purely production and construction times and does not take time for engineering design, obtaining approvals from government authorities or other necessary steps into account.

10.3. Hazira Port

Hazira Port is located at the southwest of Surat in Gujarat and operates as a multi-product commercial port. The port is part of tri-party agreement between Adani Hazira Port Private Limited (AHPPL) - Gujarat Maritime Board (GMB) – Shell. See Figure 39 for location and Figure 40 for demarcation of area ownership.

The main port activities are:

- Liquid bulk (chemicals, petroleum products and oil)
- Container traffic
- Bulk and break bulk (steel, fertilizer, coal, minerals)
- Liquid Natural Gas (LNG)

Shell operates and maintains the LNG terminal on the northern arm of the breakwater. Adani has full independence on operation and expansion planning of the general port.

Figure 39: Hazira Port location

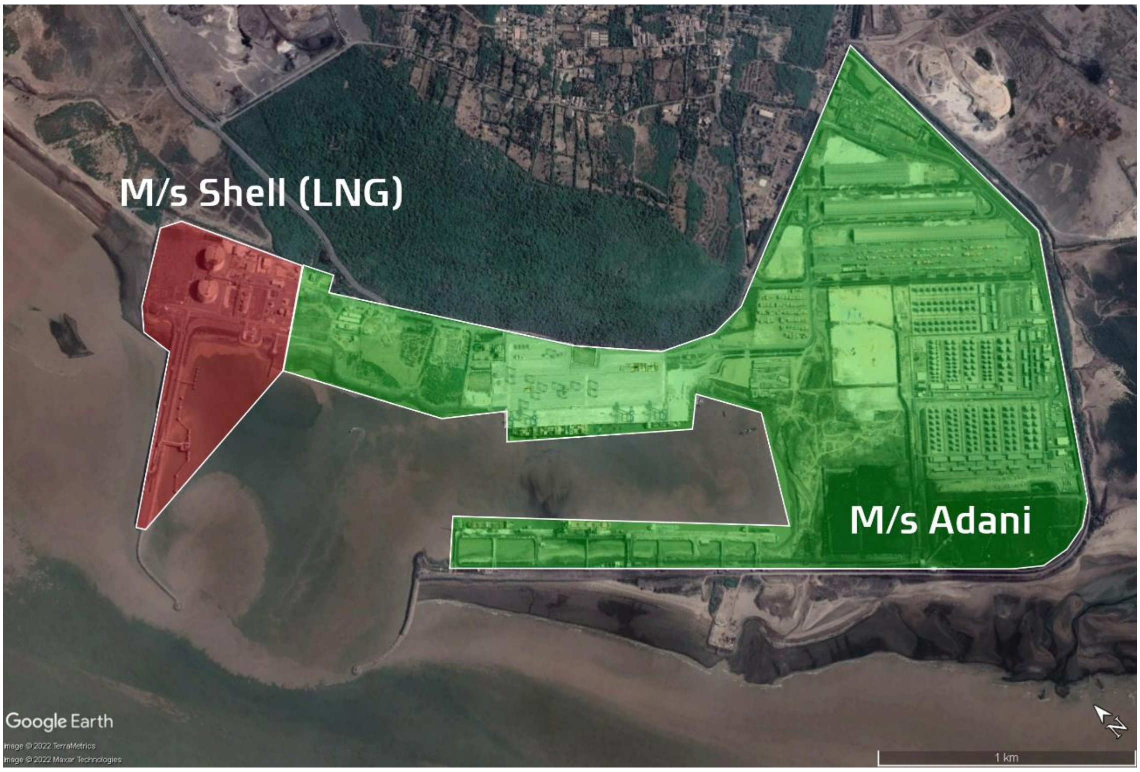

Figure 40: Hazira port – Area demarcation by ownership/operational control

10.3.1. Navigational characteristics

The navigational characteristics are presented in Table 27.

Property	Unit	Value
Distance to OWF	[km]	90-110
Harbour entrance width	[m]	650
Access channel width	[m]	500
Presence of lock/gate	[y/n]	No
Channel depth	[m]	~15
Vertical clearance	[m]	Unrestricted
Turning circle diameter	[m]	730
HAT	[mCD]	7.31
LAT	[mCD]	1.07

Table 27: Hazira Port – Navigational characteristics.

Hazira Port lies on the edge of the Gulf of Khambhat which is characterized by a high tidal range as highlighted in Table 27. As a consequence, there are high tidal currents and high volumes of sediment entering the harbour which require periodical dredging. Vessels with large draft may at times have to wait to enter during low tide (15% of the day at maximum). The Hazira port has in-house pilotage, dredger, and tug facility to assist with berthing operations.

10.3.2. Infrastructure access

Infrastructure access to port is presented in Table 28

Infrastructure	Value
Road access	NH 6 originates from Hazira Port Connects to NH 8 which is a part of the Golden Quadrilateral
Railway access	Near route between Delhi and Mumbai Railway line expected to reach port in next 2-3 years
Close Airports	Surat Airport

Table 28: Hazira Port – Infrastructure access

10.3.3. Hazira Port terminals, berths, and yards

Port layout is presented in Figure 41. Berths' characteristics and current use are provided in Table 29. The port has six operational berths, two container and four multi-purpose, and is currently handling 24 MT per annum. Yard properties are given in Table 30. At present the port is operating at full capacity and current expansion plans are addressing only the rise of cargo portfolio.

Berths at the southern side of the basin are detached jetties accessed by trestles which handle liquids, chemicals and bulk cargo. Only 50% of the berths at southern arm can handle bulk cargo.

Existing berths are already operating with full capacity and AHPPL estimate that they can only accommodate increase in cargo of 10-15%.

Figure 41: Hazira Port – Current port yards

Berth	Use	Structure Type	Length [m]	Depth [m]	Capacity [kN/m^2]
North	Container	Piled deck	720[7]	14.5[8]	37.5
South	Multipurpose	Piled deck	1200[9]	14.5[5]	37.5

Table 29: Hazira Port – Berths characteristics

Yard	Use	Area [ha]	Access	Capacity [kN/m^2]
No.1	Brownfield	20	Road	50-80
No.2	Brownfield	20	Road	50-80
No.3	Container storage	10-15	Road	50-80

Table 30: Hazira Port – Yard characteristics

Use	Detail
Container	~300m LOA
Bulk	100000 DWT
Liquid	15000-20000 DWT
LNG	165000 DWT 300m LOA (not handled)

Table 31: Hazira Port – Typical vessels calling at Hazira

Geotechnical conditions in the entire port area are characterized by deep deposits of soft sediments.

10.3.4. Hazira Port masterplan

The current port masterplan, shown in Figure 42, envisages the addition of six to seven berths inside the existing harbour. Construction of the new berths is already planned to intercept the rise in the traffic projections for the existing cargo portfolio. With construction of these berths, the port would exhaust the expansion potential within the existing basin.

The port is also contemplating the development of a new sheltered basin to the west of the existing port. This would be a long-term plan, with a horizon of about 25 years out and is not a part of the current port masterplan.

It is noted that the current master plan for Hazira Port does not consider any development of terminals for OW installation or O&M.

[7] This is the total berth length. The number of vessels that can be moored depends on their length.
[8] Constant dredging required inside the harbour due to large tidal range.
[9] This is the total berth length. Only 50% of the berths can handle bulk cargo. The remaining can handle liquids and chemicals.

Shell currently operates with two LNG tanks within the port and has approved plans to expand to four LNG tanks.

The area opposite to the harbour entrance cannot be used for construction of new berths due to unsuitable tranquillity conditions as well as the planned development of a tug harbour.

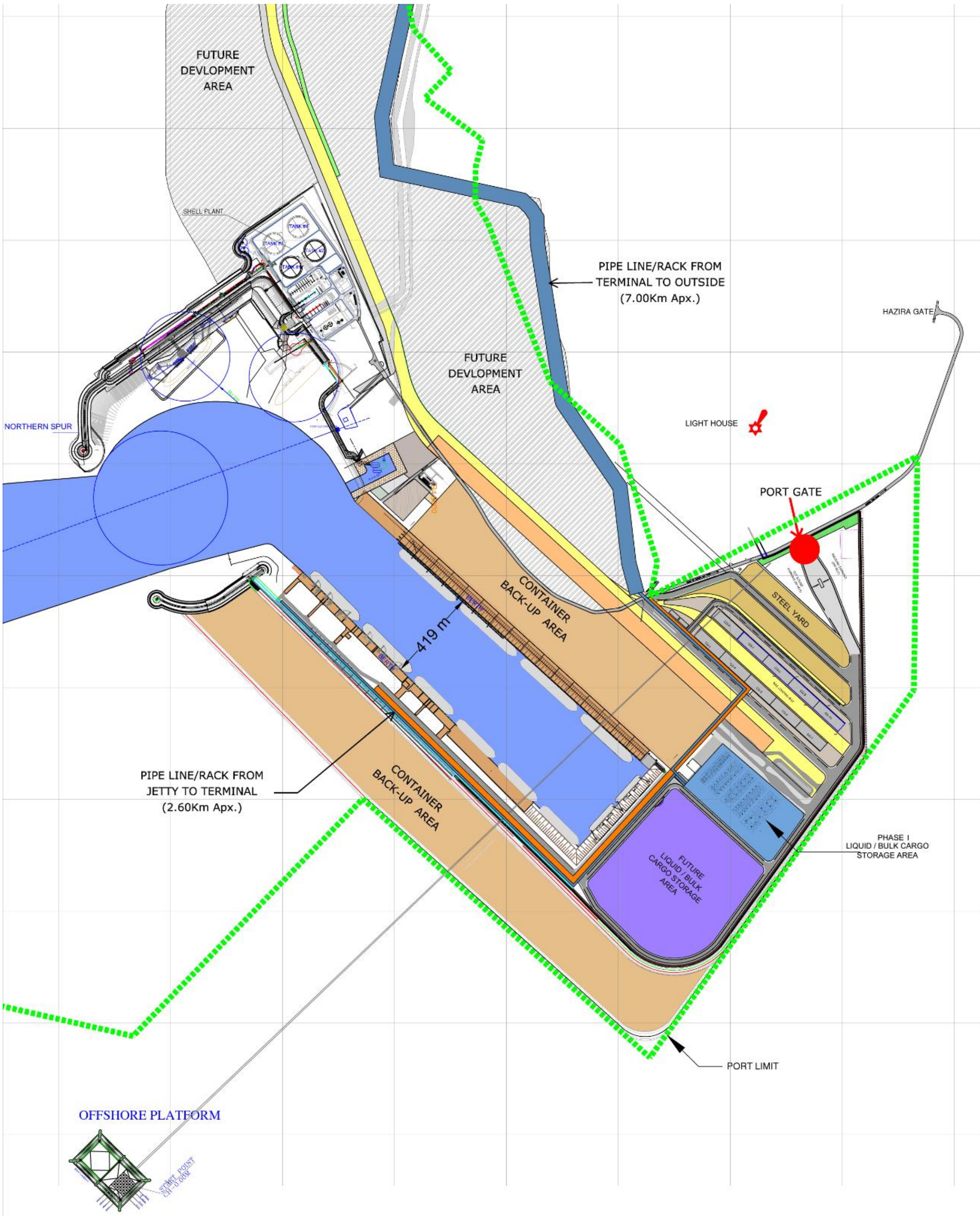

Figure 42: Hazira Port – Masterplan (Ref. Adani Ports)

10.3.5. Hazira Port suggested expansion for OW installation

Based on collected data and interviews with AHPPL, it is concluded that it is not possible to plan a turbine and foundation marshalling and installation from any of the existing berths / yards. One reason is that port is committed to existing cargo operations and does not have excess capacity to plan for an entirely new large-scale operation. Another is that current berths are not suited to heavy load requirements of component staging and load-out. Their decommissioning, reconstruction or upgrades are not considered feasible given the intensity of existing use.

The interest of AHPPL for development of purpose-built terminal for OW component installation would be governed by the pipeline of such projects. An option to consider could be to splice such operation into current masterplan.

Shown in Figure 43 is one possibility of such development that could be congruent with port's planned development. An idea would be that the development of new container berths is done to satisfy the envelope of both container traffic (STS cranes and utilities) and staging of OW components (heavy load areas).

In this way, AHPPL could continue increasing the container traffic while at the same time leasing the excess capacity to OW project for a limited period of time (1 year or so). Following the end of construction, Adani Group would outfit the terminal with STS cranes and RTGs and finalize other works in the yard, such as pavement. At the same time, opportunity to readily lease the area and host the other port activities that OW installation generates (refuelling, accommodation, and other supporting activities) would create a new revenue stream for the port operators.

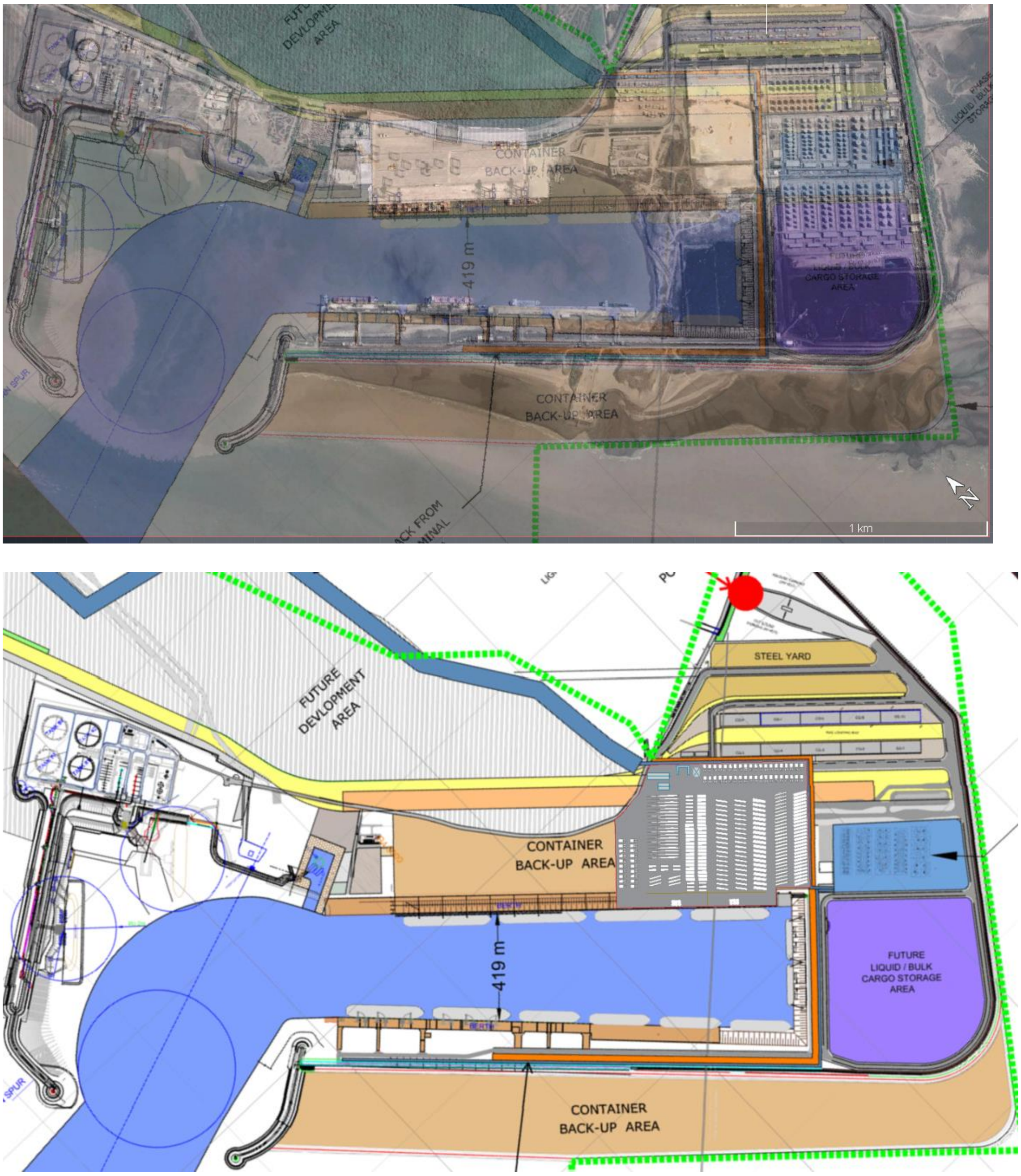

Figure 43: Hazira Port – Layout option for yards and berths to service OWF Shown within current port master plan layout

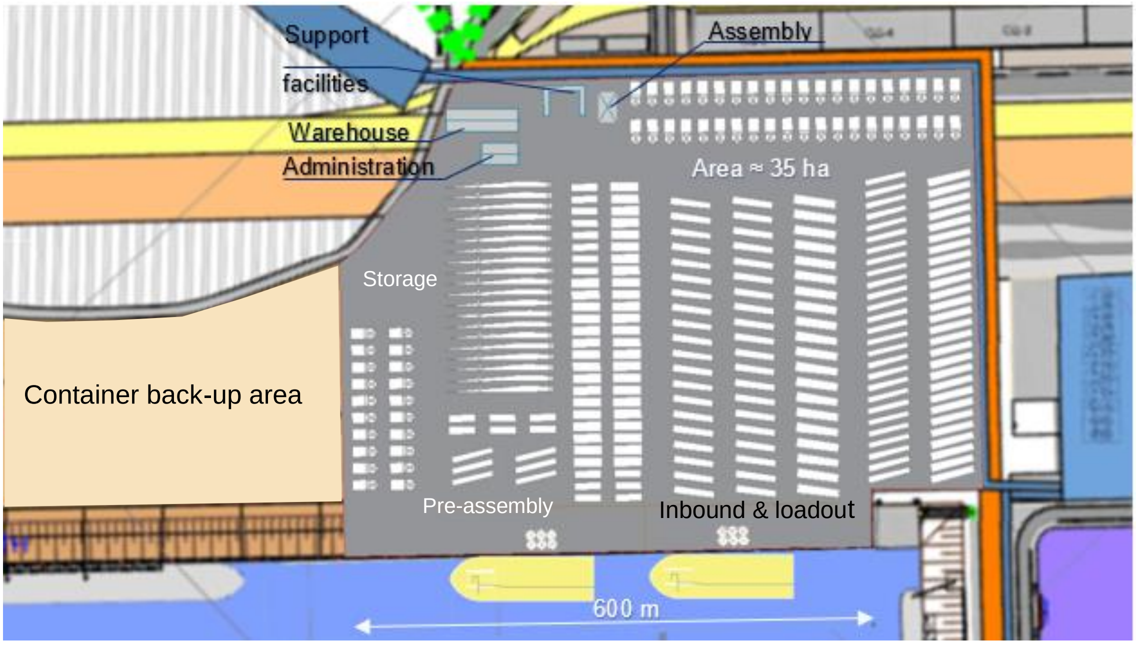

Figure 44: Hazira Port – Proposed port expansion for OWF

10.3.6. Indicative assessment of construction works

The purpose of this section is to give an indication of cost and length of development for the variant shown on Figure 44. It should be noted that comprehensive site investigation works (land and sea-bed) as well as other supporting studies and assessments would need to be carried out prior to design and construction

Construction works are described below in an approximate sequence of execution (shown by numbers) and illustrated with figures. The detailed description of sequence of works including the miscellaneous items required for the berth structure such as quay furniture, buildings and electrical works shall remain the same as described in section 10.1.10 for all port developments. The below descriptions of works (shown in Figure 45) highlight only the major civil works that exclusively pertain to the development of Hazira port. It should be noted that most of these works have already been identified as part of next phase development of the Hazira container terminal and will satisfy the OWF T&I requirements. In principle, only the berth structure needs to be designed for higher loads and maybe the ground improvement in the backup yard needs to be upgraded for the increased bearing capacity requirement.

Dredging [Step 1]: Dredging shall be carried out in the inner harbour area for the proposed berth length of 600m as shown in Figure 44. Significant dredging approx. 4 million m^3 is estimated.

Yard [Step 2]: Yard area of approx. 35 hectares is planned for storage facilities of the OW installation. Most of the yard area is already reclaimed and is either partially unoccupied or used for empty container stacking. Only a minor portion of ~3-4 ha needs to be reclaimed to the level of the existing backyard i.e., (+)10.5m CD.

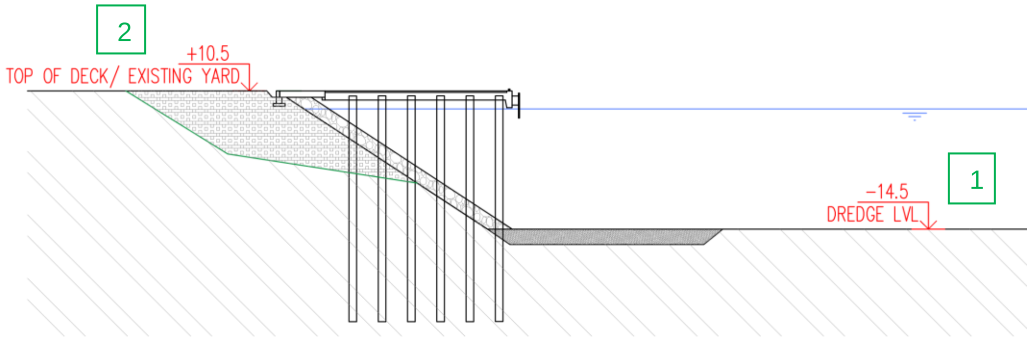

Figure 45: Hazira Port – Proposed sequence of works

10.3.7. Cost Estimate

An indicative cost estimate is shown Table 32 which pertains to the requirement of developing the port to serve OW installation works. The Hazira port has already planned for next phase development works which is forecasted to share most of the benefits from the development for OW berth. It is envisaged that the additional cost to cater to OWF requirements is approximately 16 million USD which is already included in the table below.

Construction	Cost [INR crore]	Cost [mill USD]
Dredging, reclamation and Shore protection	245	30
Soil improvement	8	1
Suspended deck construction – for container terminal works	251	30
Additional cost for deck construction and associated works to suit OWF requirements	133	16
Quay furniture	11	1
Lighting and electrical works	8	1
Buildings, parking and fencing	14	2
Mobilization & demobilization (8%)	54	7
Engineering and project management (5%)	36	4
Total	**760**	**92**

Table 32: Hazira Port – Indicative cost estimate of OW terminal development
Note: Following works/items have not been included in cost estimate: drainage, sewage, water utilities, equipment and vessels.

10.3.8. Estimated Duration

Indicative duration of the works is shown on Figure 46. The diagram only includes major works which form the critical path.

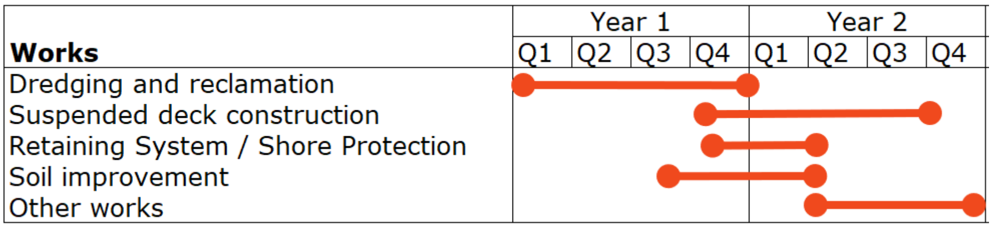

Figure 46: Hazira Port – Indicative duration of works for OW terminal developement

With respect to the piling works and given the information that the port shall experience severe cyclones for about 2-3 months and has a significant downtime of 15-20% of the day due to high tidal variations, this period considers driving of piles using minimum of 2 sets of piling equipment being mobilized simultaneously.

Works have been assumed to be staggered with minimal delay to produced shortest time overall. Total construction for refitting the terminal is expected to be around 24 months.

The indicative duration only represents purely production and construction times and does not take time for engineering design, obtaining approvals from government authorities or other necessary steps into account.

10.4. Pipavav Port

Gujarat Pipavav Port Limited (GPPL) is managed and operated by APM Terminals, the ports and terminals company of the A.P. Moller-Maersk Group. GPPL, a successful public-private enterprise, is emerging as an important gateway port on the West Coast of India for handling Multi Commodities which include Containers, Bulk, Liquid and Ro-Ro cargo. Due to favourable oceanographic conditions, the port offers day and night navigation to all vessels, other than LPG vessels, which are berthed or de-berthed only during the day. The port is located in Gujarat as shown in Figure 47.

Positioned opposite two islands, which act as a natural breakwater, the port is safe in all weather conditions, even during the monsoon season, with wave heights less than 0.5m most of the time.

The main port activities are listed below:

- Liquid cargo
- Container traffic
- Dry bulk cargo

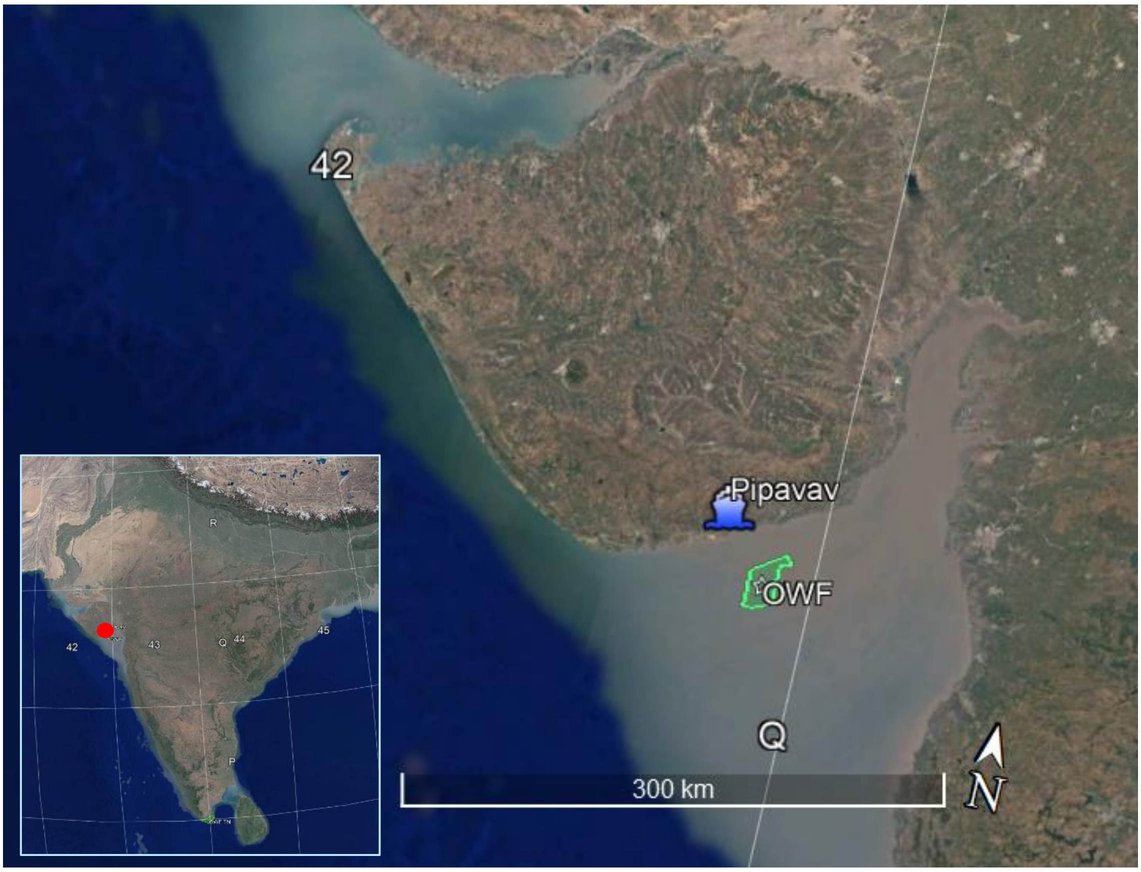

Figure 47: Pipavav Port location

10.4.1. Navigational characteristics

The navigational characteristics are presented in Table 33.

Property	Unit	Value
Distance to OWF	[km]	30-40
Harbour entrance width	[m]	200-530
Access channel width	[m]	250
Presence of lock/gate	[y/n]	No
Inner channel depth	[mCD]	13.5
Outer channel depth	[mCD]	14.5
Vertical clearance	[m]	Unrestricted
Turning circle diameter	[m]	550
Turning circle depth	[mCD]	13.5
HAT	[mCD]	+4.5
LAT	[mCD]	-0.5

Table 33: Pipavav Port – Navigational characteristics.

10.4.2. Infrastructure access

Infrastructure access to port is presented in Table 34.

Infrastructure	Value
Road access	National Highway-51 (NH-8E) Bhavnagar to Somnath through a dedicated 4 lane Port approach road (10 km long road).
Railway access	Direct connection to Indian Railway with own rail siding which is DFCC compliant and electrified with High Rise Overhead electrification.
Close Airports	Nearest Airport is Diu 78 km away.

Table 34: Pipavav Port – infrastructure access

10.4.3. Pipavav Port terminals, berths and yards

Port layout is presented in Figure 48. Berths use and characteristics are given in Table 35. The container and cargo terminals berths are connected to the storage areas by approach trestles with dimensions provided in Table 36. This may constrain the SPMT or crawler crane access to berth for loadout. The port presents sufficient yard area for components storage. Yard properties are given in Table 37. The port also has a shipyard located at the western side of the container and bulk terminals. Approach, turning basin and berth layout are shown in Figure 49 and Figure 50.

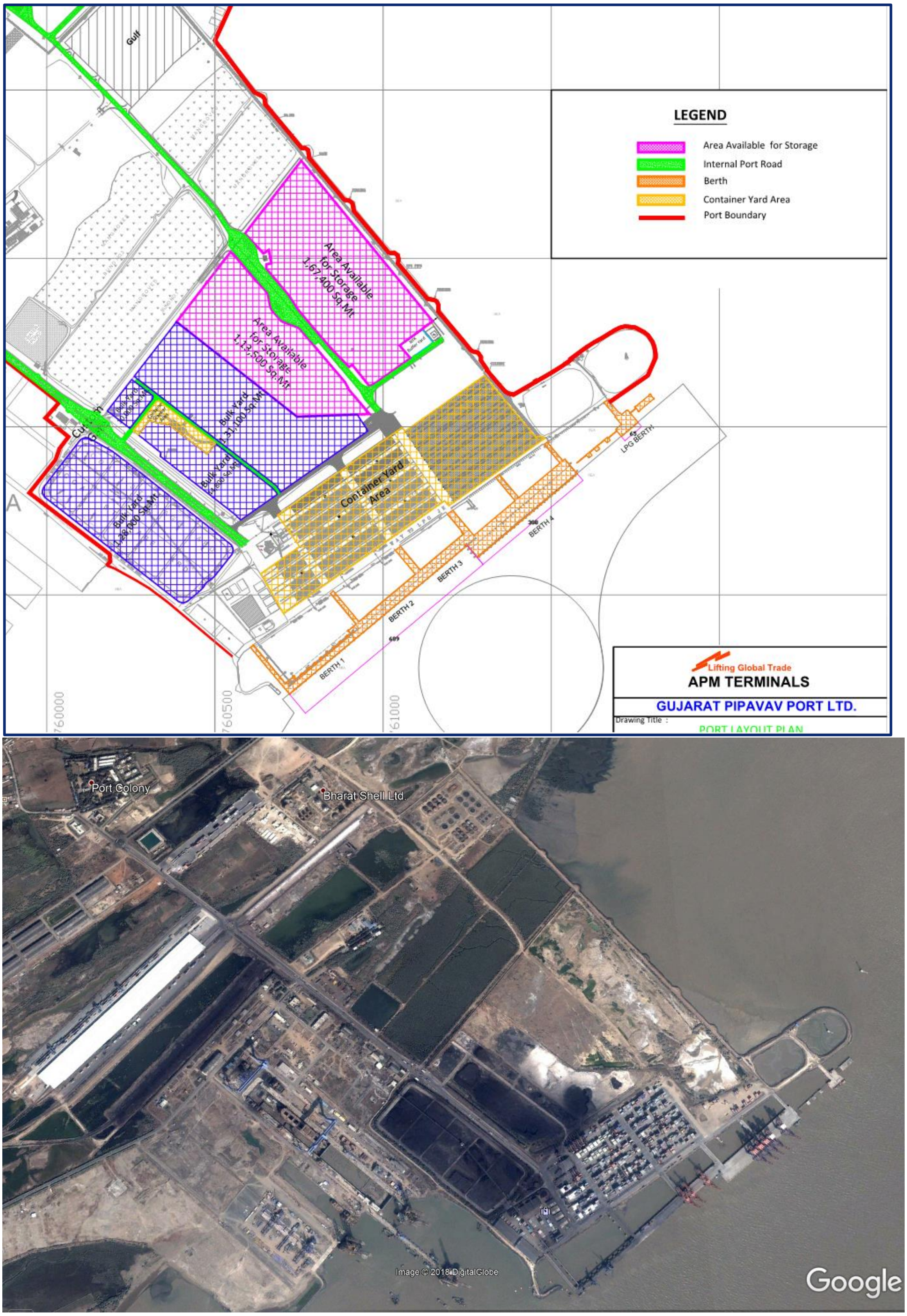

Figure 48: Pipavav Port – Existing plan

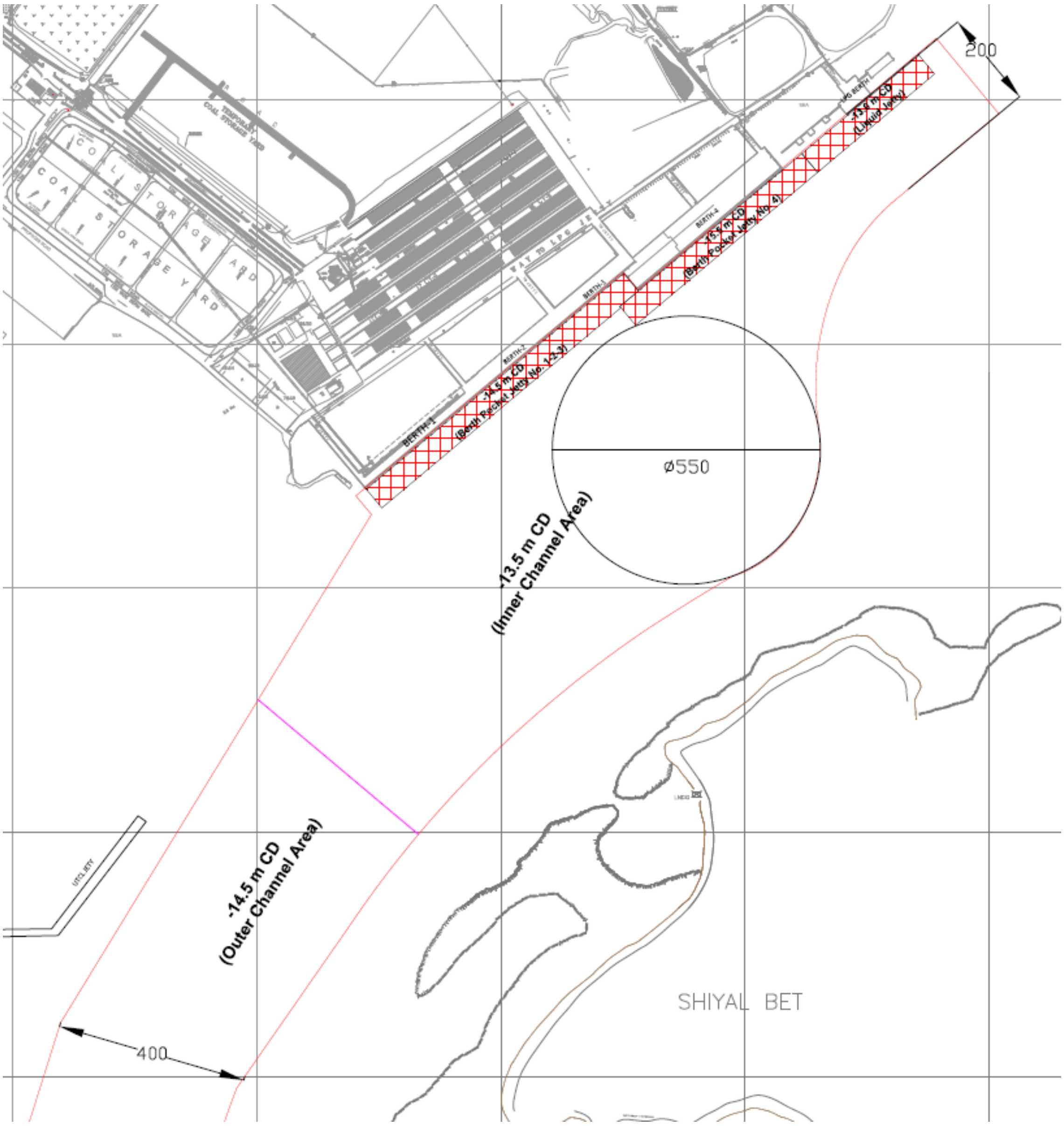

Figure 49: Pipavav Port – Approach channel and turning basin

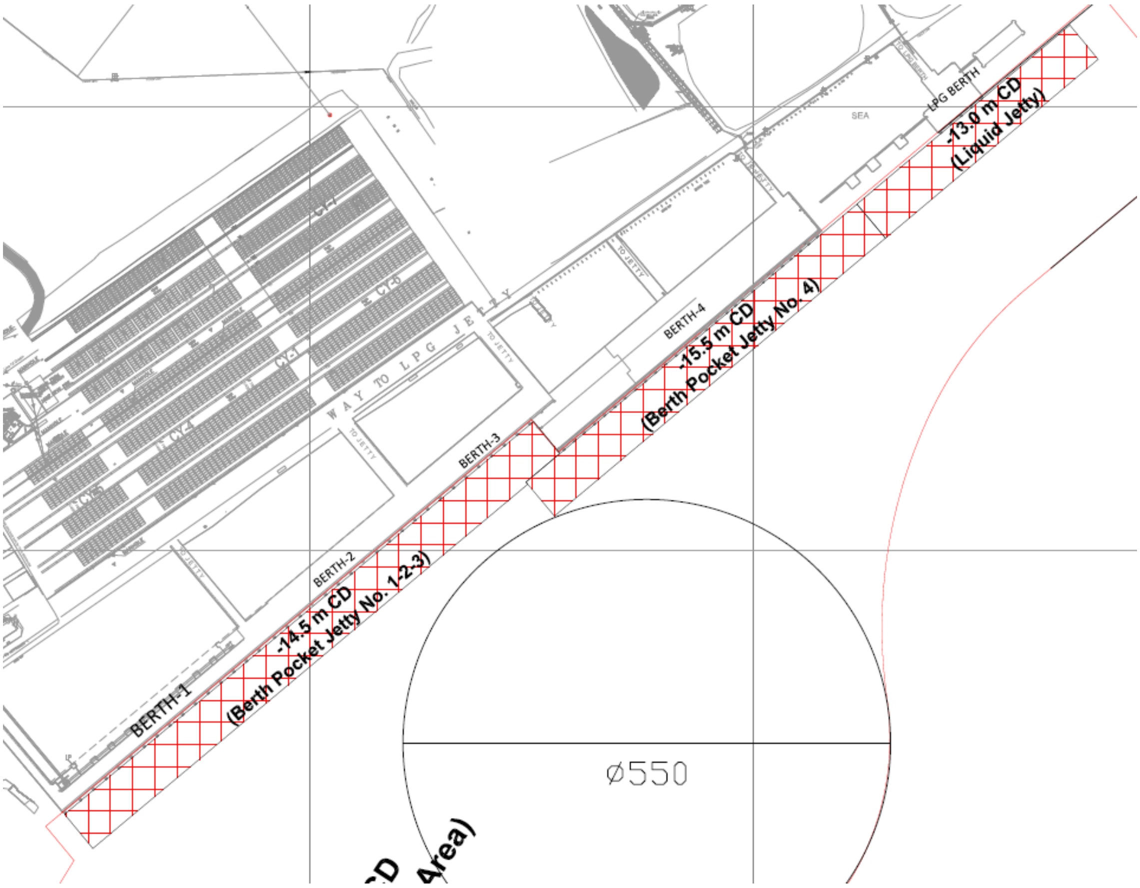

Figure 50: Pipavav Port – Berths layout

Berth	Use	Structure Type	Const. Year	Length [m]	Depth [mCD]	Capacity [kN/m^2]
No.1	Dry bulk cargo	Piled deck	1996	330	14.5	30
No.2	Dry bulk cargo	Piled deck	1999	186	14.5	30
No.3	Multipurpose	Piled deck	1999	174	14.5	50
No.4	Container	Piled deck	2008	387	15.5	50
No.5	LPG	Piled deck	2008	366*	13	50

Table 35: Pipavav Port – Berths characteristics.
**Includes mooring dolphin.*

Approach Trestle	Length [m]	Width [m]	Serving Berth No.
No. 1	163	9	1
No. 2	120	10	1 & 2
No. 3	99	18	2 & 3
No. 4	84	18	3 & 4
No. 5	91	14	4
No. 6	72	11	4

Table 36: Pipavav Port – Dimensions of approach trestles connecting berths to yard.

Yard	Use	Area [ha]	Access	Capacity [kN/m^2]
No.1	Container storage	20	Road	40
No.2	Bulk storage	28	Road and rail	40
No.3	Available storage	28	Road	40

Table 37: Pipavav Port – Yard characteristics

Previous geotechnical investigations report that the port area is characterized by a rock stratum available at -20m CD.

In meetings with GPPL it is clear that there is interest in supporting the OW Installation operations and providing offshore base facilities and this is under technical and commercial feasibility.

10.4.4. Pipavav Port masterplan

As part of the evaluation of the port masterplan various options for expansion of port facilities are considered. Discussions with the port revealed that decommissioning of the coal handling stockyard (approximately 10 - 20 ha) is envisaged due to forecasted lower profitability in the future, and the existing shipyard facility is in the process of closing down, and hence there are plans to synergize the shipyard and port.

GPPL believes there should not be any hinderance towards obtaining environmental clearance for the port development.

10.4.5. Pipavav Port suggested OW improvements

GPPL has mentioned there is the interest in supporting the OW Installation operations and providing offshore base facilities and this is under technical and commercial feasibility.

Shown on Figure 51 is a possible redevelopment of existing berth 1 and the coal yard behind into a general cargo terminal suitable for OW. Unlike the previous detached jetty, it is considered that new jetty should be continuously connected with the yard. This is to allow for flexibility in transporting of components to and from the apron. Berth would be 450m long to allow enough space for two vessels. Existing coal yard, along with the areas behind provides sufficient area and location at one end of the port allows for separation between different operations. As the new berth would have to follow cope line set by berth 4, it would create a "pocket" for berths 2 and 3 that could pose some hinderance in access for container vessels. This should be investigated through a detailed berth and navigation study.

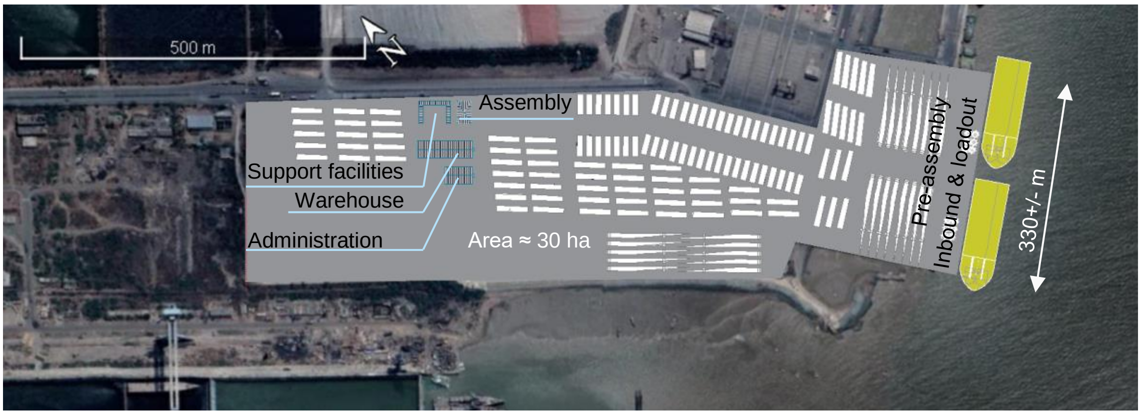

Figure 51: Pipavav Port – Proposal for OW-dedicated terminal

10.4.6. Indicative assessment of construction works

The purpose of this section is to give an indication of cost and length of development for the variant shown on Figure 51. It should be noted that comprehensive site investigation works (land and sea-bed) as well as other supporting studies and assessments would need to be carried out prior to design and construction

Construction works described below in Figure 52 show an approximate sequence of execution (shown by numbers) and illustrated with figures. The detailed description of sequence of works including the miscellaneous items required for the berth structure such as quay furniture, buildings and electrical works shall remain the same as described in section 10.1.10 for all port developments. The below descriptions of works highlight only the major civil works that exclusively pertain to the development of Pipavav port.

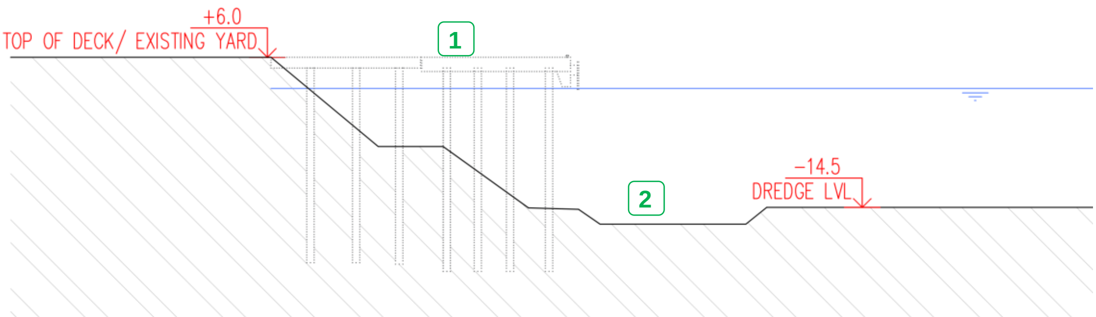

Figure 52: Pipavav Port – Proposed sequence of works-2

- **Decommissioning & demolition of berth 1 [Step 1]:** Since the existing berth is not designed to carry the heavy loads required and given the age of the structure it is envisaged that it may be easier to demolish the current berth and install a new berth in its place specifically designed to carry the loads required to support OWF transportation & installation.

- **Dredging [Step 2]:** The existing berths are operated at a dredged depth of (-)14.5m CD, which is sufficient for the proposed OW installation operations. Hence, significant dredging work is not envisaged.

- **Yard [Step 3]:** Total yard area of approx. 28 hectares is planned for storage facilities of the OW installation. Most of the yard area is already reclaimed and is either partially unoccupied or used as coal storage. From the Figure 53, it is evident that there is no significant requirement of reclamation, however only a minor portion of area immediately behind the proposed berth development (~7ha) needs to be reclaimed to the level of the existing backyard i.e., ~(+)6m CD

Figure 53: Pipavav Port – Location of proposed development

The proposed berth structure is 450 m in length comprising of bored cast-in situ concrete piles (approximately 5 m by 5 m grid size) with connecting concrete deck structures finishing upto the level of the existing terminals. [Step 4]

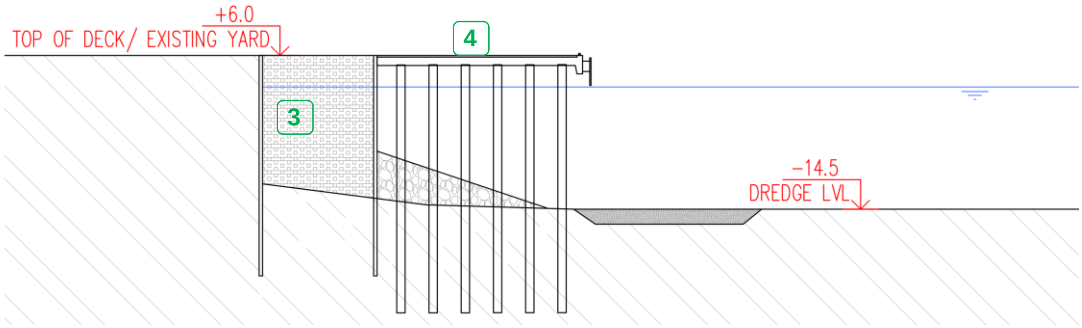

Figure 54: Pipavav Port – Proposed sequence of works-2

10.4.7. Cost Estimate

An indicative cost estimate for Pipavav Port is provided in Table 38. Costs have been calculated for the development according to the assumptions of various work descriptions given in section 10.4.6 and are presented in Table 38.

Construction	Cost [INR crore]	Cost [mill USD]
Dismantling of the existing coal terminal	10	1
Dredging, reclamation and Shore protection	72	9
Soil improvement	8	1
Suspended deck construction	432	52
Quay furniture	8	1
Lighting and electrical works	4	0
Buildings, parking and fencing	14	2
Mobilization & demobilization (8%)	44	5
Engineering and project management (5%)	30	4
Total	**622**	**75**

Table 38: Pipavav Port – Indicative estimate of costs for OW terminal development

Note: Following works/items have not been included in cost estimate: drainage, sewage, water utilities, equipment and vessels.

10.4.8. Estimated Duration

Indicative duration of the works is shown on Figure 55. The diagram only includes major works which form the critical path.

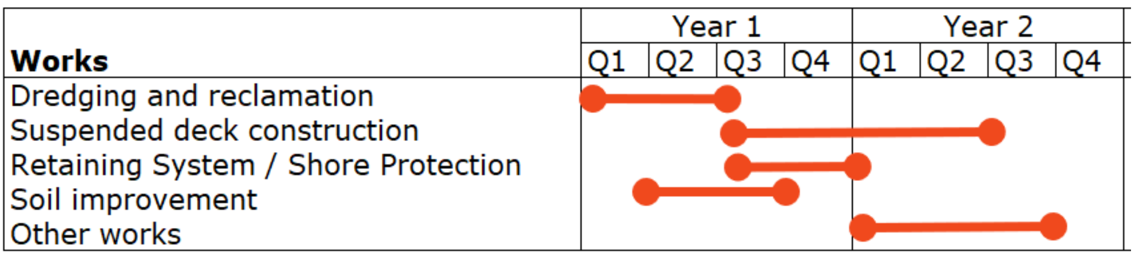

Figure 55: Pipavav Port – Indicative duration of works

With respect to the piling works and given the information that the port shall experience severe cyclones for about 2-3 months, this period considers driving of piles using minimum of 2 sets of piling equipment being mobilized simultaneously.

Works have been assumed to be staggered with minimal delay to produced shortest time overall. Total construction for refitting the terminal is expected to be around 21 months.

The indicative duration only represents purely production and construction times and does not take time for engineering design, obtaining approvals from government authorities or other necessary steps into account.

10.5. Risks associated with development of new terminals

Any project can be negatively affected by risks due to different causes. At this level of analysis, risk screening can only be done on a relatively high level. In Table 39 a sample of risks are listed, some that could be more prominent for some of the ports compared to the others. More generic risks that could affect any such development have been omitted at this stage.

	Tuticorin	Vizhinjam	Hazira	Pipavav
Schedule – Each of the ports discussed herein require additional berths to be developed due to the extreme loading requirements as demanded by OW installation. Delays due to different causes could affect the timeline of OW projects.	x	x	x	x
Ownership structure – Private-owned ports could be more difficult to accommodate OW-installation in good time if there is no attractive business case.		x	x	x
Incompatibility with existing master plan – Although all proposed developed concepts are aimed to be congruent with the masterplan, in cases of some ports it can easily happen that Owners opt for developments that are seen to generate better returns.		x	x	
Available space for expansion – Depending on the development of planned expansions, available space within existing port basins could be occupied at the time needed for OW component marshalling terminal.			x	
Soft soil conditions – Soft soil requires costlier structures and measures (such as soil improvement) to achieve suitability for the purpose. In some cases, cost can be traded off with longer construction time which can also impact the project.		x	x	x
Dredging in the rock – Depending on the rock hardness, dredging operation can be costly and time consuming.	x			
High tidal range – Should not negatively impact lo-lo operations and jack-up feature of the WTIV makes it completely insensitive to this. Nevertheless, sailing and inbound cargo loading operations could be affected in a way that they incur delays due to large tidal oscillations.			x	
Decommissioning of existing assets – Could give additional layer of complexity and cost uncertainty.				x

Table 39: Indicative risk matrix for OW terminal development

11. Coarse screening for Operations & Maintenance ports

The selection of the O&M base will depend on many factors such as downtime and travel distance, workforce availability, maintenance strategy, etc.

In this case, it is still unknown how many OWF the O&M base would serve, which developers will participate in the market and which investments will be done. Therefore, only a coarse screening is presented in this report.

It is assumed that any major port (including those selected for installation) will be able to accommodate SOV vessels and that the maximum recommended travel distance can range up to 200 km. Therefore, only CTV vessels are considered below.

The ports are shortlisted in Table 41 for the Tamil Nadu region and Table 42 for the Gujarat region. The ports were initially selected only due to their favourable location (within 50 km radius from OWF centre and/or edges, ref. Figure 56 and Figure 57). After, a coarse screening is done based on distances, navigational and yard characteristics (potential to provide sufficient yard area to accommodate O&M facilities). The tables below show estimated parameters mentioned above for each considered port. The parameters have not been assigned a score nor weight. Rather, a simple "traffic light" system was used to designate whether a certain parameter falls within or outside the criteria described in Section 9.6, see Table 40 below.

Light code	Description
🔴 (red)	Does not meet the minimally acceptable criteria
🟡 (yellow)	Between recommended and minimum acceptable values
🟢 (green)	Currently meets the recommended values

Table 40: O&M Ports – Traffic light system for port screening

For Tamil Nadu OWZ, Kudankulam and Muttom are viable options with respect to distance, sheltered area, ease of navigation, water depth and yard area. Tuticorin, although a bit further, is also a possibility if none of the close ports present a good candidature in terms of required investment and available workforce.

For Gujarat OWZ, Pipavav is a viable option since it presents enough water depth and easy access for vessels, as well as a sheltered area (which is not present at the other locations), local industry, and hence more likely access to qualified workforce.

Figure 56: O&M Ports – Potential O&M bases for Tamil Nadu OWZ.
Red curves denote 50km and 100km radius from OWZ central point.

Port	Distance to OWF [km]	Depth at entrance & berth [m]	Entrance width [m]	Vertical clearance	Space for berths	Adjacent area for facilities
Tuticorin Port	100-120	9.3-15	>100	Unrestricted	Yes	Sufficient
Chinnamutton Port	40	2-3 0-1	~100	Unrestricted	Limited	Limited
Muttom Port	70	10-12 5-8	~200	Unrestricted	Yes	Sufficient
Kudankulam Port	35	unknown	~100	Unrestricted	Yes	Sufficient
Kallamoli Port	60	unknown	n/a	Unrestricted	Yes	Sufficient
Thengapattanam Port	93	unknown	~80	Unrestricted	Yes	Sufficient
Colachel	80	unknown	~40	Unrestricted	Yes	Limited

Table 41: O&M Ports – Candidate ports to serve as O&M base for TN OWZ
Note that numbers are based on rough measurements using publicly available information and images.
Distances measured to OWZ central point.

Figure 57: O&M Ports – Potential O&M bases for Gujarat OWZ.
Red curve denotes 50km radius from OWZ central point.

Port	Distance to OWZ [km]	Depth at entrance & berth [m]	Entrance width [m]	Vertical clearance	Space for berths	Adjacent area for facilities
Pipavav Port	30-40	12-14.5	n/a	Unrestricted	Yes	Sufficient
Babarkot Port	40	Insufficient	n/a	Unrestricted	Yes	Sufficient
Bhankodar Port	30	Unknown	n/a	Unrestricted	Yes	Sufficient
Chanch Port	30	Unknown	n/a	Unrestricted	Yes	Sufficient

Table 42: O&M Ports – Candidate ports to serve as O&M base for GJ OWZ
Note that numbers are based on rough measurements using publicly available information and images.
Distances measured to central point.

Figure 58: O&M Ports – Kundakulam cargo area.
Pontoon and 4 CTV vessels depicted.

Figure 59: O&M Ports – Muttom Port
Pontoon and 4 CTV vessels depicted.

12. Development of marshalling terminals

12.1. Introduction

Ports are a key enabler for the development of offshore wind. Ports supports the local supply chain, logistics and supporting infrastructure as have been described earlier in this report

In earlier work done for the DEA, COWI has benchmarked and analysed European ports from both a technical and economic development point of view and developed benchmarks for port requirements based on European experience, which has seen several ports upgraded specifically to suit the needs of the offshore wind industry in the last 30 years. Six European ports: Esbjerg, Grenaa, Rønne, Bremerhaven, Cuxhaven and Eemshaven were profiled.

Key takeaways from these profiles are:

- Offshore wind projects can come in cycles, which challenges continuity of business at the port.
- Convenient location and strategic investments can kick-start a future offshore wind hub.
- Colocation of manufacturing facilities is ideal but not a necessity for successful OW port business.
- Existing and un-utilized general purpose, Ro-Ro and industry quays can be repurposed to OFW without prohibitive up-front investments.
- A single OW installation project is not sufficient to pay for infrastructure investments.

12.2. Ports for offshore wind

Ports can only deliver services supporting offshore wind if significant investments are made to upgrade and expand their infrastructure. Often there will be requirements around expansion of land, reinforcement of quays, upgrading deep-sea berths and other civil works.

There are currently different approaches based on the number and types of installation and transport vessels, and the level of assembly to be carried out in the port.

- **Transiting strategy:** Transport of components to the wind farm in installation vessels. Depending on the operations carried out in the port terminal, two methods of construction can be further differentiated: if manufacture and assembly of components is carried out in the port, or only preassembly thereof.

- **Feeding approach:** Components are transported to the wind farm in transport or feeder vessels. Today, the most widely used strategy is transporting components which have been preassembled in the port.

During preinstallation and installation of offshore wind farms, ports must have major components and facilities, and depending on the applied installation strategy the following types are foreseen:

- **Marshalling/ Assembly ports:** Preassembly of components received from manufacturing plants takes place here. Components are received either by road transport or, increasingly, by sea especially during the construction phase of a windfarm.

- **Operational and Maintenance (O&M) ports:** Used to host activities associated with the ongoing reasonably foreseeable O&M activities of an offshore windfarm during its design life.

12.3. Port ownership/models

In the past many ports were owned and operated by the public sector, but private sector investments and involvement in the ports have emerged from the 1980's. The public sector may still own and operate ports, often defined as a public sector service port. The opposite would be a private sector service port.

Generally, ports are classified into four main models as illustrated below and in Table 43 providing further details on port functions, characteristics, and ownership structure:

- **Public service ports**
  Public service ports are predominantly public owned however the numbers are declining and in transition toward a landlord port structure. Some ports in developing countries are still managed according to the service model where the port authority offers the complete range of services required for the functioning of the seaport system. The port owns, maintains, and operates every available asset, and cargo handling activities are carried out by labour employed by the port authority.

- **Tool ports**
  In the Tool port, the port authority owns, develops, and maintains the port infrastructure as well as the superstructure, including cargo handling equipment such as quay cranes and trucks. Port authority staff usually operates all port owned equipment. The private cargo handling firm usually signs the cargo handling contract with the shipowner or cargo owner. The cargo handling firm however, is not able to fully control the cargo handling operations itself as being the responsibility of the port authority.

- **Landlord port**
  Landlord ports are characterized by its mixed public-private orientation. The port authority acts as regulatory body and landlord, while most port operations are carried out by private

companies. Infrastructure is leased to private operating companies or to industries. The private port operators may provide and maintain their own superstructure including buildings, and may purchase and install their own equipment on the terminal grounds as required by their business, or a mix thereof. Examples of landlord ports are Rotterdam, Antwerp, New York, and since 1997, Singapore. Today, the landlord port is the dominant port model in larger and medium sized ports.

- **Fully privatized port or private service port**
  Private service ports are still limited and can be found mainly in the United Kingdom (U.K.) and New Zealand. Full privatization is considered by many as an extreme form of port reform. Port land is privately owned, unlike the situation in other port management models. This requires the transfer of ownership of such land from the public to the private sector. In addition, along with the sale of public port land, some governments may simultaneously transfer the regulatory functions to private successor companies.

Type	Infrastructure	Superstructure	Port labour	Other functions
Public service port	*Public*	*Public*	*Public*	*Majority public*
Tool port	*Public*	*Public*	*Private*	*Public/private*
Landlord port	*Public*	*Private*	*Private*	*Public/private*
Private service port	*Private*	*Private*	*Private*	*Majority public*

Table 43: Basic Port Management Models
Source: WB. 2007a. Port Reform Toolkit. 2nd ed. Washington, DC: World Bank. [#1381]

Major ports in India have seen continuous improvements in their performance for more than 25 years. The GoI has been encouraging private sector participation in ports since 1996 especially by awarding Public Private Partnership (PPP) concessions. They have been mainly on a Build, Operate and Transfer (BOT) basis with revenue sharing formulas, and include the construction of berths for cargo handling, container terminals, cargo handling equipment, warehousing and the construction of dry docks and ship repair facilities. The Indien ports analysed in this study are all classified as landlord ports.

12.3.1. Port development models for offshore wind industry

Ports for offshore wind have been successfully developed in several countries i.e., Netherlands, Denmark, Germany, UK, and US. The commercial attractiveness of OW projects is one of the key drivers for successful project implementation which sometimes require financial support from several stakeholders. There is no unique port model for port/offshore wind projects, however as seen from the already established and on-going developments, there are several conditions being favourable for successful project agreements and implementation, including:

- Political engagement and support towards green transition and renewable energy targets as well as creating incentives enabling engagement of private sector partners,
- Public recognition of the OW supply chain challenges and opportunities, and drivers for local and regional economic development and job-creations,

- Sufficient regulatory environment supporting private development projects,
- Ideal location of port i.e., available wind resource, existing infrastructure/superstructure etc., land availability and space for redevelopment, cooperation with nearby neighboring ports,
- Common understanding of project scope and roles of respectively port authority, central and local government agencies and private developers including short- and long-term visions for the port development recognizing the port/OW cooperation,
- Willingness of port authority/governments to financially support infrastructure/ super-structure development,
- Financial support from structural funds or if applicable use of concessional/blended finance funding.

Offshore wind projects cannot be developed or achieved without supportive marshalling/assembly ports. If the OW industry for a particular OW market location is at an early stage with only one, or relatively few projects the developer may take the lead in identifying suitable ports among existing ports and estimate the need for upgrades and infrastructure development. Typically, the developer is looking for solutions that can deliver in the shortest possible time at the least cost.

As the global offshore wind industry has matured over the last 20 years, experience from European early adopters shows that each country has charted its own path and that there are multiple ways to establish a successful offshore wind industry. The paths that these countries have taken are highly influenced by the existing regulatory frameworks, political preferences, and characteristics of the available wind resource.

Ports in Denmark, Germany, and the Netherlands, expanded and invested in offshore wind services as the sector expanded and as more countries committed to offshore wind targets. However, today the next generation of technology will be using 15-20 MW turbines and developers will be looking for opportunities that are in the size of 500 -1000 MW wind farms. For such large projects, capital expenditures for a wind farm are typically in the low to medium billions of Euros, with the development expenses running into the millions. The necessary port upgrades enabling the OW industry may also require large investment of EUR 100-500 million depending on the ports purpose and functions.

The number one driver for any port upgrades and investment will be the stakeholder's confidence in the offshore wind market and ultimate the build-out rate of the sector. With countries committing to the green transition and importance of net zero, the magnitude of offshore wind development and number of GW needed has become clear. If a country decides to promote OW today, with large turbines and large projects, the port considerations, and the related models may be quite different compared to just a few years ago.

Developer driven model:

Developers are typically not interested in becoming a port owner/operator and will engage with existing port authorities/owners of the port. It is common that local and regional governments are eager to get involved, as there are expectations for local economic development including other investments. Public funding or incentives may support some of the port improvements.

The timing and size of the OW project will also influence how to develop the ports. If there is only one or a few projects, the Developer Driven Model is the best way forward. An existing (international) developer will have a wealth of experience and knowledge about how to go about the upgrades, which may enhance the implementation and lowering the costs of the projects. If the port authorities/port operators have limited experience in dealing with the private sector, there may be a (perceived) risk that the private OW stakeholders may be getting a more favourable deal.

Various sets of standardized and templated port requirements already exist including the work in this report, which should further clarify the necessity and cost implications for early upgrades. Another possibility could be to bring in external transaction advisors helping the port owner structuring the specific project regarding technical, financial, or legal issues, thereby helping to de-risk the concerns of both the port authorities and the developer.

Developers of OW recognize that staging/marshalling ports are a prerequisite for development of an OW-farm and are interested in working with existing port-owners'. A developer will often be an anchor tenant for some years, thus allowing the upgrades and investment to move forward.

Experience from the past has shown that developers looking for suitable ports have found it difficult to identify readily available ports. At the same time, port owners and operators have signalled frustration that developers were reluctant to commit to contracts or tenancies that would require specific investment in terms of quayside or land development for the long term.

Moving forward, the developer driven model today is more constructive to public-private dialogue (but not necessarily a PPP ownership model) among OW stakeholders including other entities in the supply chain.

National or state governments may consider engaging in a more strategic planning approach to port development and to determine what sort of upgrades would be required. In parallel early engagement and dialogue with developers and other stakeholders on their needs and expectations would facilitate this “open book” approach.

The case study 1 from State Pier in Connecticut, USA is an interesting case for a project developer model, including a 20-year PPP concession to the terminal operator and a 10-year lease of the facilities by the OW developer. In the Indian context this may be an appropriate model for the initial projects, and financial support for port upgrades from either the national or state level would send a strong signal of support to the sector.

Offshore Wind Cluster Model:

The cluster-based model for offshore wind development is an option if stakeholders have long term confidence in offshore wind and higher certainty in the first rounds of individual projects, or if significant growth is anticipated at a future stage, or a maturing industry. There has been a keen interest and support for this model, in for example the UK's wind industry, where there today are eight recognized wind clusters in different regions of the UK.

Economic development and job-creation are important drivers and therefore regional development agencies and private sector stakeholders including wind developers get together to develop an initial strategy and implementation plans. The cluster objective is to build a self-reinforcing industrial centre made up of growing local/regional suppliers, which have entered the offshore wind supply chain along with global suppliers and developers that have set up operations to serve the local and regional markets. A cluster-based development for offshore wind port development needs to be an integrated public private partnership, which works on critical portions across the entire offshore wind value chain.

The OW cluster approach is inspired by academic industrial competition cluster theory, later adopted to the OW sector[10].

The Humber Offshore wind cluster in the UK, (see Case Study 2 included as Appendix 15.1) is considered as one of the "best in class" and several reports and presentations are available in the public domain[11].

[10] https://lido.hull.ac.uk/Uploads/Publications/BD1651B7436E353E0B1795054BC54BAB/University_of_Hull_Capability_of_the_Humber_region_-_with_Appendices_-_November_2013_for_print.pdf
[11] https://www.humberoffshorewindcluster.co.uk/

Attributes of an advanced Offshore Wind Cluster

Strong links with local policy the cluster must be set within a local policy context which is supportive

Related industry/cross-sector linkages transferable expertise, products and services which can work between different sectors thus limiting risk for the supplier

Entrepreneurship the creation of scalable new business(es)

Fully established supply chain an integrated supply chain from end user to original suppliers

Identified key specialisms identified areas where there exists a strong offer around products, services, technology or expertise

International recognition and readily exporting having international recognition for sector delivery and where products, services and skills are exported to developing and new markets

National recognition having national recognition, often by national government and other geographies as 'go to' places for access to products, services and skills

Research, development and innovation new products, services and skills usually developed to solve problems and challenges of growing/developing industry

Public/private sector cooperation/collaboration open channels of communication between industry requirements for development and public sector to assist to de-risk and enable

Brand and vision a common brand and vision around which all stakeholders in the cluster can align

Supporting organisations public and private sector supporting organisations which can act to foster cluster collaboration

Networking business(es) and individuals within a cluster interacting with each other to exchange information, develop contacts and seed collaborations

Finance investment readily available to support innovation and expansion in products and services

Physical infrastructure & ports a concentration of relevant infrastructure which can be adapted to support the sector, including from related/previous industry

Skilled workforce a concentration of people within the cluster whom have relevant or transferable skills, in some cases from related/previous industry

Growing company base increasing concentrations of supply chain companies in the cluster

Supportive political setting policy or financial instruments acting to de-risk projects for developers and supply chains

Geographical proximity to market close to wind farm zones

Pre-existing manufacturing base close to a manufacturing base which may have been originally established for a different but related industry

Pre-existing knowledge base close to a knowledge base which may have been originally established for a different but related industry

Figure 60: Attributes of an advanced Offshore Wind Cluster.

The above list of 20 attributes is not ranked and exclusive and will change from region to region (or project to project), however the geographical proximity to the wind farm zones and the physical infrastructure and ports would normally be the more important attributes.

The cluster approach has many interesting features but is a very ambitious undertaking. In the case of the UK, the government also contributed significant public funding to the sector through Offshore wind Sector Deal[12].

While the OW cluster is a promising concept, it can also be a risky strategy and approach if the cluster cannot keep up with the changing needs of the OW industry. As a case in point is the Bremerhaven's OW port. In the early 2000, Bremerhaven was promoted as "Europe's premier location for offshore wind energy projects", but as the OW industry became more specialized and consolidated the early stakeholders located in the port became marginalized, as such the Port has to some extent lost its relevance. At the same time other clusters emerged, particularly in Cuxhaven, where upgrades and investments were made by the port authority and sub-national government agencies for the expansion of new assets on greenfield land.

[12] https://www.gov.uk/government/publications/offshore-wind-sector-deal/offshore-wind-sector-deal

As the build-out rate increases in the Tamil Nadu OWZ, the Offshore Wind Cluster model may be relevant. However early stakeholder engagement and networking to develop a common vision towards the cluster approach could start immediately.

Furthermore, port ownership structure may impact how they can support the offshore wind industry. Most of the major ports around the world are organized as a landlord model and operate as public enterprises or quasi-autonomous organizations and seek to have a profitable business. As such when investing in upgrades or new investments, the ports must have confidence that the investment will generate appropriate returns.

If a port has a public governance structure or ownership, it may be less concerned with making short-term returns and may have a longer-term outlook on investment into infrastructure. Such a port can decide to proactively invest into port infrastructure, enabling them to attract a series of inward investments and create an established offshore wind path, as part of a long-term strategic vision. The fully private port will in contrast be reacting to a growing offshore wind market and make investments into port infrastructure following contractually binding investment commitments of firms to ensure future returns.

Port model	Advantages	Disadvantages
Developer Driven Port **Quasi-Public Port Authorities**	Pro-active investments. Positive political influence. Degree of coordination and priorities of regional strategies.	Short term vision. Only serving one developer and a few projects.
Developer Driven Port **Private Sector**	Reactive investments. Driven by market and profit oriented. Quicker decision making.	May be challenging to get public funding/grants. Less coordination of regional/national priorities. Risk of over-developing of additional ports.
Offshore Wind Cluster Approach **Public Private Partnership**	Long term vision. Supporting many stakeholders in the supply chain. Can accommodate several port functions. Can attract inward investments and fabrication/manufacturing. Can support more than one developer.	(Nationall) policies or market conditions may change making the cluster obsolete. Risky to be first mover for nascent new sector.

Table 44: Summary of advantages and disadvantages of different port models.

At this point, there will be not just be one model that is better than the other for the Indian ports. Any approach will depend on the specific circumstances, as well as the commitment of the government either at the national, regional, or local level in supporting the OW industry and the green transition. However, Indian Port Administrators could benefit from a more formal knowledge exchange with European Ports that already have a vision and brand being an Offshore wind port. For example, a twinning partnership between the ports for the initial projects and Esbjerg port in Denmark could be one option for this.

12.3.2. Financing of OW ports

Financing of re-development of ports to adequately accommodate offshore wind farms can be seen isolated or in combination with the financing of offshore wind development projects.

Financing of re-development and adaption of ports for offshore wind faces infrastructure and cost challenges, therefore requiring a long-term revenue certainty for the exploitation of those facilities as part of the national energy policy. Government and political support enabling legislation ideally decreasing investment risk, while technological consolidation will allow ports to strategically plan the expansion or adaptation of their facilities in the most efficient way in cooperation with i.e., a private offshore wind developer.

Port infrastructure re-development is important for sufficient port capacity to meet a government's offshore wind goals, and public funding is often mobilised. Sub-national government agencies across various countries are becoming involved in harnessing and valorising port infrastructure to also catalyse port adaptation and diversification into offshore wind, alleviate economic decline and create new regional paths. However, policy decisions on ports development are often happening at a regional level, and since offshore activities can compete, with other industry activities that may provide higher returns in the short term (e.g., container terminal or logistics).

It is also important that the public are made aware of the high societal value of investing in offshore-ready ports and financial instruments are made available accordingly for ports and project developers. An example is the EU Recovery Strategy that will mobilise investments of EUR 750 billion in the Next Generation EU for the coming years as an opportunity for investing in port infrastructure as key in the offshore wind supply chain.

Grants remain a vital tool to preparing port facilities for offshore wind development, ensuring a viable business case based on a longer return of investments.

Loans are equally important as they provide attractive pricing and a signalling effect, helping the project attract the necessary capital for such large investments. Financing institutions will play a crucial role to reduce investment risks and leverage finance from commercial banks.

.Other interventions, such as outlining a clear and credible policy, support for supply chain and skills development, and investment in ancillary infrastructure such as ports, are also essential to establish an offshore wind market.

Concessional finance can help accelerate deployment within offshore wind in India towards its goal of reaching 30 GW by 2030. In particular, the first projects off the Gujarat and Tamil Nadu coastlines are expected to be accompanied by higher tariffs, and therefore the need for public financial support is stronger. Concessional finance may help to reduce the tariff to a level that is more affordable for the GoI and electricity consumers. Addressing high project and debt financing costs using concessional financing is an immediate entry point for offshore wind projects. In India, a full-service package of concessional financing can be deployed in conjunction with public and private interventions for the first offshore wind projects in both Gujarat and Tamil Nadu regions.

Financial support could be targeted to different parts of the energy supply chain, including the port sector as they have an essential role in supporting offshore wind. A public private shared approach to the needed infrastructure, would reduce the total private sector CAPEX requirement.

12.3.3. Opportunities for local economic development

Offshore wind energy is a viable option available for developing utility-scale renewable energy in many densely populated countries. The growing offshore wind energy industry will create more opportunities for clean energy jobs, urban renewal, and environmental restoration.

Understanding the benefits and the requirements necessary to successfully support the construction, operation, and maintenance of offshore wind energy farms is critical for the successful redevelopment and revitalization of ports. While port redevelopment and upgrading will require a major shift of port infrastructure design, communities and ports alike will greatly benefit from focusing their harbour strategies to support the growth of offshore wind energy potential. The Belfast Harbour OW project (Case 3 in annex) is an example of seeking such local economic development.

In earlier work done for the DEA[13], COWI had benchmarked and analysed European ports.

Offshore Wind Farms represent very large investments and sustain economic activity over an extended period. As such, there is a considerable focus on generating as much economic activity as possible within the region seeking to establish the OWF. Creating the optimal conditions for colocation of manufacturing, assembly, staging, operation and maintenance and decommissioning is always in focus to generate as much of the value creation from OWFs as possible.

The case studies of European ports supporting OWF construction and maintenance provide a few insights regarding local economic development.

1. Port design has, to a large extent, been an evolution based on a combination of foresight and necessity. The cases show that development is ongoing based on expectations of future development and strategic considerations.
2. A considerable pipeline of OWF projects is necessary before co-location of manufacturing takes place. The cases point to several examples of colocation evolving over time and in anticipation of a continued pipeline of OWF projects.

[13] Danish Energy Agency (2020) COWI report: JOINT STUDY ON WIND FARM PORT CONSTRUCTION FOR FOSTERING WIND INDUSTRIES AND CREATING JOBS

3. O&M activities can generate a sustained economic activity around a port with high percentage of local input.

During port construction or upgrade: the scale of the construction needed to upgrade a port is the determining factor in job creation. Local job generation potential will mainly be linked to the available local expertise in port construction.

During OWF construction: Availability of a local port with facilities for at least staging and shipping of components will impact local economic development even initially.

12.4. Development of marshalling terminals - takeaways

Today a new OWF will minimum be in the 500-1000 MW range, and the availability of a marshalling/assembly port should be prioritized collectively by public and private stakeholders. Timing may be critical if political climate ambitions must be met.

While engineering specifications are well known, any project will need detailed design and permitting, where the latter often can take years to be approved.

The information and analysis presented above are based on different models for port ownership, investment, and industrial strategies. It can be concluded that the main driver for OW and OW-port development is the build-out rate of offshore and long-term confidence in the sector and early certainty of the initial round of offshore projects. Which model to select will depend on the specific circumstances, as well as the commitment of the government either at the national, regional or local level in supporting the OW industry and the green transition.

If a more strategic approach to planning of OW ports is initiated, this should include stakeholders from both the public and private sector.

For the first port development projects in both Gujarat and Tamil Nadu, upgrades should be designed based on inputs from the industry. . As the sector matures and the build-out increases, the Offshore wind cluster approach could be an interesting opportunity – particularly for the Tamil Nadu OWZ. In the meantime, early stakeholder engagement and networking to develop a common vision for the cluster approach should start immediately.

Indian Port Authorities and port operators could benefit from learning from European ports that already have a vision and a brand as an offshore wind port. Providing an opportunity for exchange of best practice, know-how and to jointly discuss opportunities and challenges that ports face would be helpful for Indian ports. For example, a twinning partnership between Indian Ports and the Port of Esbjerg in Denmark could be a first step.

Finally, addressing high project and debt financing costs using concessional financing is an immediate entry point for offshore wind projects. In India, a full-service package of concessional financing can be deployed in conjunction with public and private interventions for the first offshore wind projects in both Gujarat and Tamil Nadu regions.

Financial support could be targeted to different parts of the energy supply chain, including the port sector as they have an essential role in supporting offshore wind. A public private shared approach to the needed infrastructure, would reduce the total private sector CAPEX requirement.

13. Concluding analysis and recommendations

The development of 37 GW of offshore wind translates to an investment in the neighbourhood of $100 billion[14]. Recognizing the significance of this, port owners and local government officials in Tamil Nadu, Gujarat and neighbouring states that are interested in being a part of this development may look to gain an early foothold on this and prepare accordingly. Relatively small investments by both port owners and the government can be made now that could provide the first steps toward this goal and plan to further expand future investment in port infrastructure as the offshore wind zones are auctioned off and development grows.

13.1. Key findings

- The analysis has shown that none of the potential installation port candidates has readily made assets to support OW installation, particularly for 1 GW developments and 15+ MW turbines. Fortunately, each of the ports identified has sufficient space available to allow for development of at least one purpose-built terminal with an adjoined yard.

Tamil Nadu OWZ

Costs to develop an OW terminal to serve the Tamil Nadu OWZ will require an investment between 750 to 1000 INR Crore (90 to 120 million USD) and construction can be accomplished within 30 months.

In the OWZ off the coast of Tamil Nadu where the bulk of the OW development is expected both Vizhinjam Port and Tuticorin Port are capable of developing the port infrastructure to meet this goal; however, Tuticorin Port might be a more ideal choice due to its proximity to the adjacent OWFs, protected harbour and potential capacity to support the expected demand. Although the development of Tuticorin requires a greater investment, the result is a larger terminal dedicated to OW with potential capacity to meet the OW goals of GoI.

- It should be noted that to accomplish the installation of 30 GW of offshore wind using modern WTIVs with currently available installation technology is not insignificant and will require three to four installation vessels working around the clock for many years. To keep such pace of installation it will require to have the necessary port infrastructure, as outlined in the benchmark, in multiple locations.
- Both Tuticorin and Vizhinjam ports are suitable to support OW development in the Tamil Nadu OWZ, and have the potential capability to host multiple terminals which conform to the infrastructure benchmark as outlined in this report. However, to have even one of

[14] estimated based on CAPEX estimation presented in FIMOI report (https://coe-osw.org/the-fimoi-report/) for OW projects in Tamil Nadu FID 2025 (INR207.5 mINR/MW)

such terminals ready in two to three years, development would have to begin immediately. Support for OW component staging and installation is counterintuitive to traditional port business model and will require the ports to provide prime real estate developed to demanding specifications for a relatively low volume of cargo and short lease periods.

Gujarat OWZ

Costs to develop an OW terminal to serve the Gujarat OWZ will require an investment of up to approximately 620 to 760 INR Crore (75 to 92 million USD) and construction can be accomplished within 24 months.

Here both candidate ports have the potential to develop OW; however, Pipavav appears to have an advantage due to its significantly closer proximity and relatively subtle tidal range.

- In the case of the Gujarat OWZ, where the line of sight on the potential project pipeline is more limited, it is not certain that there will be a sufficient motivation to precipitate timely investment from port owners. As such, some sort of financial support or incentive scheme might want to be looked at.
- Through interviews and feedback with OW industry professionals a benchmark of necessary OW port criteria has been established to help port owners and operators understand the demands of OW terminals and how to develop infrastructure to support these needs. This includes spatial dimensions for navigation, berth lengths, yard areas, clearances, etc

13.2. Recommendations

This study is intended for stakeholders both locally in India, including port owners and operators, national, state and local authorities, as well as private stakeholders from the offshore wind industry, including manufacturers, developers, vendors and contractors, to inform the next steps towards development of offshore wind in India. The following recommendations are for consideration by key stakeholders.

13.2.1. Government agencies

GoI and the states adjacent to the Tamil Nadu and Gujarat OWZs can consider the following to help reach GoI’s goal of developing offshore wind in India.

- Further engage with owners, operators and local authorities of short-listed ports to investigate ambitions, motivation, challenges and pique their interest to participate.

- Facilitate contacts between international actors (developers, OEMs, contractors) and port owners.
- Identify initial projects that require port assets.
- Engage in feasibility studies that contain due diligence reports and are focused on specific development for each port. These should demonstrate financial viability, socio-economic impact, technical feasibility, and environmental impact assessment.
- Expedition of permitting and environmental clearances. If necessary, the authorities responsible for environmental could consider dedicating staff to review and process permits and environmental clearances.
- Develop financing opportunities to incentivize OW port/terminal development. Also consider ways to motivate and/or partially de-risks asset owners.
- Development of a locally sourced skilled work force including job training programs.

13.2.2. Port owners and operators (for both T&I and O&M)

- Dialogue with potential partners / tenants to learn their requirements.
- Develop feasibility studies which identify in detail requirements of potential OEMs/developers for development of an OW terminal. Additionally, develop a business case that considers the eventual evolution of the OW terminal to other uses in the future, e.g., container cargo, break-bulk, bulk, project cargo, cruise terminal, etc.
- Update masterplans to allow for development of OW-targeted assets and ensure compatibility with traditional cargo portfolio. These master plans should consider O&M development if feasible.
- Review their existing infrastructure with respect to the standards outlined in the baseline and begin early planning necessary improvements to accommodate offshore wind.

13.2.3. Developers and OEMs

- Provide an in-depth look at the key ports that are most viable for offshore wind development in India to begin planning installation schedules and approaching ports.

13.2.4. Other stakeholders (contractors, vendors, suppliers)

- Start an early dialogue with both port owners and developers regarding how to proceed with necessary infrastructure improvements. This could include development of forums focused on OW development such as a local Chamber of Commerce, conferences, etc.

13.2.5. Long term development

In cases, such as the Tamil Nadu OWZ where project OW development is likely to extend to more than 10 years out, further activities can include:

- Education of port owners and local officials about specificities of OW-related port business and the need for outside vendor and contractor services that will be necessary to support this local industry. This can include accommodation for crew, repairs, refuelling, etc. and the opportunity created by this “economic engine” will drive local economic development.
- Realistic portioning of the pipeline that simultaneously allows for multiple terminals to capture close-to-full utilization of each developed asset, and support different parties in each of the projects such as contractors, OEMs, developers, etc.
- Engage in dialogue with OEM’s and steel fabricators to enable co-location and maximization of local economic development.

13.2.6. New terminal development

Ports intending to develop a new multifunctional terminal suitable to support staging of components for 1GW developments, specific steps should involve:

- Dialogue with potential partners / tenants to learn their requirements
- Due diligence / existing asset conditions (if intended for upgrade, retrofitting or demolition)
- Bankable feasibility study demonstrating financial viability, socio-economic impact, technical feasibility, environmental impact assessment.
- Preliminary and / or detailed design, depending on the project delivery model (Design Build, Design Bid Build, Private Public Partnership, Early contractor involvement, etc).

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15. Appendix

15.1. Case Studies in Offshore Wind

Introduction:

When the Ports of India will be expanding in order to serve the OW industry, it would be important that they review the experience from other ports that have enter the OW industry. European Offshore wind ports have been an important stakeholder in growing the OW -Industry and have much experience that could be relevant for India. On the other hand, other countries, including the US are just entering the OW industry, with an ambitious build-out target for the next decade. The cases represent the two different OW development models, namely the wind developer model and the wind cluster development model.

Case 1: New London State Pier Infrastructure Improvement projects[15]

Vision Statement:

It is the goal of the Connecticut Port Authority (CPA) to make generational improvements to transform the State Pier in New London into a state-of-the-art heavy-lift capable port facility that will accommodate a wide variety of cargoes, including wind turbine generator staging and assembly. The proposed State Pier infrastructure improvements are being designed to address previously identified facility shortcomings and enhance the State Pier facility and site conditions to accommodate future cargo needs and capitalize on opportunities for the State of Connecticut.

General summary:

The Connecticut Port Authority is the owner of the State Pier in New London Connecticut. The pier is more than 100 years old and was barely in working conditions. A 2011 State Pier Needs and Deficiency Planning Study recommended various improvements to State Pier, but only if a commercial partner could be identified and involved.

- In 2017, there was an emerging interest from OW developers in the port. Particularly, Ørsted and Eversource were interested and looking for a stagging port for three windfarms Revolution Wind (700MW), Sunrise Wind (880 MW), and South Fork Wind (132 MW) with a combined capacity of more than 1.7GW.
- Summer of 2018, there was a solicited RFP for a 20-year concession for port operator and/or wind developer.
- Spring of 2019, the terminal operator “Gateway New London” was awarded the concession. Gateway is the only independent and privately owned marine terminal in the state of Connecticut.

[15] https://statepiernewlondon.com/

- May of 2019 a MoU between, the Port Authorities, and Ørsted/Eversource and the Gateway was signed.
- Feb of 2020, a final Harbour Development Agreement is signed.

The Harbour Development Agreement[16] outlined how to redevelop State Pier into a state-of-the-art port facility through a combined public-private investment of USD 157 million.

The infrastructure upgrades will make State Pier as a modern, heavy-lift capable port and meet the facility requirements of the offshore wind industry. The improvements will benefit the port's long-term growth by increasing its capacity to accommodate heavy-lift cargo for years to come while maintaining.

The CPA will oversee the project while working in collaboration with Ørsted and Eversource throughout the permitting and construction process. The construction was original planned to last about 2 years.

Following the completion of the infrastructure upgrade project, Ørsted and Eversource joint venture company will enter into a ten-year lease agreement, which will allow it to use State Pier for wind turbine generator pre-assembly and staging to power their three wind farms.

During periods where Ørsted and Eversource are not using State Pier, Gateway Terminal will market the facility to other customers to ensure maximum utilization of State Pier.

It is estimated that about 400 jobs will be created for the reconstruction and another 400 jobs during the installation of the windfarms.

Financial details:

- Initial investment estimates: USD 157 million
- Port Authorities to invest: USD 98 million but would also be responsible for any additional investment costs.
- Wind Developer (Ørsted /Eversource)
- USD 50 million towards upgrades
- USD 20 million in lease over 10 years (USD 2 million/ year)
- Subtotal USD 70 million
- In addition, Wind developer would pay an incentive for early completion USD 10 million to be split between PA USD 7.5 million and City of New London USD 2.5 million.

The Wind Developer and the City of New London has also agreed to a host community agreement[17], where the developer would pay USD 750,000 annually for five years to the city for

[16] https://portal.ct.gov/Office-of-the-Governor/News/Press-Releases/2020/02-2020/Governor-Lamont-Announces-Final-Harbour-Development-Agreement-for-New-London-State-Pier

[17] https://insideinvestigator.org/wp-content/uploads/2022/04/2021-02_NewLondon-Host-Community-Agreement.pdf

a total of USD 5,250,000. This agreement is essentially to make the city a “goodwill ambassador” for the project but also to provide direct benefits for the city and not just the Port Authorities.

In addition, the PA would receive from the Gateway Terminal Operator annual lease payments.

The Gateway terminal operator would be entitled to charge additional cargo and shipping fees for installation and OEM vessels using the port, as well as additional fees for other usage.

The investment upgrades may now be in the USD 250 million range and is expected that the port will be operation by medio 2023, just in time for installation start of the Revolution Wind.

Figure 61: Case Study 1 – New London State Pier Infrastructure Improvement projects

Case 2: The Green Port of Hull and the Humber Offshore wind cluster.

While there has been OW activities since the early 2000 in the UK when the government committed to rapid increase in offshore wind deployment to meet the 2020 EU renewable energy target., it was only when the more ambitious target of 33 GW by 2020 was announced that international stakeholders were prepared to invest in the UK offshore wind supply chain to provide local content and lower the investment cost (LCOE).

UK ports are not publicly owned and must therefore be, largely financed privately, and the UK government was constrained in providing financial support to upgrade the port. However, in 2010, the government announced it would support such investment needs by pledging to make £60 million available for the development of ports, to help manufacturers of offshore wind turbines looking to locate new facilities in the UK.

The WTG manufacture Siemens had been contemplating investing in a production facility of offshore wind turbines and with the UK government support, Siemens, and the Government in 2010 signed a MoU outlining that Siemens would be willing to invest more than £80 million in a production facility.

Siemens executed a location study and the shortlist criteria included:

- Good access to markets
- Suitable configuration of the site: ability to support the size requirements
- Attractiveness of the financial offering
- Sufficient strength and depth offered by partners
- Strength of political support.

To better respond to Siemens's solicitation, local stakeholders (Hull City Council, Yorkshire Council (state level), Hull University and port owner) came together to create the Green Hull Port Initiative.

The vision was to establish Hull and the region as a leading centre for renewable energy. This entity would also include the provision of training and upskilling, thus addressing the concern of Siemens regarding the local skill set. It would also prepare for the skills required to attract other players in the renewable supply chain to set up in the region thereby creating jobs and economic development for the region.

Eventually four locations were considered, and the final winner was the Port of Hull. The Port is privately owned by the Associated British Ports (ABP). Among the reasons that Hull was selected included, proximity to the Humber Offshore wind area[18], the length of the quay and the reputation of ABP and their financial commitment to invest in the upgrades.

In January 2011 Siemens and ABP signed a MOU in 2011, outlining Port of Hull was the preferred location.

In 2012, the city and regional council was awarded £25 million from a regional growth fund to lead the Green Port Growth Program that should attach inwards investment into renewable sector, creates news jobs and uptrain existing jobs.

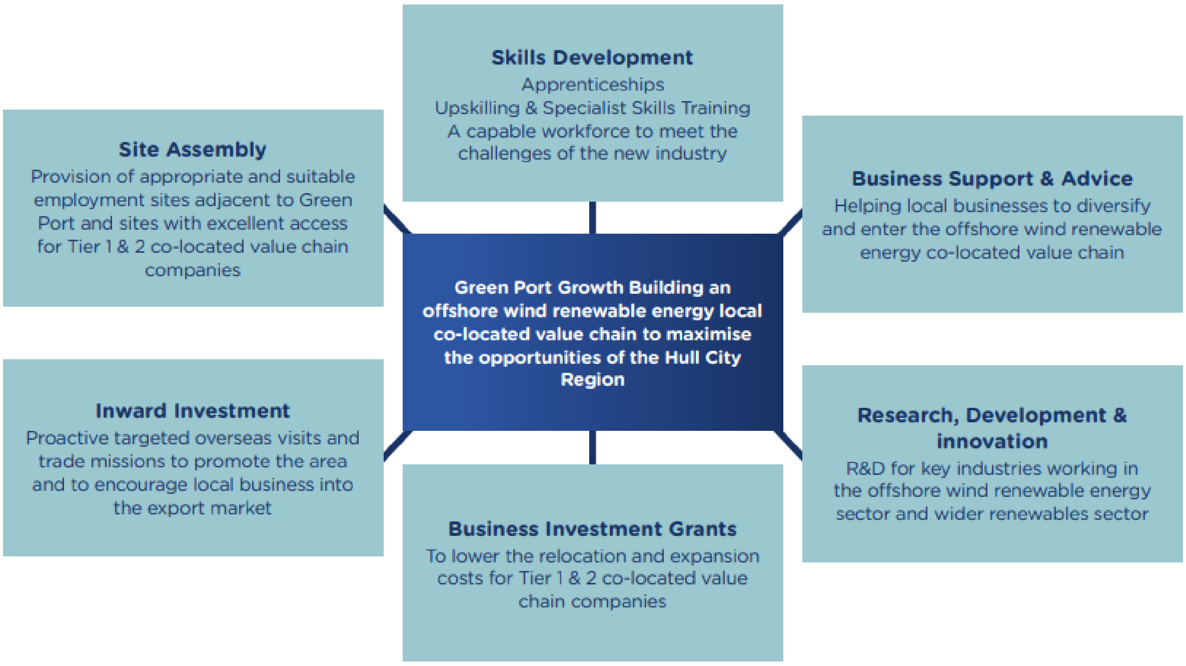

Figure 62: Case Study 2 – The Green Port Growth Programs and its activities.

Finally, in 2013, and investment agreement between Siemens and ABS was finalized outlining that Siemens would invest about £160 million in a manufacturing facility and that ABS would invest another £150m in the infrastructure development at Alexandra Dock to support Siemens's facilities.

Construction began in 2014, however instead of having a turbine manufacturing plant, the plans changed to a rotor blade manufacturing plant that would be at Alexandra Dock site. Construction was on time and the first installation vessels were loaded in January 2017. In 2021, it was announced that additional investments would be doubling the size of the manufacturing facilities. Part of the investments would come from the UK governments Offshore Wind Manufacturing Investment Support scheme.

[18] The Humber Offshore wind area has is home to six operational offshore wind farms supplying 2.5GW of clean energy to British homes and businesses, and a pipeline of projects including Hornsea 2, 3 and 4. The ambition is to deliver at least 10GW by 2030, representing 1/3 of the UK's total energy production.

Attracting Siemens to the port of Hull was an important catalyst for the broader region, however the Regional Development Agency for Yorkshire and the Humber had identified renewables as a potential growth area for the wider Humber region as early as 2006. A few miles down the river is another port: the port of Grimsby, that is also own by ABP. Grimsby's port is the closest major port to existing Round 1 and 2 wind farms and to the major Round 3 sites at Hornsea and Dogger Bank and has become a centre for offshore wind companies' Operations and Maintenance (O&M) activities. Dockside development specifically took place in Grimsby to improve vessel access and berthing to attract O&M operations. Both Orsted and RWE have established O&M operations in the Port.

Over the last 12 years significant progress has been made through a strong partnership between the business community, national, regional, and local government, educational partners and a range of organizations that have seen high levels of inward investment, increased demand for skills training, growing employment levels and regenerated urban centres. The growth was essentially organic market-oriented growth but since 2018 there has been a more systematic and focused strategy inspired by industrial cluster theory. Today the Humber Offshore wind cluster is one of eight OW clusters in the UK and is consider the leading centre of excellence[19].

Figure 63: Case Study 2 – The Humber Offshore Wind Cluster.

[19] A comprehensive and detailed description of the Humber Offshore Wind Cluster is available at https://www.humberoffshorewindcluster.co.uk/

Case 3: Port of Belfast and OW

Targets were set by the Irish Government in the Climate Action Plan 2021 for 80% of electricity to be generated from renewable sources by 2030, of which 5 GW is to be from installed offshore wind. To achieve these targets, a significant number of offshore wind projects are planned around the Irish coast.

Belfast Harbour has handed over its new Pound 50 million offshore wind terminal to DONG Energy and Scottish Power Renewables. The terminal, the first purpose-built offshore wind installation and pre-assembly harbour in the UK or Ireland, will be used as a hub to help service a market valued more than Pound 100 billion. It is expected that up to 300 jobs are to be created, ranging from welders to electricians and engineers.

Belfast Harbour is currently suitable to support the construction of an offshore wind farm, showing the "urgent" need to bolster other ports to take advantage of the coming renewable energy revolution.

According to Wind Energy Ireland, such investment opportunities could be lost to other countries if they were not supported to make infrastructural improvements. The large-scale wind and hydrogen energy production off Ireland's west and south coast is seen as an economic opportunity and a "game-changer" for the country's transition to renewable energy.

Figure 64: Case Study 3 – Offshore wind facilities at Port of Belfast

The Harbour has over the years helped bring other industries to Belfast such as shipbuilding and aerospace by investing heavily in infrastructure and land reclamation. This is a continuation of that strategy and a demonstration of their long-term commitment to enhance the local economy.

Belfast's facilities include a maintained channel depth of 9.3 m, berths for vessels of up to 9.5 m draught, no air restrictions and a purpose-built 50-acre offshore wind terminal which includes a 480-m heavy-duty quay (capacity up to 50 ton/m2) with jacking-up capability for installation vessels. To date, Belfast Harbour has been instrumental as a staging port to support construction of the West of Duddon Sands, Walney Extension West and Burbo Bank Extension offshore windfarms.

Figure 65: Case Study 3 – Port of Belfast OW Terminal

15.2. Components storage and handling

Figure 66: Figure Crawler cranes used in loadout of many major OWF components.

Figure 67: Loading of Monopile foundations and transition pieces

Figure 68: Transportation of monopiles with SPMT

Figure 69: SPMT for transportation of large and heavy components

Figure 70: Tower assembly and loadout (source: Port of Esbjerg)

Figure 71: Open storage (source: Port of Esbjerg)

Figure 72: Monopile foundation on steel cradles prepared for loadout

Figure 73: Monopile stored on earth embankments

Figure 74: Storage of transition pieces. Bladt Industries

Figure 75: Transport of transition piece. Ableuk


Figure 76: Storage of transition piece. Abicor Binzel

Figure 77: Loadout of jacket foundations by ring crane. Mammoet.