DECEMBER 2020
DANISH ENERGY AGENCY, EMBASSY OF DENMARK TO KOREA, KOREAN ENERGY AGENCY

JOINT STUDY ON WIND FARM PORT CONSTRUCTION FOR FOSTERING WIND INDUSTRIES AND CREATING JOBS

FINAL REPORT

COWI

ADDRESS COWI A/S
Parallelvej 2
2800 Kongens Lyngby
Denmark

TEL +45 56 40 00 00
FAX +45 56 40 99 99
WWW cowi.com

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ABBREVIATIONS

Abbreviation	Term
A.L.L.W	Approximated Lowest Low Water Level
CAPEX	Capital expenditure
CTV	Crew transfer Vessel
DEA	Danish Energy Agency
DKK	Danish Kroner
DL	Datum Level
FTE	Full time equivalent(s)
FOW	Floating offshore wind
ha	Hectare
IO table	Input-Output table
KEA	Korean Energy Agency
LCOE	Levelized cost of energy
LOA	Length overall
LoLo	Lift on – Lift off
MLLW	Mean Lower Low Water
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
OPEX	Operational expenditure
OW	Offshore wind
OWF	Offshore wind farm(s)
OWI	Offshore wind industry
RoRo	Roll On – Roll Off
SGRE	Siemens Gamesa Renewable Energy
SOLAS	International Convention for the Safety of Life at Sea
SOV	Service operation vessel(s)
SPMT	Self-propelled Modular Transport
TOC	Terminal Operating Company
USD	US dollar
UDL	Uniform distributed load
WTIV	Wind turbine installation vessel(s)

The following currency conversion rates were used in this study:

- 1 USD to 1111 South Korean won
- 1 USD to 6.25 DKK
- 1 USD to 0.84 EUR

EXECUTIVE SUMMARY

As Korea is gearing up to meet the ambitious goal of 12 GW offshore wind capacity by 2030, the country is investigating ways to enable this build-out. One of the required infrastructures for large-scale implementation of offshore wind farms is sufficient port capacity. To this end, the Danish Energy Agency and the Korean Energy Agency have jointly commissioned COWI to perform a desktop study which:

- Estimates the construction work that is required to upgrade/develop port facilities
- Estimates the number of local jobs that will be created and the impact on the local economy

COWI began this task by developing a benchmark 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
- A single OW installation project is not sufficient to pay for infrastructure investments
- Convenient location and strategic investments can kick-start a future offshore wind hub
- Colocation of manufacturing facilities is not a necessity for successful OW port business
- Existing and un-utilized general purpose, RoRo and industry quays can be repurposed to OFW without prohibitive up-front investments.

This study shows that the installation and operation and maintenance phases of the offshore wind farm lifecycle are the most important in creating local impact. The port-related operations (such as pre-assembly, temporary storage of parts before load-out to wind farm) in these phases are not only critical enablers in the construction of OWF, they must also be in relative proximity to the site to be cost efficient. Manufacturing facilities, on the other hand, are part of a complex supply chain spread on different locations and there are many different production constellations which can successfully work for a particular wind farm.

These port examples were supplemented with overview of the main drivers for setting harbor, quay and yard properties such as cargo and vessel characteristics. This combination was used to determine a baseline for the main port properties, with a focus on installation port for wind farms with bottom-fixed foundations. In the same way, a baseline was produced for port facility to support the operation and maintenance (O&M) phase. A baseline for floating foundations was provided for indicative purposes, as the track record necessary to develop a reliable benchmark does not yet exist.

In order to estimate the upgrade / construction work needed to meet this benchmark, several Korean ports with potential to serve the wind industry were selected as case studies. The ports of Busan, Ulsan, Pohang, Daesan, Mokpo and Gunsan were profiled and gap analysis was performed against the benchmark for fixed-foundation installation ports. It is important to note that no existing and empty wharves were identified in this study, which indicates that new wharves will need to be constructed in the mid-term to meet the offshore wind goals.

Based on the gap analysis, the ports of Gunsan and Mokpo were selected to perform case studies on the necessary upgrade works and economic impact. Both roadmaps describe construction of new terminals on plots that have been earmarked for offshore wind-related development. As seen in the survey of European ports, the roadmap assumes that offshore wind activities are spearheaded with the turbine staging facility, expands with O&M and introduces co-location only in subsequent stages.

The economic impact was calculated for these upgrades and, additionally, for the construction and the O&M of one 500 MW offshore wind farm. The biggest impact is generated by construction of the wind farm, then followed by O&M (over the whole wind farm lifetime). The economic impact in FTE of port construction is considerably less.

	CAPEX	Total local employment effect
Gunsan Port construction	USD 196.3 million	3,220 FTE
Mokpo Port construction	USD 103.5 million	1,698 FTE
Construction of a 500 MW OWF	USD 1,750 million (USD 3.14 million/MW)	23,180 FTE
O&M of a 500 MW OWF (yearly)	USD 28.5 million/year (USD 0.057 million/MW/year)	339 FTE/y
O&M of 500 MW OWF (25 years)	USD 712,5 million	8,483 FTE

In terms of both economics and port usage, it is recommended to aim for a stable pipeline rather than a fast and immediate growth. If the pipeline is kept stable, the sector will also remain in work and the slow growth will have a more long-term effect on the economy, rather than a temporary effect of quick growth which then afterwards leaves the sector unemployed for longer periods of time. A stable pipeline will also increase the likelihood of sustaining a local supply chain and thereby a high share of local content.

1 Introduction

1.1 Purpose

As per the assignment terms of reference, the main objectives of the specific assignment are to:

- Estimate the construction work that is required to upgrade/develop port facilities to accommodate extensive offshore wind construction in Korea.
- Estimate the number of local jobs that will be created and the (positive) impact on the local economy both during the process of upgrading the ports for offshore wind activities and during the operation and maintenance work.

The purpose of this study has been to investigate these questions at a high-level using case studies. The conclusions in this report are aimed at indicating the scale of upgrades and benefits and can serve as a starting point for future, more detailed, studies.

1.2 Scope

The scope of this study is generally based on the terms of reference for the assignment. In addition to those terms, COWI notes the following clarifications:

- The case studies for European ports have been chosen to give a good wide view of European experience and do not represent an exhaustive survey.
- The most common technologies and cases are covered in this study due to its high-level nature. Rare or niche solutions, such as gravity foundations for offshore wind turbines, are not covered.
- When examining Korean ports for potential OWF wharves, only unoccupied wharves were considered. A more detailed study could also look into the re-purposing of wharves currently in use at a port, in close collaboration with the port authorities.
- This analysis does not represent a study of the technical feasibility of building any port structures
- In line with the ToR, analysis was generally based on one 500 MW wind farm

1.3 Korean Offshore Wind Sites

The 2020 “Offshore windfarm development plan” published by the Korean Government is a central document forming the basis of this study [1]. This document shows three major offshore wind farm sites which are targeted. Figure 1-1 shows these sites, along with English translations of the names that will be used to refer to the sites in this study:

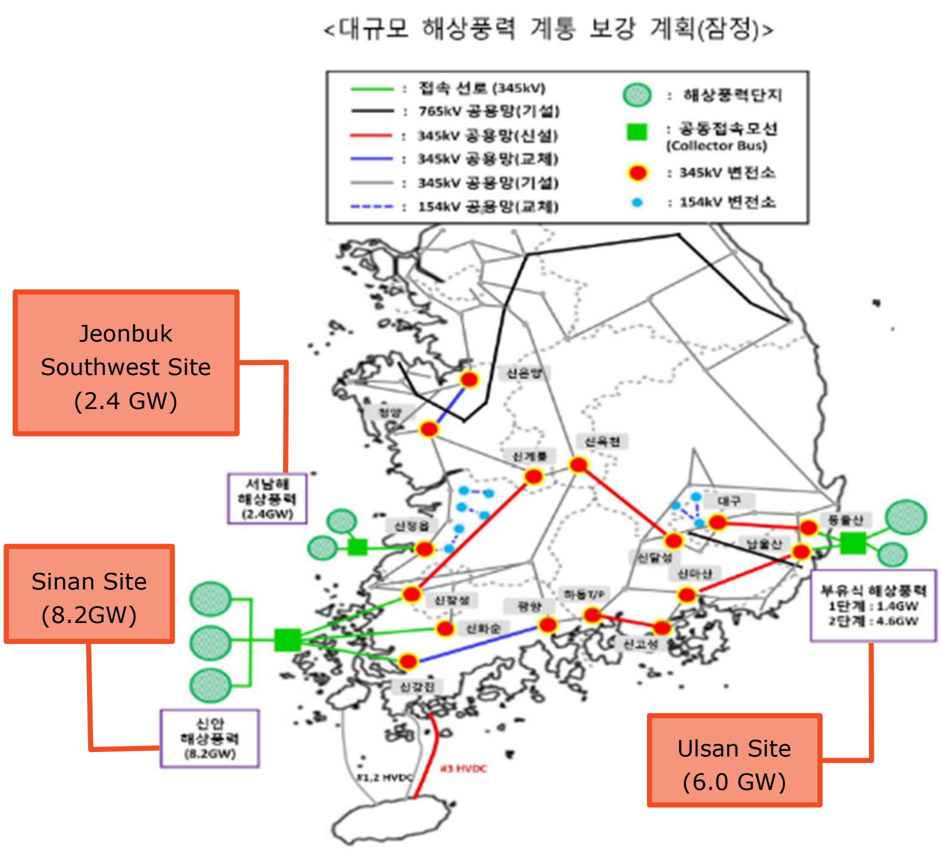


Figure 1-1 Planned major offshore windfarm sites [1]

The Jeonbuk Southwest site is planned with a total of 2.4GW, Sinan site with 8.2GW and Ulsan with 6.0GW. Jeonbuk Southwest site is the fastest mover and is expected to start the construction in 2022.

1.4 Guide to an 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 bodies of water. Turbines are typically grouped into arrays which form an offshore wind farm (OWF).

Despite harsh offshore environments, logistical challenges and expensive initial projects, industry has over the time matured to offer Levelized Cost of Energy (LCOE) comparable to gas-fired power plants. This was achieved through continuous technological innovations, increase in turbine size, optimization of supply chain, purpose-made vessel and other factors.

An offshore wind farm (OWF) typically consists of several components schematically shown in Figure 1-2.

Turbines are typically connected to each other by inter-array cables in strings of 6 to 10 turbines. Historically, inter-array cable voltage has been 32 to 34.5kV depending on the country, but more recent projects are adopting a 66 to 69 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.

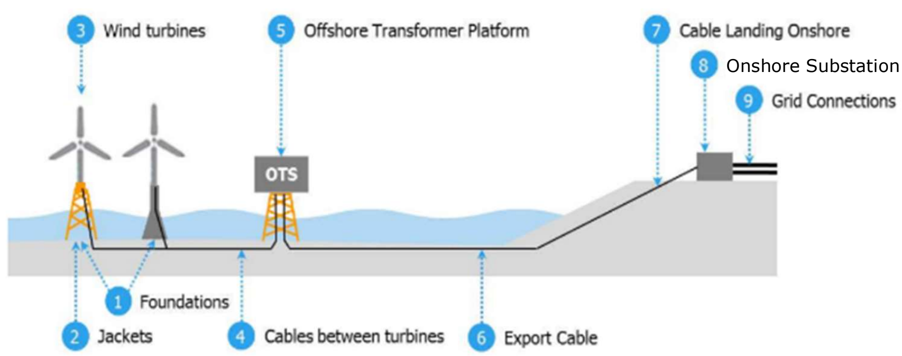


Figure 1-2: Schematic of the OWF components (source: C-Power website)

OWF can have any number of wind turbines, depending on the size of location. Commercial projects start at 200MW. The world's current largest OWF, Hornsea 1, commissioned in 2020, has 174 turbines of 7MW for a total of 1.2GW installed capacity. OW turbines have steadily increased in size over the previous 20 years. In current projects turbines are between 6MW and 8MW while project in the pipeline can have turbines up to 12MW (15MW announced).

Components of a typical OW turbine are shown on Figure 1-3. Choice of foundation is governed by depth and geotechnical conditions. Great majority of projects is based on monopile foundations that remain the most flexible concept and still keeps pushing the boundaries. Jackets remain reserved for greater depths (currently deepest is 45m) and geotechnical conditions unsuitable for monopiles (too hard for driving or too soft to provide sufficient lateral support).

A typical timeframe for development of OWF in Western Europe is 3-5 years (construction lasting 1-2). In other countries this process can take longer time depending on various factors such as permitting and supply chain. Typical current design lifetime is 25 years (and increasing).

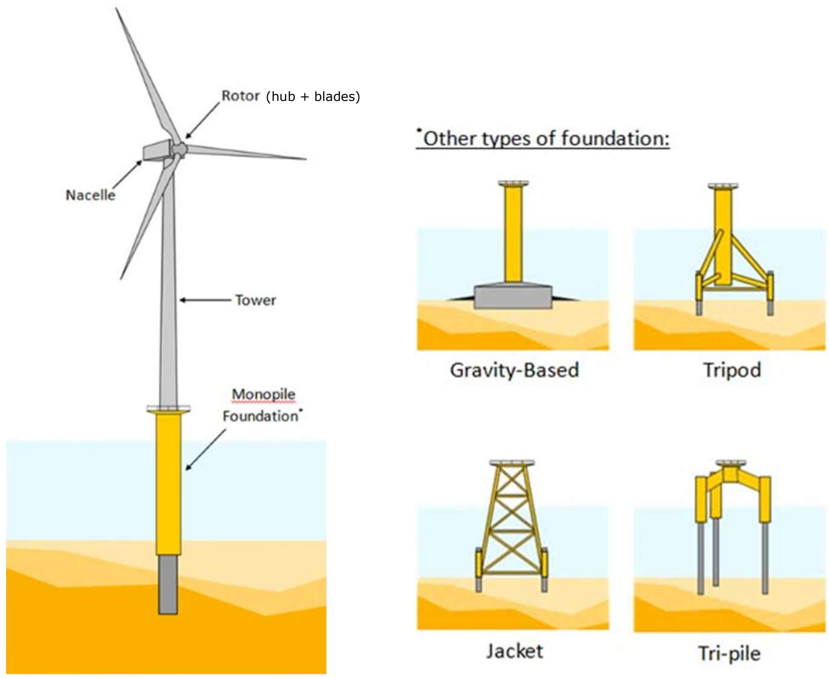


Figure 1-3: Principle components of an OW turbine (source: EWEA)

1.4.1 Role of ports in offshore wind

OWF are inseparable from port operations due to the very fact that access to the wind farm location must be conducted by seafaring vessels. Roles of ports in the offshore wind industry (OWI) are also evolving as the industry is maturing and are shaped by markets which dynamically price the availability of facilities, vessels, components, weather windows and distances between different sites of interest.

The life cycle of an offshore wind farm can be divided into 5 phases. These are shown in Table 1-1, along with typical activities and functions that ports facilitate.

Table 1-1: OWF lifecycle and role of ports, with the focus phases of this report marked in orange

Phase #	OWF phase name	Role of port
1	Planning, design, development and consent	Survey vessels, test areas, installation of wind measurement equipment
2	Manufacturing and procurement	Loading, unloading and storage of main components (turbine and foundations) to/from production facilities; Fabrication of sub-station (foundation and topsides); Export, import and trans-shipment of components;
3	Installation and commissioning	Pre-assembly and staging of turbines and foundations;
4	Operation and maintenance (O&M)	Berthing of O&M vessels, hosting of spare parts storage and crew charter;
5	Decommissioning and disposal (D&D)	Break-up and recycling

The focus of this report will be 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 critical enabler in the construction of OWF but also must be located in relative proximity to the site.

The role of ports in production activities, which are a part of Phase 2, "Manufacturing and procurement", are recognized but discussed only from the perspective of co-location potential. This is because it is not essential that production facilities are located near the port. As the experience from European ports has shown, the production facilities can be located in entirely different ports or even countries. The offshore wind (OW) supply chain is complex and there are many different production constellations which can successfully work for a particular wind farm.

Furthermore, experience from European wind farms has shown that manufacturing at ports is often a second-mover, which is only prepared to make significant investments into building up new facilities when it is clear that the port has a long-term pipeline for OW which warrants the investment.

As the aim of this study is to estimate creation of jobs from the port-related activities, keeping the focus on activities that are inseparable from location will provide a more accurate picture.

For similar reasons, other operations included in Phase 2, such as substation fabrication and installation and cable laying are not considered in this study.

Decommissioning works of Phase 5 is another work-intensive activity which is closely port-related. However, with Korean OWF deployment only starting, it is considered not to be relevant for this report.

Finally, the activities done in Phase 1, Planning, design, development and consent, do not typically require dedicated port planning or development.

1.4.2 Offshore wind installation logistics

A typical process of sourcing and installation of components in OWF is shown in Figure 1-4.

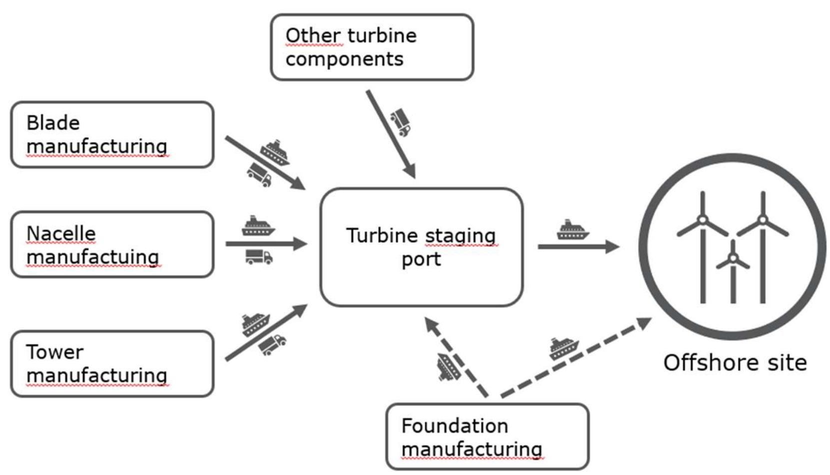


Figure 1-4: Typical process of sourcing and installation of components (source: COWI)

Turbine components, such as blades, nacelles, etc. are manufactured in other locations (in-land or in vicinity or other ports) and transported to a staging port. A staging port serves several functions:

1 Staging (marshalling), where components are unloaded and stored together on site.

2 Pre-assembly, where towers (which were delivered in several pieces) are assembled into the upright position and stored that way on site. In similar ways, nacelles and hubs can also be finished with smaller components.

3 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).

Installation of turbines is carried out by specialized jack-up vessels (see section 2.2.3). Charter of these vessels is more costly than ordinary cargo vessels and their availability can be limited which is why staging process is intensive. Port facilities are in turn planned as to minimize (or ideally, eliminate) any down-time during installation.

Ports used for staging operations are often called base ports for installation. Main characteristic is flexibility of areas and relative proximity to an offshore site.

Inbound traffic of cargo to the installation base can happen in three ways:

- by land from hinterlands
- by land within the port
- by sea

How the incoming deliveries of components to the installation port is executed varies between each specific case and it depends on interplay of factors, of which the two most important are:

- Location of production facility
- Cost of transport

Example of Denmark shows that manufacturers have been successful in solving the road-transport puzzle. Currently, most of the component factories are located inland, with a few examples given in Table 1-2:

Producer	Location (Denmark)	Component
Siemens Gamesa	Brande	Nacelles
Vestas	Viborg, Skjern	Blades
LM Wind Power	Lunderskov	Blades
Welcon	Give	Offshore turbine towers

Table 1-2 Locations of some inland component factories

These factories ship components by road traveling up to 200km to reach ports or testing facilities.

Figure 1-5: Road transport of OWT components

However, as the components are increasing in size, road traffic may become cost prohibitive or even impossible (too heavy or too large to clear overpasses, tunnels, and bridges). As the industry matures there has been a clear trend towards establishing production facilities close to ports and markets, preferably both.

In case of foundations, transport by road is not possible because of the weight and production facilities are always located in the industrial parks with direct access to quays. Foundation sourcing is more flexible than turbines: they can be shipped directly to the installation site, staged in a separate port (foundation staging) or staged in the same port as for the turbine installation. Installation of foundations is a completely separate operation from turbines and sometimes executed by a different contractor and set of vessels altogether.

1.4.3 Floating offshore wind

Around 80% of the offshore wind resource is located in waters deeper than 60m, which is generally seen as the limit for fixed foundations. In addition, to this, wind speeds are usually higher and more consistent with increase of distance from the shore. This implies that majority of the OW potential is in the areas where bottom fixed foundations are borderline feasible, cost prohibitive or simply technically unsuitable.

Floating offshore wind (FOW) presents an opportunity to unlock this potential and put LCOE on the same downward track that has been achieved for the fixed foundations over the past 20 years.

FOW is now reaching maturity for commercial deployment with operational demonstrator projects installed in both Europe and Asia. As of 2020, there are 11 such projects totaling 74 MW of electricity generating capacity. Considering projects under construction and those that have secured permitting, there could be almost 350MW installed in next few years. If the momentum persists, exponential growth could lead to 3-7 GW by 2030 [2].

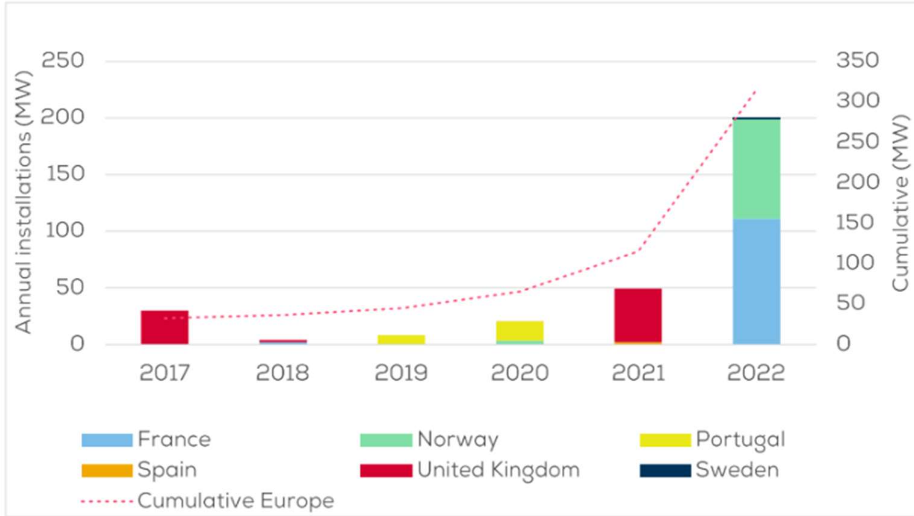


Figure 1-6: Timeline of FOW projects in Europe [2]

One of the main challenges for deducing a reasonable benchmark is that the track record of FOW simply does not exist. The projects currently in operation are demonstrators and it is difficult to project benchmark requirements from such a small and inconsistent pool. Further, there are several concepts in competitions that have very different assembly and installation requirements.

There are four main types of FOW platforms are currently in demonstration:

Barge	Stability of the barge type platform is ensured primarily by its water plane area moment given the large footprint and shallow draught. The production of the structure is completed onshore and towed to location. Structure is anchored using catenary mooring. A typical weight of current floaters is 4000t.
Semi-submersible	This type of platform is stabilized by keeping the center of gravity below the center of buoyancy by adding ballast water. It is executed as several separate hulls connected by jacket or frame structure with turbine placed in the center or one of the corners. It also has a larger draught than barge type (when deployed) and uses catenary mooring. A typical weight of current projects is 2500t.
Spar-buoy	A cylindrical structure that is stabilized by keeping the center of gravity below the center of buoyancy using solid ballast. Spar-buoys require considerable draught of up to 90m when in operation. It uses catenary mooring. Typical weight of current projects is 2500t.

Tension Leg Platform	TLP is a lighter floating structure that maintains buoyancy through interaction of buoyancy and tension force on the anchors. It has a shallow draught and uses straight mooring lines which project directly to the seabed. There are no currently installed projects but are under construction.

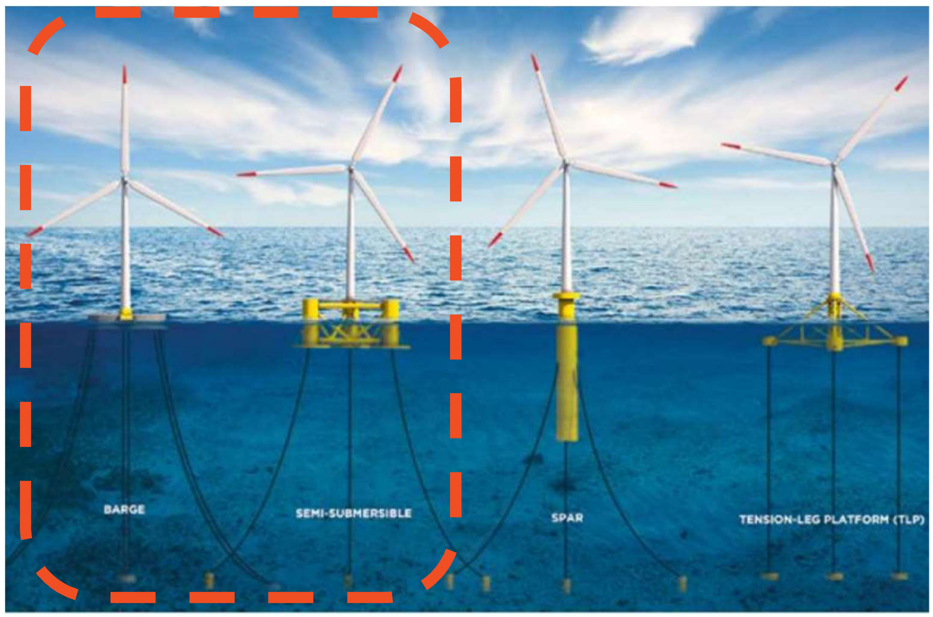


Figure 1-7: Four competing FOW platform concepts

As there is no commercial track record, this study directly derives recommendations based on executed demonstration projects and requirements of the fabrication and installation.

To derive benchmark recommendations for the port facilities, study will focus only on barge and semi-sub types. The reason is that these two types partially share construction considerations and have port depth requirements that is less restrictive. Furthermore, majority of announced commercial projects are based on these two types [3].

2 Benchmark from European Offshore Ports

2.1 Introduction

This chapter elaborates a set of properties that are determining for ability of a port to service selected OW-related activities such as:

- installation base (staging, pre-assembly) for bottom-fixed turbines
- installation base (staging, pre-assembly) for floating turbines
- operations and maintenance

As a first step, a general overview of OW-related port processes is given for each of the port roles. Intention is to explain processes and show the main drivers such as vessels, components, equipment and facilities.

This general overview is supplemented and cross-checked against six case studies of European ports which have served OW projects in the past 20 years.

Based on the combination of general guidance and specific examples, a benchmark table of determining port properties is given in the conclusion of the chapter.

To help with understanding of port related terms, definitions are shown on *Figure 2-1* and presented in the table below (copied or paraphrased from ref. [4]).

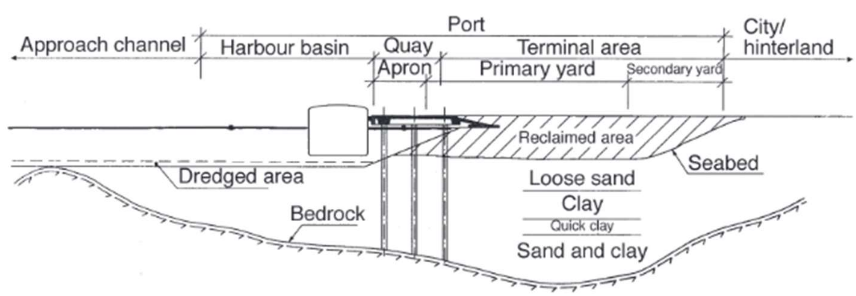


Figure 2-1: Definitions of port related terms (source: ref. [4])

Term	Definition
Apron	The area between the berth line and the storage area for loading and unloading of cargo
Berth	A place where the ship can moor. In the case of a quay or jetty structure it will include the section of the structure

	where labor, equipment and cargo move to and from the ship.
Dredging	Dredging refers to loosening and lifting earth and sand from the bottom of water bodies. Dredging is often carried out to widen the stream of a river, deepen a harbor or navigational channel, or collect earth and sand for landfill; it is also carried out to remove contaminated bottom deposit or sludge to improve water quality.
Harbor	Protected water area to provide safe and suitable accommodation for ships for transfer of cargo, refueling, repairs, etc.
Marginal berth	Berth structure parallel to the shore.
Quay	A berth structure parallel to the shoreline.
Turning Basin	An area of water or enlargement of a channel used for turning around of ships
RoRo	Roll on/roll off ships that are loaded and discharged by way of ramps.
Yard	adjacent to the apron, and primarily used for temporary storage of in-bound and outbound cargo (the storage area).

2.2 Port Usage in installation of bottom-fixed turbines

2.2.1 Pre-assembly and load-out process

Port operations for a turbine staging facility are governed by activities of the pre-assembly and load-out process. The main activities are:

- 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)
- Preparation of main components in storage area
- Sub-assembly of secondary components (in building)
- Tower pre-assembly
- Tower final assembly
- Nacelle preparation for load-out
- Blade preparation for load-out
- Quality control walk-down and hand-over documentation

› Load-out (loading components onto the installation vessel)

An indicative schematic drawing of the cargo and operation flow in the staging port is shown on *Figure 2-2:*. As indicated, staging of turbines and foundations can be done in the same port.

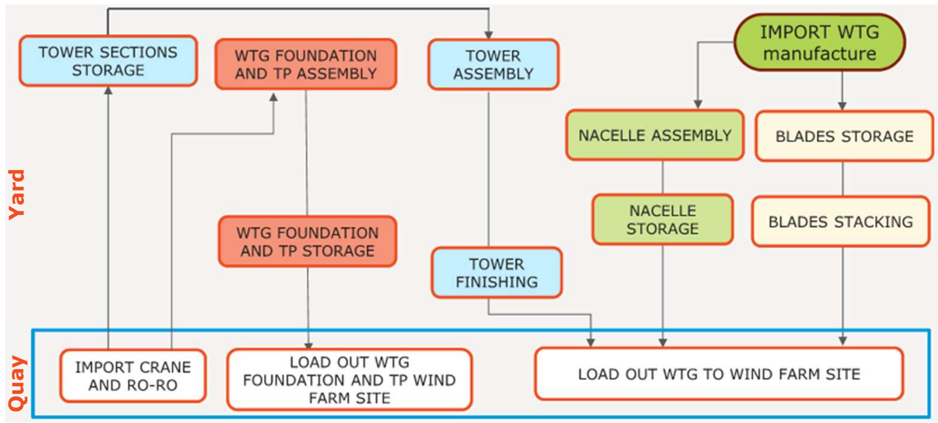


Figure 2-2: Diagram of staging port operations

2.2.2 Components 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 staging port. Component size can vary with producer as well as the assembly and storage process.

In general, turbine size increases with turbine's rated capacity. There is a clear tendency in the market to decrease cost by installing fewer units with higher capacity, with 10 MW units available on the market today, such as MHI Vestas V164-10 MW. Siemens Gamesa Renewable Energy has announced an 11MW model (SG 11.0-200 DD) which will enter serial production in 2022 and a 14MW model is in planning for serial production in 2024. Typical component sizes for currently available turbine models are shown in Table 2-1.

Table 2-1: Indicative sizes and weights of turbine components

Component	6 MW		8 MW		10 - 12 MW	
	Size	Weight	Size	Weight	Size	Weight
Tower	D=6 m L =93m	500 t	D=6,75 L=94m	310 t	D=8m L=110m	850 t
Nacelle (with hub)	L/W/H 20/7/7 m	390 t	L/W/H 21/9,6/6	500 t	L/W/H 22/10/12	650 t
Blades	D=4 m, L=75 m	20 t	L=85m	40 t	L=100-120m	50 - 60 t

Table 2-2: Indicative sizes of foundations

Element	Size	Weight
Monopile	D=6–7 m, L=50 - 80m	800 - 1200 t
Transition piece	D= 6–7 m, L= 30 m	400 – 500 t
Jacket	L/W/H up to 20/20/50 m	550 t
Substations	L/W/H 34/27/24 m	1,000 t

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 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.

Transition pieces 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 can be completed in the staging port.

The handling of the wind farm components requires crane capacity for unloading/loading of components and pre-assembly activities. Load-out of components from quay side is usually done by crane on board of a WTIV. Other lifting operations can include:

- loading and unloading of cargo (foundations, nacelles, blades, towers)
- assembly of towers
- lifting of components onto the transport vehicles

Crawler cranes are typically used for such operations due to their versatility (see Figure 2-3 and Figure 2-4).

Figure 2-3: Crawler cranes are used in loadout of many major OWF components.

Figure 2-4: Loading of Mono –pile foundations (MP) and transition pieces (TP)

An example of such crawler crane is Liebherr 11350 with max. load capacity of 1350t. Max. load below the tracks (within 2.5 X 2.5m area) can go to 60-80 t/m^2. It is ideal to design quay and fill so to allow lifting operations over the entire yard and apron. However, many ports use load spreaders (additional gravel layer and mats) and limit the minimal distance to the cope line to extend the use of existing assets for lifting of heavy loads.

In addition to crawler cranes, handling and moving components in the port area via Self Propelled Modular Transporter (SPMT) vehicles is also common (Figure 2-5 and Figure 2-5). Because they are modular, SPMTs can be configured with additional axles to effectively spread loads and UDLs within port, especially for transport of heavy structural components such as nacelles, towers and foundations. This has the potential to reduce UDLs to 10-15 t/m^2 in heavy transport areas, which can help limit port upgrades. SPMTs are seeing increased usage as a method to load components directly in or out the vessel via RoRo ramp. This is preferred method for loading of nacelles as it minimizes the possibility of damage during lifting operations.

Figure 2-5: Transportation of Mono-piles with SPMT

Figure 2-6: SPMT for transportation of large heavy components

Assembly and load-out of towers requires dedicated foundations with fixing templates. This allows for the entire tower to be assembled loaded out onto the WTIV in the upright position. These foundations are placed in "packs" close to the quay edge and must be capable of supporting the entire weight of the tower (see Figure 2-7).

In a similar way, loading operations of MPs require steel cradles with foundations close to quay capable of taking point load of up to 600t. Embankments are used for storage of monopiles in the yard to allow the standoff for the SPMT to enter below the MP and lift it.

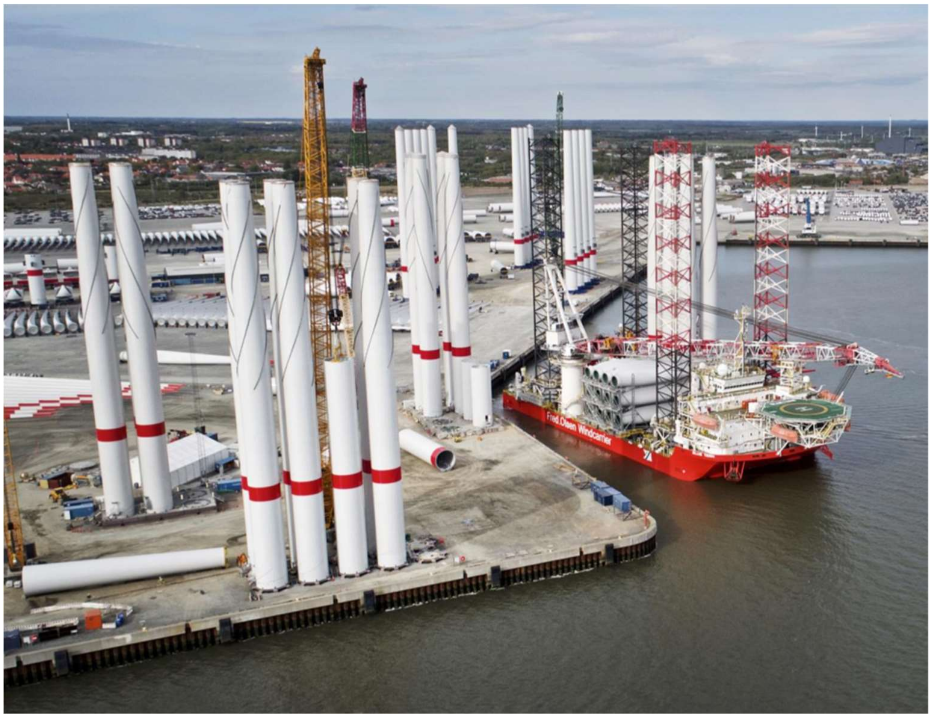


Figure 2-7: Foundation "packs" for tower assembly and loadout (source: Port of Esbjerg)

Components are kept in an open-storage yard away from the quay. Each component has a transport frame to facilitate manipulation and lifting.

Figure 2-8: Open storage (source: Port of Esbjerg)

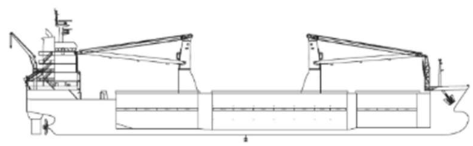
2.2.3 Vessel portfolio

This chapter gives an overview of typical vessels that call at staging facilities.

Transportation of turbine components is done by multi-cargo transporters. These vessels can accommodate outsized cargo as well as containers or break bulk (goods that must be loaded individually, as opposed to goods that are packed in containers). Several holds allow the cargo to be combined and the vessel is equipped with cranes, as illustrated in Figure 2-9.

Some contractors have adapted these vessels to serve the installation of monopiles and transition pieces, as the vessels can both carry heavy cargo and lift it with their own cranes.

Multi-cargo vessel



Name:	M/V Pacifica
LOA (overall length):	138.5 m
Beam:	21 m
Draft:	8 m
Comment:	Geared to 300t (2 X 150t)

Figure 2-9 Example of a multi-cargo vessel

Some multi-cargo transporters have also been converted to serve exclusively the transport of blades or nacelles. They can be equipped with lifting bow to allow RoRo loading process. An example is provided in Figure 2-10.

Specialized offshore component transporter

Name:	Rotra Vente
LOA:	141 m
Beam:	20 m
Draft:	6.5 m
Comment:	Ro-ro equipped bow and flush deck; specialized for transport of nacelles and tower segments

Figure 2-10: Example of a specialized offshore component transporter

The transportation of heavy components can also be done by vessels which are suitable for transport of outsized cargo including assembled topsides segments, such as the open deck carrier illustrated in Figure 2-11.

Open deck carrier

Name:	M/S Meri
LOA:	105,5 m
Beam:	18.8 m
Draft:	4.7 m
Comment:	1660 m² deck area

Figure 2-11: Example of an open deck carrier

WTG components (tower, nacelle and blades) are installed using WTIV, which is a jack-up vessel specifically designed for offshore wind installations. Jack-ups are required due to the large hub-heights of turbines and in order to maintain stability and control during heavy lift activities over these heights with tight tolerances. Jack-ups can be used for installation of foundations as well. Modern jack-up vessels have evolved from jack-up barges, by adding high capacity cranes, accommodation, propulsion and precision positioning. Development was driven by OW industry.

Wind turbine installation vessel (jack-up vessel)

Name:	Pacific Orca
LOA:	160.90
Beam:	49
Draft:	6
Comment:	Deadweight for jacking: 8400t Main crane capacity: 1200t@31m

Figure 2-12: Example of a jack-up vessel

In order to load components, the WTIV is required to jack-up near the quay. This minimizes movement and potential damage to components during lifting and sea-fastening and it is one of 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. However, increase in component sizes has resulted in shortening of the crane reach and the preference is now to ensure that vessels can jack-up without standoff. This is ensured by various methods of seabed strengthening.

Next generation of installation vessels is following industry's overall increase in size of components (examples on Figure 2-13 and Figure 2-14) in offering increased deck areas and lifting capabilities, which also leads to increased overall dimensions.

Foundations sometimes also installed using WTIV but can also be installed using geared cargo vessels, shear-leg cranes (combined with feeder barges), etc. Choice is governed by tolerances for specific operations and preference of the contractor.

Wind turbine installation vessel – to be commissioned in 2022

Name:	Voltaire
LOA:	169.30 m
Beam:	60 m
Draft:	7.5
Comment:	Deadweight for jacking: 14000t Main crane capacity: 3000t

Figure 2-13: Example of future wind turbine installation vessel

Offshore heavy lift installation – to be commissioned in 2020

Name:	Orion
LOA:	216.50 m
Beam:	49 m
Draft:	11 m
Comment:	Main crane capacity: 5000t@35m

Figure 2-14: Example of future offshore heavy lift installation vessel

Other vessels which are involved in construction activities are:

- Transport barges
- 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.

2.2.4 Distance to site

COWI has analyzed the distances between major OWF and their installation ports as shown in Figure 2-15. The data used for this analysis is given in Appendix A.

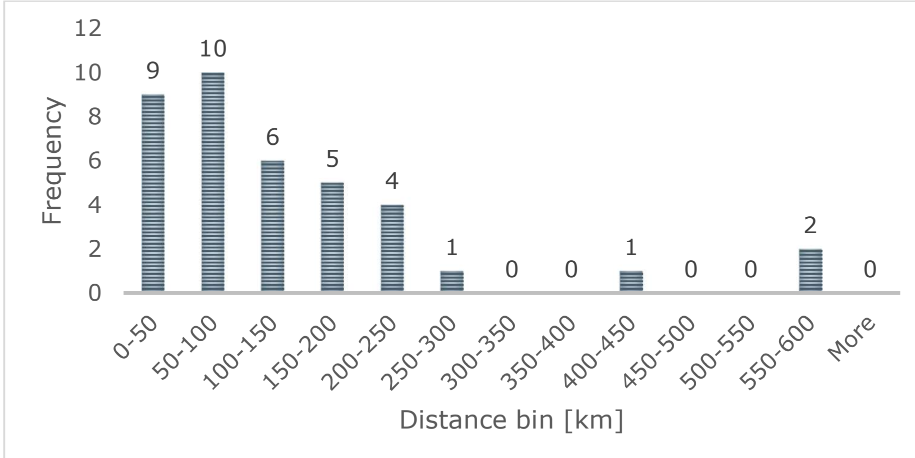


Figure 2-15: Distances between OWFs and installation port facilities (frequency in number of wind farms)

Based on the sample of 40 OWFs, including all European projects from the past 5 years, modal distance range is 50-100km with great majority of projects, 36 out of 40, being less than 250km.

Some outliers, such as Northwind (Belgium) and Westermost Rough (England), where installation was carried out of Esbjerg despite a distance of close to 600km, shows that other factors can take precedence.

2.3 Port Usage in Operation and Maintenance Phase

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

- Management of the asset: remote monitoring, environmental monitoring, el. sales, administration etc.
- Preventive maintenance: routine inspections, change of lubrication oils and preventive repair of parts known to wear down over time
- Corrective maintenance: repair or replacement of failed or damaged components

O&M strategy differs from one operator (or Original Equipment Manufacturer, OEM) to the next but always tries to find optimal intersection of:

- Access to the asset: transit time and time period in which a turbine can be reached by particular means
- Onshore support: availability of parts and services taking part in maintenance or repair

While the development of O&M infrastructure represents a small portion of the initial offshore wind capital investment, over the long-term (typical lifetime of 25 years), O&M make up a larger portion of the overall cost of energy. Operating expenses can comprise up to 30-40% of the LCOE [5]. Hence, early planning of

O&M strategies and identification of suitable O&M infrastructure can make a significant difference to a project's economic viability.

Although O&M ports must satisfy technical requirements, discussions with developers are mostly commercial. Another factor is strategic commitment of the port to support these operations as it lasts throughout the lifecycle [6].

O&M ports can be entirely different from the installation ports, as their main requirement is a close proximity to the farm and as infrastructure requirements are less demanding compared to installation.

Based on European experience, a building at the port of at least 300 m² 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 components such as bolts, cables, tools 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. There should also be showers, changing rooms as well as facilities for drying of work clothes.

2.3.1 Vessel portfolio

Two principal models to address this optimization challenge for regular inspection and maintenance activities are to use either Crew Transfer Vessels (CTV) or Service Operation Vessels (SOV). Helicopters are possibility as well but not discussed in this study because they are used in relatively few cases.

CTVs are smaller vessels limited to return trips within a single day. There are many examples in European experience where short distance to the shore favored the CTV approach to O&M.

Assuming 1.5 to 2 hours transport time to OWF and speed between 15 and 25 knots, this limits the distance between the base and the OWF to 90km or 50nm for use of a CTV vessel.

These boats are usually aluminum catamaran designs, with overall lengths ranging from 14 to 26m. Those at the larger end are governed by the logic that such vessel offers better comfort (reduced motion sickness) and can operate in wider range of weather conditions (significant wave height below 2.5m). Development of the larger vessels is driven in part by increased distance of wind turbine sites from the shore.

In all cases, work boats are limited to a 12-passenger capacity to maintain the classification of non-convention vessels according to SOLAS (vessel not engaged on international voyages). Vessels are fitted with a fender-lined push-on bow that facilitates transfer of personnel to the turbine landing. With some producers, a gripping mechanism at the bow allows safer transfer and possibility to operate in larger wave conditions. Work boats do not have overnight stay possibility for passengers (but do for crew). Two examples of CTV vessels are given in Figure 2-16.

	Vessel type:	Crew Transfer Vessel
	Name:	Damen Fast Crew Supplier 2610
	LOA:	26.3 m
	Beam:	10.3 m
	Draft:	2.4 m
	Comment:	12 personnel and 100 m² deck area
	Name:	Ribcraft CRC Voyager
	LOA:	15.0 m
	Beam:	3.6 m
	Draft:	0.7 m
	Comment:	12 personnel and 1500 kg payload

Figure 2-16: Examples of Crew Transfer Vessels (CTV)

With distance of OWF to land rising, the use of SOV's is also increasing. SOVs are larger vessels, as illustrated in Figure 2-17, that also 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 "walk to work" where gyro-stabilized gangways give safe access to turbines even in high wave conditions, up to 3m.

Name:	Esvagt Faraday
LOA:	83.7 m
Beam:	17.6 m
Draft:	6.5 m
Comment:	40 personnel and 450m² deck area

Figure 2-17: Example of service operation vessel (SOV)

The decision on whether to use CTV or SOV must not depend on distance alone but also on the overall O&M strategy of each operator. It is not uncommon that both types of vessels are used for same windfarm, such as at the English OWF Hornsea 2.

If a major component replacement is needed, such for example, a blade, hub or generator, a jack-up vessel with a crane must be engaged and requirements will be similar to those used in installation.

2.3.2 Distance to site

Based on the data set given in Appendix A, COWI has analyzed the distances between major OWF and their O&M port. The results are shown in Figure 2-18, below.

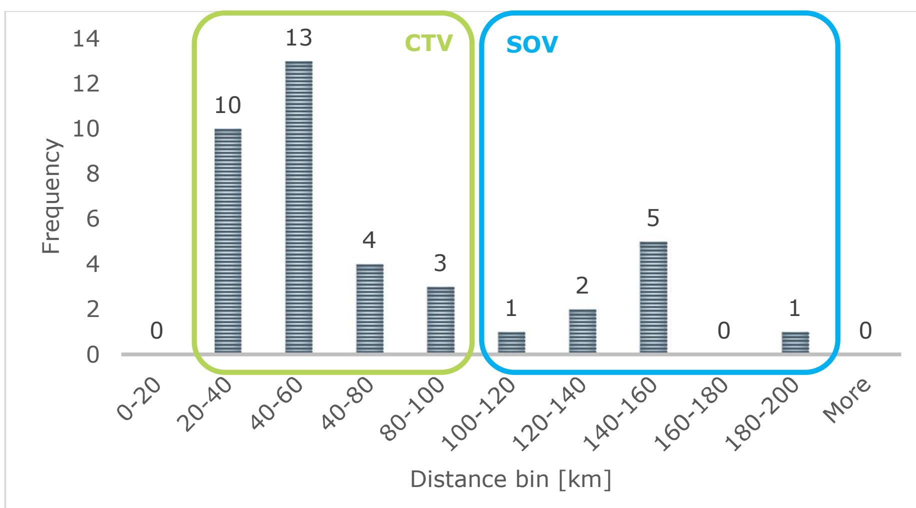


Figure 2-18: Distances between OWFs and installation port facilities

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

2.4 Floating Foundation Installation

Both barge and semi-sub floaters can be executed in either in steel or concrete. Existing demonstrator projects favored steel whereas concrete is starting to appear in projects currently proposed.

Floating turbine deployment can be split in these steps:

- fabrication of the floater
- launching of the floater
- fitting out with secondary elements
- integration with turbine
- pre-commissioning
- wet towage / installation

Fabrication of the floater can be done in the yard or production hall. Structure is skidded onto the semi-submersible barge or ship-lift and launched (see Figure 2-19). An alternative is fabrication in a dry dock (either graving or floating) and subsequent launching by flooding the dock (see Figure 2-20)

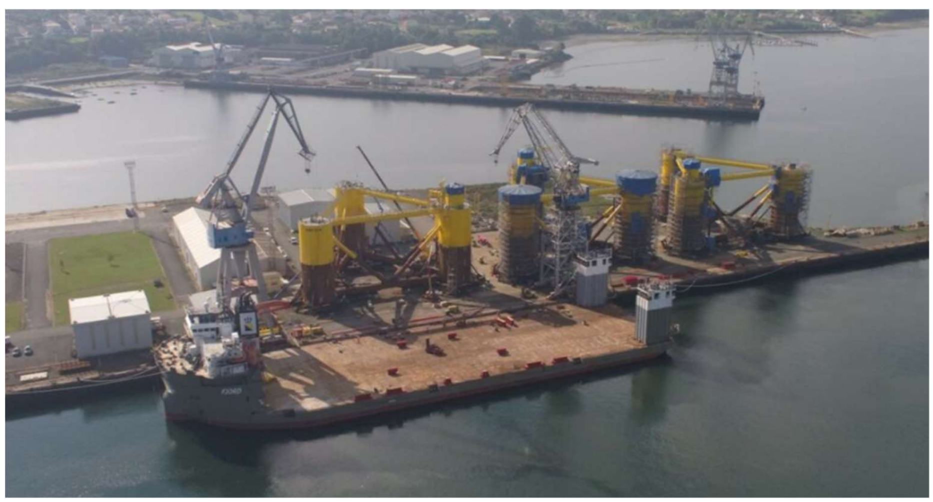


Figure 2-19: Loadout of floating foundation in Spain for Kincardine floating wind farm

Figure 2-20: Ideol Hibiki damping pool barge floater (3MW) at Sakai Works drydock

Whether executed in concrete or in steel, floating structures are work intensive and industrial levels of efficiency are yet to be introduced through serial production and standardization. Unlike bottom fixed foundations, floaters can be type-certified as they do not depend on the soil conditions. Serial production could be done in large graving docks where several floaters are produced simultaneously.

Alternatively, specialized equipment can be introduced as is the current practice for caissons. An example of this is floating dock method used by Spanish contractors for production of concrete caissons (see Figure 2-21) equipped with slipform and immersed days after the casting of each lift.

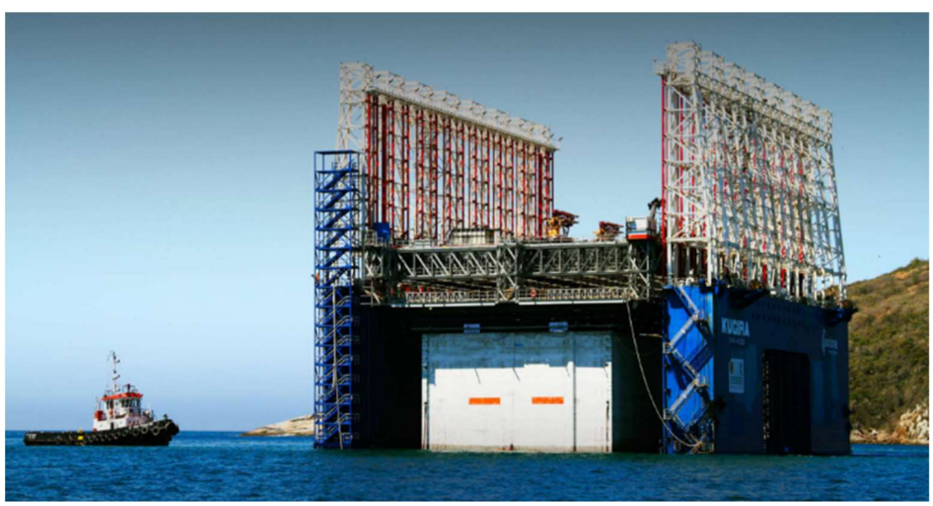


Figure 2-21: Specialized caisson building dock "Kugira" (Acciona)

The highest production rate would be using a precast yard for serial production (again used for caisson), albeit with highest CAPEX.

The next step is quayside mooring of the floater where it is fitted with secondary structures (landing, davit crane, platform, rails …).

Unlike fixed-bottom foundations, the turbine can be installed on floaters while they are moored quayside. Following placement of the tower (in segments), nacelle and the blades, turbine is pre-commissioned (see Figure 2-22 and Figure 2-23).

Figure 2-22: WindFloat Atlantic semi-sub

Installation tempo depends on the production rates. Even with intensive parallelization, production of the floating foundations will be an activity on critical path allowing float for turbine installation. Rather than intensive campaign, it is anticipated that deployment of floating turbines would be a protracted process. This reduces requirement for the available yard as it is expected that pace of inbound components would be set to match floater production to minimize storage space requirements.

It is possible to use separate ports for the fabrication of the platforms and the integration with turbines.

Figure 2-23: Ideol Damping Pool barge at Saint-Nazaire

Once the turbine is mounted and pre-commissioned, the entire assembly is towed to the site where the mooring system has already been pre-installed. Wet towage should possibly increase weather window for installation, which should in turn increase radius for installation from port.

Indicative sizes of floaters for turbine size of 8MW are:

Property		Barge	Semi-submersible
Draught when deployed	[m]	10	15 – 25
Length	[m]	55 (square)	50 (triangle)

2.5 Case Studies

2.5.1 Selection of representative cases

By the end of 2022, European offshore wind is expected to boast a total of 22 GW of installed capacity [7]. Development of this large scale has been closely followed by a better understanding of port operations needed to support OW projects and resulting reduction of installation costs.

As Korea moves forward from a concept investigation to a rapid deployment towards 2030, it is helpful to consider European experience, understand its specificities and avoid costly mistakes.

To do that this study surveys six major European ports which are shown in Figure 2-24.

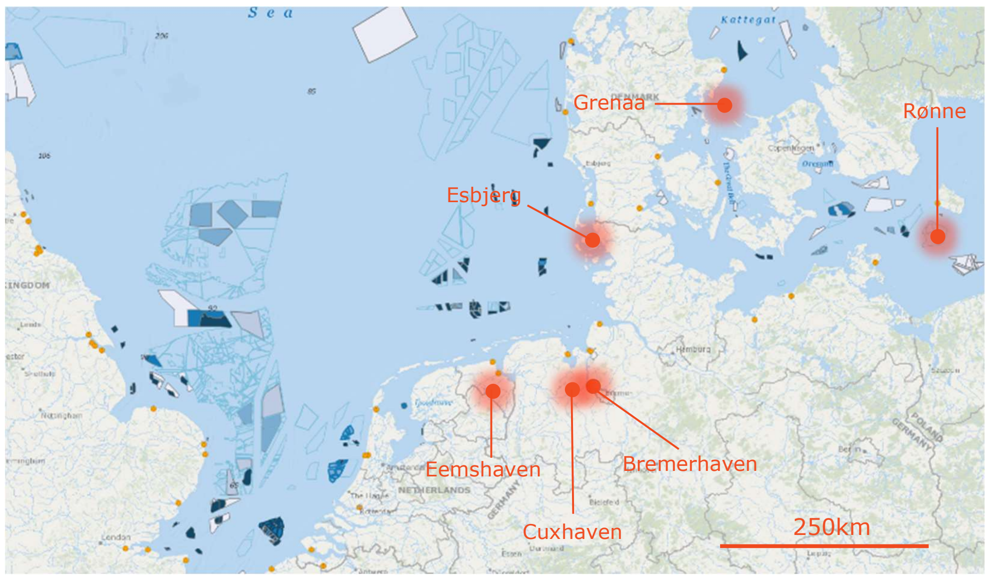


Figure 2-24: Overview of selected ports

These ports have been chosen by COWI to provide a broad range of different development stages and scenarios.

Relevant information on OW ports has been sourced from publicly available information (studies, port documents and brochures) and supplemented with interviews (Grenaa, Eemshaven) or written response from port authorities (Cuxhaven, Esbjerg).

The focus of case studies has been only OW-related port infrastructure and facilities, rather than all berths and yards present in a given port.

COWI collected information which represents port parameters that can have deciding impact on qualifying facility to serve the installation and operation of OWF. Parameters are derived from section 2.2 as minimum necessary set which is influenced by the requirements of vessels, components (cargo) and operations.

These are parameters are:

- Location (distance to OWF)
- Harbor (depth, lock, clearance, turning circle…)
- Berth (length, depth, apron load capacity, seabed…)
- Yard (area, equipment…)
- Co-location of production
- Development history and insight

Load allowance refers to Uniform Distributed Load which is live load assumed to act over the entire area. Load that acts on smaller area can be considerably higher (see Chapter 2.6.1).

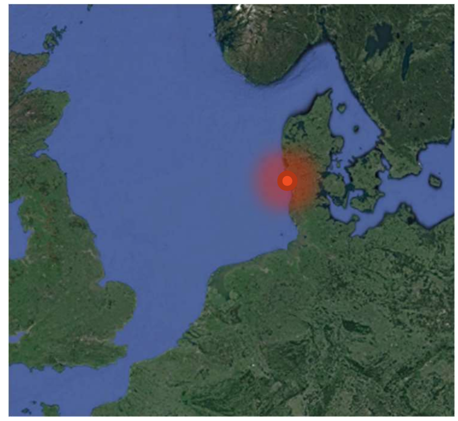
Some factors have been scoped out of the information gathered, such as:

- Connectivity
- Tidal variation

Tidal variation is a site characteristic which is not a qualifier for port. Connectivity is not relevant in itself but only when specific supply chain nodes in the hinterlands are considered (outside of the scope of this study).

2.5.2 Esbjerg

Overview and history



The Port of Esbjerg is located on southwest coast of Jutland in Denmark. It was established in 1868 and initially served export of agricultural goods. At the start of 20th century, Esbjerg attracted fisherman as well.

Port business underwent its major transformation in '70s with the establishment of the Danish offshore oil and gas sector, where the port became major service center for all Danish operations.

The Port of Esbjerg's first involvement with offshore wind came with Danish OWF Horns Rev I in 2001. Encouraged by the influx of new business and with a visible pipeline of Danish investments in OW, the port initiated the first of several subsequent expansion projects which facilitated transformation into a major hub for the OW sector.

Momentum for OW has also in part been perpetuated by oil crisis in 2014, where a drop in oil price encouraged local companies to see OW as potential for strategic diversification. Over the years, more than 50 European wind farms have received components or services from Esbjerg port and 25% of port's current income comes from OW sector. Apart from Horns Rev I and Horns Rev II, the Port of Esbjerg has been the primary base for a number of foreign wind farms. These include Butendiek, Northwind, Sandbank, Dantysk, Humber Gateway and Westermost Rough.

An overview of the entire port is shown on Figure 2-25.

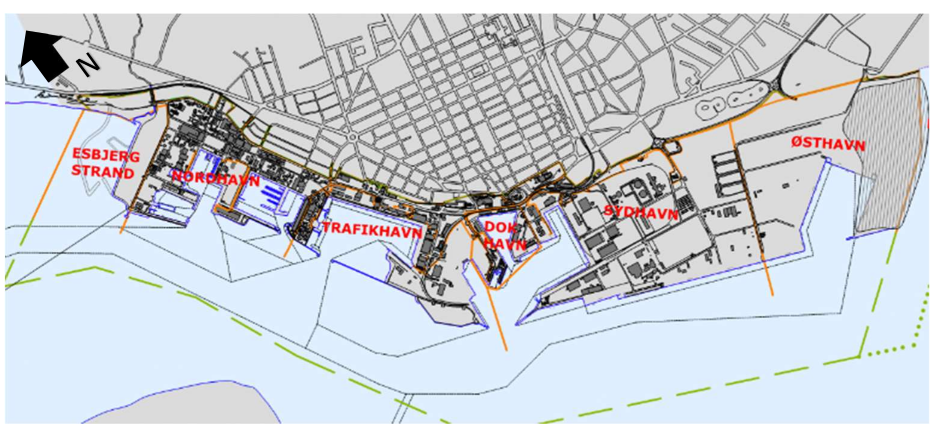


Figure 2-25: Overview of Port of Esbjerg

Facilities used by OW sector

Today, the main part of the port used by off-shore wind sectors are South Port and East Port with overview shown on Figure 2-25 and properties given in Table 2-3.

Figure 2-26: Overview of OW-related terminals

The main characteristics of the quays relevant for OW are summarized below in Table 2-3.

Table 2-3: Properties of quays in Port of Esbjerg available to OW-related port and manufacturing operations

		South pot (Aries, Taurus quays)	East port (Gemini, Leo, Virgo quays)
Depth at channel (entrance) at MLLW	[m] MLWS	9.3	9.3
Harbor entrance width	[m]	-	320
Presence of lock/gate		No	No
Vertical clearance	[m]	Unrestricted	Unrestricted
Berth length	[m]	450 + 380	330 + 150 + 500
Depth at berth (MLWS)	[m] MLWS	10.5	10.5
Load capacity (UDL)	[kN/m^2]	50	50
Strengthened seabed		Yes	Yes
Storage yard area	[ha]	50	70

Siemens Gamesa Renewable Energy (SGRE) is using Esbjerg port for the staging of its turbine components. For that reason, quay area also has 10 foundations for upended (vertically stored) towers which can weigh 1000 tons each.

Figure 2-27: Loadout of components from Aries quay

It is important to mention that Esbjerg serves as export facility for several manufactures located further inland (see Chapter 1.4.2) which ship components via road network.

Co-location

Today, there are more than 120 companies involved in the offshore wind sector in Esbjerg. Large part of these represent services and also take part in offshore oil and gas operations. Some of the major ones are:

- SGRE: Nacelle assembly and service center
- Semco Maritime: Substation topsides, O&M
- Esvagt: O&M

The role of SGRE is especially important in tracking the development of the Port of Esbjerg. Having used it as staging facility for Horns Rev 1, 2 and 3, SGRE invested in new factory in Esbjerg. Optimization of the logistical chain can be seen in introduction of specialized transport vessels, such as Rotra Vente, that have custom-built bow with extendible RoRo ramps. This allows safer and quicker loadout of nacelles and tower segments compared to crane operations.

Figure 2-28: Specialized vessel, named Rotra Vente, for transport of turbine components using RoRo ramp.

However, production is also susceptible to fluctuations, as seen in 2017, when Siemens returned 20 Ha of laydown areas to the port due to a company-internal business decision to prioritize developments of production closer to markets, at that time the United Kingdom [8].

Future plans

Towards 2030, the Port of Esbjerg expects to have insufficient capacity to match rising demand. Therefore, port is already planning for future expansion in two stages that encompass an area of 100 ha. It is not clear though how much of this area is devoted exclusively to OW-related operations.

Figure 2-29: Plans for expansion of Port of Esbjerg towards 2030 (source: port of Esbjerg).

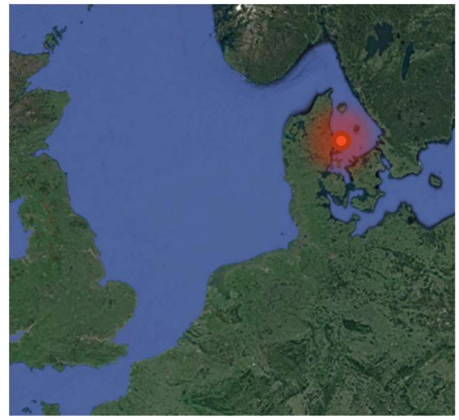
One of the potential emerging markets that Port of Esbjerg is preparing for is decommissioning. Europe projects that there will be 105.000 t of waste and port expects to capture a part of this market for recycling.

Key takeaways

- Establishing an entire supply chain and well-oiled collaboration is a mode that ensures long term competitiveness, also in foreign markets.

2.5.3 Grenaa

Overview and history



Grenaa Port is located in the north east part of Denmark's Jutland peninsula. The port expanded with the town, mostly supporting fishery and ferry lines throughout 19. century. In recent times, port underwent a major expansion towards the east to serve as industrial port.

Over the last couple of decades leading up to 2010, Grenaa experienced a gradual decline in revenues from traditional port operations.

Following its expansion in 2010, Grenaa port managed to secure Anholt OWF installation contract and the subsequent service agreement.

Figure 2-30: Overview of Grenaa OW terminal (Google Earth)

Facilities used by OW sector

Grenaa has developed a new terminal in agreement with SGRE for the purpose of staging components for a single offshore wind project – Anholt OWF.

The quay used for this project had two load-out positions. Quay side was fitted with 6 foundations for final assembly and load-out of towers. Additional 12-pack for tower pre-assembly is placed beyond the apron. The seabed adjacent to the quay has been strengthened to allow jacking up. Three were also several buildings on location for storage, electrical works and accommodation that have since been removed. The capacity at the time was 60 turbines per year. Installation was carried by 4 vessels (not simultaneously). All components have arrived at the site via road transport from existing production facilities in Denmark. The project area of 14 ha was designed to store 30 turbines (nacelles, rotor sets and tower sets).

The main characteristics of the quays relevant for OW are summarized below in Table 2-4

Table 2-4: Properties of quays in Port of Grenaa available to OW-related port operations

		Kattegat Quay
Depth at channel (entrance) at MLLW	[m] MLWS	12
Harbor entrance width	[m]	100
Presence of lock/gate		No
Vertical clearance	[m]	Unrestricted
Berth length	[m]	360
Depth at berth (MLWS)	[m] MLWS	11
Load capacity (UDL)	[kN/m^2]	75
Strengthened seabed		Yes
Storage yard area	[ha]	14

Figure 2-31: SGRE operations during installation of Anholt (source: port of Grenaa)

Port of Grenaa is a base port of O&M for Anholt and has served in 2018 as base port for a large upgrade on the OWF carried by SGRE.

Co-location

During the installation phase of the Anholt project, there was a heavy focus on capturing the increased activity to fuel local growth in employment and capabilities. Prepared for the drop of activities following commissioning, the Port of Grenaa has in time started to search for opportunities for diversification.

Being an offshore wind maintenance base means establishing a reliable component supply and storage. The ongoing activities allow further ecosystem of support business and skilled workforce to thrive.

Having established all of this, Grenaa managed to secure several contracts for docking and repair oil and gas jack-up rigs.

Future plans

Port is planning further upgrade of lay-down areas (reclamation of the areas beyond the load-out quay is ongoing) but not specifically aimed at the OW industry.

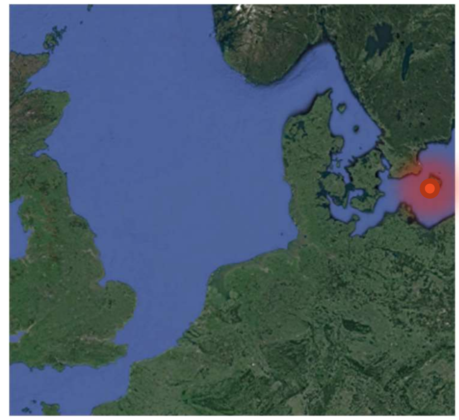
Port is also looking towards newly proposed OW developments in vicinity and decommissioning.

Key takeaways

- A single OW installation project is not sufficient to pay for infrastructure investments;
- In order get long term local value in employment and skills, ports can look for complementary industries beyond wind
- Ensuring that of increased industrial activity is captured by local businesses requires collaboration with local stakeholders and other public services

2.5.4 Rønne

Overview and history



The Port of Rønne is located on the island of Bornholm and is Denmark's easternmost industrial port. The port has been in existence as long as the town itself and has over time expanded mostly to support fishery, agricultural cargo and other bulk cargo. The port has also, over the time, developed facilities for cruise vessels and ferry lines.

Rønne has only recently started to become involved in OW projects and has built some experience serving as the base port for the German Arkona OWF, which was commissioned in 2019 and is the largest wind farm in the Baltic Sea with 60 turbines and 385 MW.

Realizing the potential of its location combined with the fact that majority of OWF's in the Baltic sea are yet to be realized, the Port of Rønne embarked on an expansion adding the south-western part of the harbor with quays and areas suitable for staging and installation operations. The port extension has been finalized just in time for the port to serve as staging facility for Kriegers Flak (Denmark, 600MW) and Arcadis Ost (Germany, 247MW) projects.

Facilities used by OW sector

Expansion of the port, illustrated in Figure 2-32, was completed considering both the port's ongoing business activities and future potential. Therefore, new quays 34 and 33 were constructed to be suitable to service vessels and operations ranging from cruise ships to project cargo.

Figure 2-32: Overview of Ronne's OW terminal

The main characteristics of the quays relevant for OW are summarized below in Table 2-5.

Table 2-5: Properties of quays in Port of Ronne available to OW-related port operations

		Quay 33 (heavy duty quay)	Quay 34 (multi-quay)
Depth at channel (entrance) at MLLW	[m] MLWS	11	11
Harbor entrance width	[m]	380	380
Presence of lock/gate		No	No
Vertical clearance	[m]	Unrestricted	Unrestricted
Berth length	[m]	300	270
Depth at berth (MLWS)	[m] MLWS	11	11
Load capacity (UDL)	[kN/m^2]	200 *	80
Strengthened seabed		No	No
Storage yard area	[ha]	8	3.5

* heavy load pad with size of 25 X 4m can support UDL of 500 kN/m².

Figure 2-33: Illustration of expected use for the newly built terminal

Co-location

Offshore Center Bornholm, an association of offshore wind companies in the area, has put together a network to connect local business that offer repair, maintenance and logistic services suitable for OW. Currently there are no OW related production facilities in the port.

Future plans

The ports masterplan does not mention further expansion aimed specifically to cater to OW projects. However, with Danish government's recent proposal to develop further 3 GW of OW near Bornholm and utilize the island as energy hub, there could be further needs for infrastructure expansion.

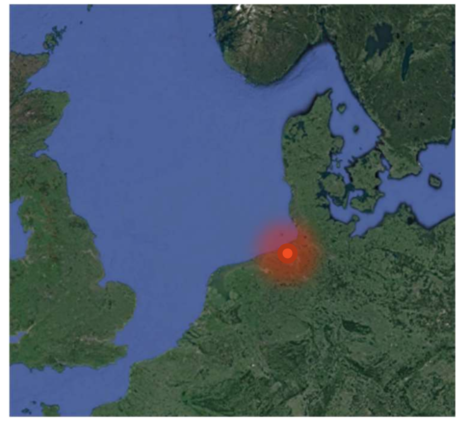
Key takeaways

> Looking for long term potential and acting in good time to have facilities ready for OW projects is a good method for securing OW business

2.5.5 Bremerhaven

Overview and history

The Port of Bremerhaven is in northern Germany at the mouth of the Weser River. It is sixteenth-largest container port in the world and fourth largest in Europe. The container terminal is situated on the bank of the river opening to the North Sea. In the wet dock parts, accessible by two large locks, is one of Europe's largest RoRo terminals and industrial park.



The port's infrastructure and proximity to the North Sea have contributed to Bremerhaven's early engagement and ongoing participation in OSW projects. The Port of Bremerhaven has supported several projects among them Germany's first OWF, Alpha Ventus, and the Nordsee Ost OFW.

Facilities used by OW sector

Port's existing quays were over repurposed and retrofitted by logistic companies over time to service specific projects and port is capable of handling both installation and fabrication activities for offshore wind turbines with capacities in the range of 6-10 MW. An overview of the main facilities dedicated to (or suitable for use by) OW projects are shown on Figure 2-34.

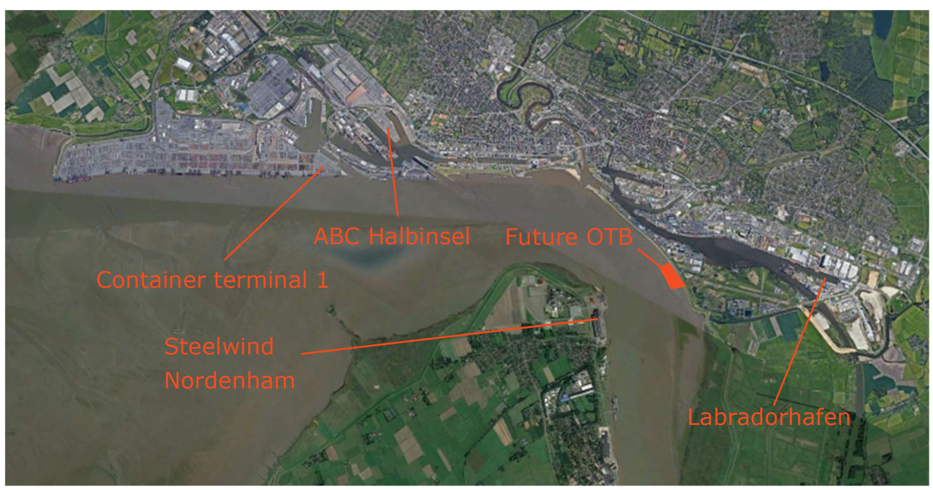


Figure 2-34: Overview of Bremerhaven

ABC Halbinsel is operated by BLG Logistics Solutions and has been used for both and production, transshipment and staging. Starting in 2011, after structural upgrades, 100 tripod foundations for Borkum West II were produced here in upright position. Since then, this terminal has also supported shipping out of towers, nacelles and other components. Not exclusively dedicated to OW, the terminal is used for storage and shipping of all kinds of vehicles and heavy cargo. This terminal is located behind the lock.

Figure 2-35: ABC Halbinsel

The southernmost zone of the container terminal has been repurposed for staging (Nordsee Ost OWF), storage and transshipment of all OW components and can be seen in Figure 2-36. The main quay faces the open sea, with the Weser river shipping channel and is not restricted by locks. Further, it has a strengthened seabed to support jacking up.

At the back, behind a lock, there is a tide-independent quay which is backed by heavy load platform.

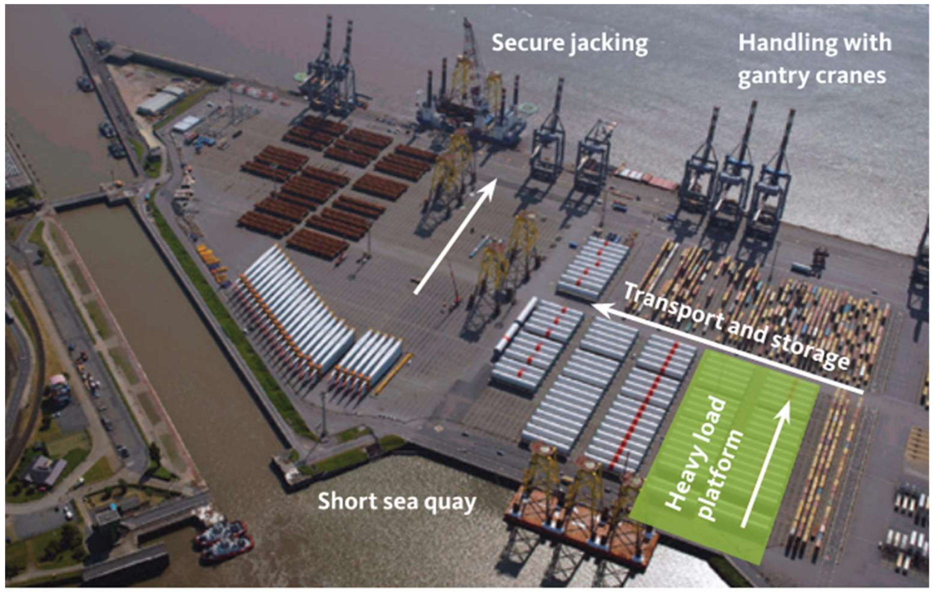


Figure 2-36: Containerterminal 1

The main characteristics of the quays relevant for OW are summarized below in Table 2-.

Table 2-6: Properties of quays in Bremerhaven available to OW-related port and manufacturing operations

		Labradorhafen	ABC Halbinsel	Containerterminal 1	Offshore Terminal Bremerhaven - OTB (planned)
Depth at channel (entrance) at MLLW	[m] MLWS	7.8	10.4	14.5	14.5
Harbor entrance width	[m]	35	55	-	-
Presence of lock/gate		Yes (L=182m)	Yes (L=305m)	No	No
Vertical clearance	[m]	-	-	-	-
Berth length	[m]	1132	570	400+200	500
Depth at berth (MLWS)	[m] MLWS	7.6	10.5	12.5	14.1
Load capacity (UDL)	[kN/m^2]	70	200	60 (200)	200 (500)
Strengthened seabed		Yes	Yes	Yes	yes
Storage yard area	[ha]	-	10	25	25

Co-location

By 2015, Bremerhaven had grown into a true offshore wind hub that hosts a diverse ecosystem of manufacturing facilities – foundations from WeserWind, blades from PowerBlades, offshore wind turbines from Adwen and both onshore and offshore wind turbines from Senvion - but since then, the port has been hit by closure after closure has left the it with no remaining manufacturing for offshore wind.

The first closure came in 2015, when the company WeserWind GmbH, which had occupied Lune hall at Labradorhafen for years and produced foundations, wind measurement masts and transformer units, declared bankruptcy.

In early 2018, after a decade in the port, PowerBlades closed its manufacturing there, due to a business decision to move the production to Portugal, where the labor costs were lower.

The closure of Adwen GmbH followed shortly thereafter in mid-2018. After being purchased from Areva by SGRE in 2016, the decision was made to consolidate servicing in Esbjerg. The presence at Bremerhaven has now been reduced to a service center.

In 2019, the last of the four offshore wind manufacturers at the port of Bremerhaven, Senvion GmbH, declared bankruptcy. The company was liquidated at the end of 2019 and the production site was closed.

A bright spot in manufacturing can be seen near the port of Bremerhaven on the left bank of Weser River, across from the planned offshore terminal, where the Steelwind Nordenham (subsidiary of Dillinger Huette) factory produces transition pieces and monopiles (output of up to 100 per year).

Factory is services by a dedicated 200m long quay with 6-10m LAT draught (tidal variation). Quay is designed for 1000 kN/m^2 live load and is serviced by two static heavy-duty (800t) cranes able to work in tandem but does not support jacking-up in front of the quay. Laydown area is 18 ha.

The factory has produced 66 monopiles (up to 960t) for Merkur OWF (6MW turbines) during 2016 – 2017, wrapped up an order of 40 monopiles and 120 additional monopile sections for the Yulin Offshore Wind Farm off the coast of Taiwan in mid-2020 and recently received an order for 28 monopile foundations for the Arcadis Ost OWF in German waters.

Future plans

In 2010, approaching the height of OW activity in the port, demand prompted the Senate of the Free Hanseatic City of Bremen to approve the plan for construction of new OW-specific trans-shipment facility on the Weser River. The proposed location (see Figure 2-37) offers both access to shipping channel unrestricted by locks and has 200ha of adjacent available estate (Luneplate) for future development of manufacturing facilities. Expected investment is 200 million euro.

Figure 2-37: Proposed location of new OTB (Luneplate industrial estate shown in blue)

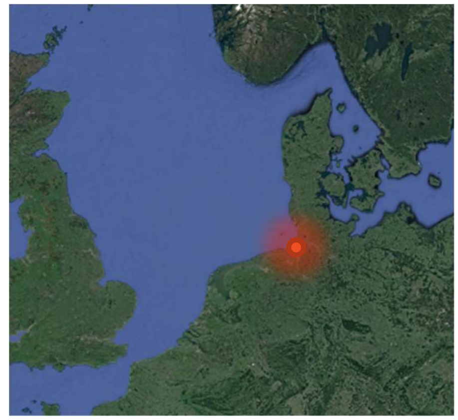
The planned extension, which is located in an environmentally protected area, has become mired in legal challenges and has lost political momentum. This loss of momentum was compounded with the recent loss of manufacturers at the port.

Key takeaways

- Existing general purpose, RoRo and industry quays can be repurposed to OFW without prohibitive up-front investments.
- Wind projects can come in cycles and it is not certain that competitiveness can be continuously maintained.
- Manufacturing presence at ports is quite susceptible to outside influences independent of the port infrastructure, such as mergers, turbine technology change or even changing labor costs, and can therefore change quickly

2.5.6 Cuxhaven

Overview and history



Cuxhaven is situated in the northern Germany, on the mouth of Elbe river, some 100km south of Hamburg. Although old, port of Cuxhaven has historically not seen much use except as harbor of refuge. Since the 19th century, the port has developed to meet the needs of fishery, navy, industry and as embarkation point for overseas passenger travel.

With establishment of the Kiel canal, the port also began to develop to handle general cargo. In the period since early '80s, Cuxhaven has established itself particularly as an important interface for the export of motor vehicles and the import of bulk goods. Continuing in the '60s and '70s to add RoRo capabilities after the war, Cuxhaven still remains one of most important German centers of the fish processing industry.

Recognizing Cuxhaven's favorable position for the offshore wind combined with port's capabilities to service the industry, port has galvanized support from State of Lower Saxony, EU and private investors to launch dedicated offshore terminal starting in 2008.

Overview of the Port of Cuxhaven is shown on Figure 2-38. Fishery quays are located behind the lock while multipurpose terminal and offshore terminals are accessible directly from Elbe.

Figure 2-38: Overview of the port of Cuxhaven

Facilities used by OW sector

Offshore terminals 1 (OT1) and 2 (OT2) have been developed from 2007 to 2019, in parallel with steel fabrication facilities. All quays are accessible to heavy lift cranes and SPMT while OT1 is equipped with portal crane with capacity of 600t while OT2 has RoRo ramp for loads up to 1.500t.

Cuxport, the operator of the port of Cuxhaven, has recently added berth 4 to its multipurpose terminal which is also capable of handling heavy loads and OW components in general.

All quays in Cuxhaven are capable of supporting loading both by cranes and by SPMTs (RoRo).

Figure 2-39: Loadout of piles and foundations from OT1 (BARD Offshore 1 OWF, 2012)

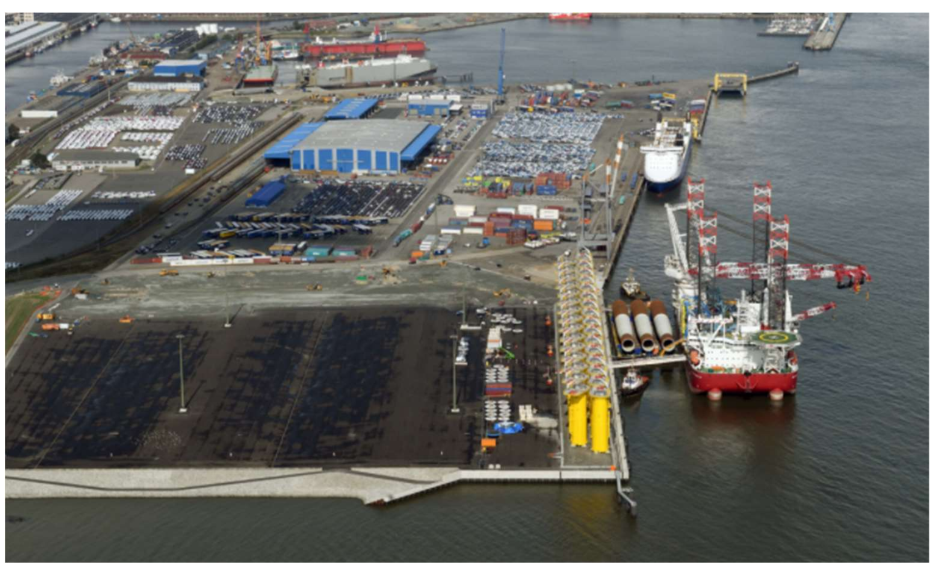


Figure 2-40: Loadout of TPs and monopiles from Berth 4 (Deutsche Bucht OWF, 2018)

The main characteristics of the quays relevant for OW are summarized below in Table 2-.

Table 2-7: Properties of harbor and quays in Port of Cuxhaven available to OW-related port operations

		Cuxport Multifunctional terminal Berth 4	Offshore terminal 1 (Berth 8)	Offshore terminal 2 (Berth 9)
Depth at channel (entrance) at MLLW	[m] MLWS	15.20		
Harbor entrance width	[m]	Unrestricted		
Presence of lock/gate		No	No	No
Vertical clearance	[m]	Unrestricted	Unrestricted	Unrestricted
Berth length	[m]	290	376	737
Depth at berth (MLWS)	[m] MLWS	15.80	9.5	9.5 – 12.7
Load capacity (UDL)	[kN/m^2]	900	200	200
Strengthened seabed		Yes	Yes	Yes
Storage yard area	[ha]	8.5	14.8	11.6

Map of Cuxhaven offshore wind terminals with legend is shown on Figure 2-24

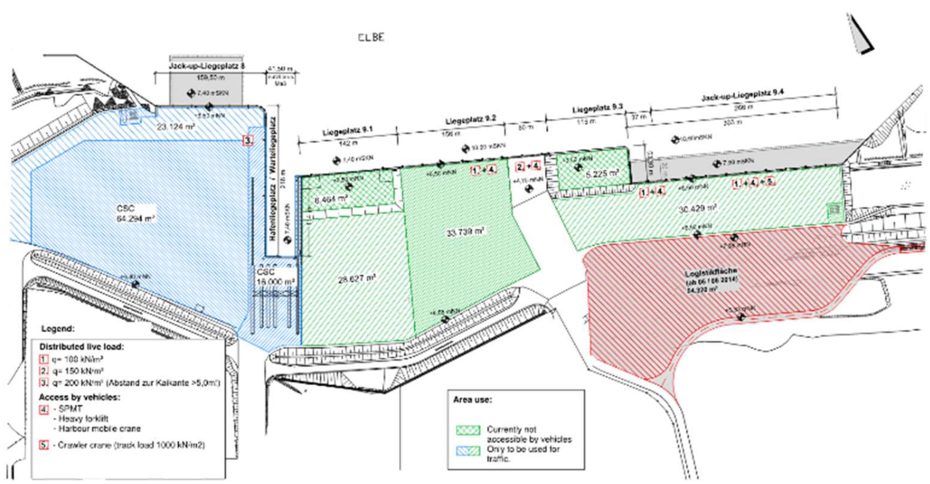


Figure 2-: Overview of the Cuxhaven offshore terminals (source: Cuxhaven homepage)

Future plans

In upcoming years N-Ports is looking to close the gap between berth 4 and OT1 (Berth 8) by constructing new multifunctional terminals (berth 5,6 and7). The length of new berths is expected to be 1250m with around 28ha of backup area. It is expected that these berths will be equipped with heavy load apron able to cope with large dimensions and weight of OW components.

Co-location

Steel fabrication capabilities have developed simultaneously with OW port capacity, with Titan Wind Energy Europe (former CSC and Ambau) establishing Cuxhaven Steel Construction in 2008. With ample land area available directly behind heavy load terminals (70ha), Offshore Terminals development is keenly aware of the co-location opportunities in the future. Largest offshore wind related manufacturers currently located in Cuxhaven are:

› Titan Wind Energy (Suzhou) Co Ltd:	Turbine towers
› SGRE	Nacelles
› Nordmark	Machining of large-scale steel components (such as hubs)

Apart from these, several other companies specializing in logistics, heavy lifting, corrosion protection, etc. are located nearby.

Figure 2-41: OW manufacturing industry at Cuxhaven port

It is worth noticing that co-location of fabrication facilities does not automatically imply synergy in every single case. During recent construction of Deutsche

Bucht, Van Oord chose to fabricate TPs in Spain and monopiles in Rostock. Only the staging of the foundations for installation has been done on Berth 4.

Key takeaways

› Convenient location and strategic investments can kick-start a future OW hub.

2.5.1 Eemshaven

Overview and history

Eemshaven is located in the province of Groningen in the north of the Netherlands. The port was established in 1973 as an initiative of the Dutch government to strengthen economy of the region. It was originally designed for oil-refinery and petro-chemical industries, which never fully materialized due to the oil crisis. Since then, industry and shipping have slowly developed at the port, although they have not yet reached the planned capacity.

Over the last 20 years the situation has changed, starting with companies' initiative to develop several power plants in the port (two gas fired, one coal fired and one onshore wind park) in effect establishing an energy park with 8 GW capacity. This is complemented by staging of the nearby OWF, development of an O&M base, hosting and management of export cables landfall facilities (Gemini) and establishing of datacenter and a recycling park.

Overall, port activities are grouped into the logistical zone to the west, energy part to the east and recycling yard at the south, as illustrated in Figure 2-42.

Figure 2-42: Overview of the port of Eemshaven

Regarding the OW-related activities, Emshaven has been used in installation of following OWF: Alpha Ventus, Bard Offshore I, Borkum Riffgat, Borkum Riffgrund

I, Trianel Windpark Borkum, Global Tech I, Gemini, Gode Wind I & II, Veja Mate, Race Bank, Nordsee One, Merkur Offshore, Borkum Riffgrund II, Hohe See, Albatros, Trianel Windpark Borkum II, Hornsea 2.

Eemshaven is also in use for operation and maintenance activities. Currently the wind farms Gemini (SGRE), Veja Mate (SGRE), Merkur Offshore (General Electric – GE) and Deutsche Bucht (MHI Vestas) have their O&M service base in Eemshaven. Also, Global Tech I and BARD Offshore are maintained and/or repowered from Eemshaven (in the port).

Facilities used by OW sector

Emmahaven is 500 meters long with a width of 120 to 150 meters, and a depth of 9.0 meters. A floating jetty and a services jetty provide more than 700 meters of berthing places for small and medium sized vessels.

At the northern part of the Emmahaven Sealane operates a quay of 130 meters for general and/or dedicated cargo.

Beatrixhaven is 1,200 meters long with a width of 110 to 150 meters, and a depth of 9.0 meters. At the northern part, AG EMS operates a ferry terminal and EMS Maritime Offshore (EMO) runs an offshore service facility. EMO provides direct access to the water via a jetty with a capacity of 300 meters and offers lots of space for different configuration options. EMO is also the offshore service base for SGRE (Gemini, Veja Mate) and General Electric (Merkur Offshore) and the operator of Heliport Eemshaven. At the southern part stevedoring company Wijnne Barends operates a terminal and accommodates the Norwegian company Seaway Offshore Cables. Bek & Verburg, a specialist in waste collection and segregation, and DHSS, a vessel agency and port service provider, together construct a new offshore service base behind the southern quay as well. MHI Vestas uses the DHSS Facility as O&M base for the 269 MW Deutsche Bucht wind farm.

Julianahaven is 1150m long and 315m wide. It is operated by BUSS in collaboration with partners and functions as a multi-purpose terminal. Over the years it has mostly been used for pre-assembly and staging of offshore wind projects. Most recently BUSS terminal has been selected to serve as a staging facility for Hornsea Two (165 monopiles and TPs).

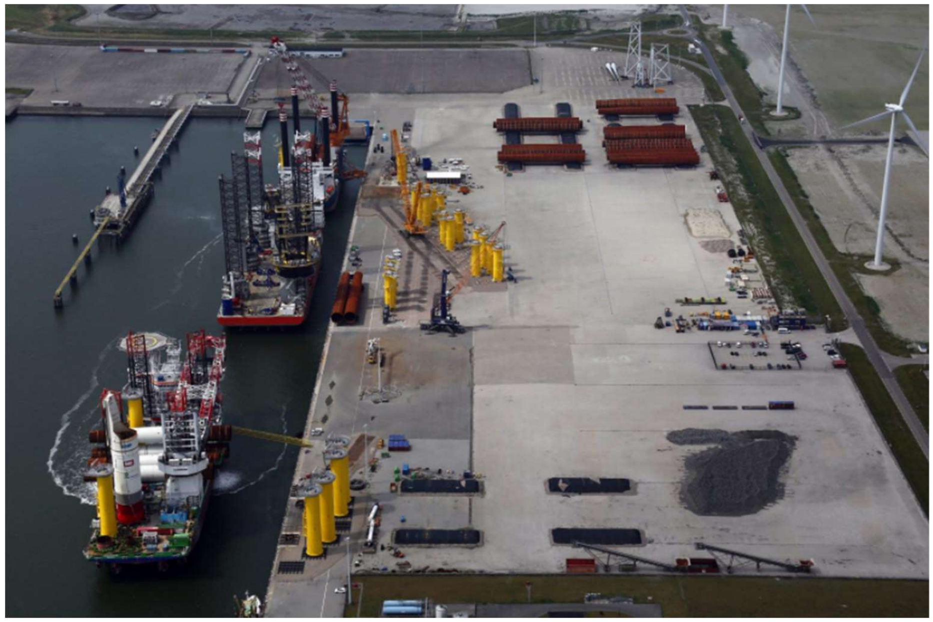


Figure 2-43: Foundation staging operations on yards surrounding Julianahaven

Latest addition to the port was new BOW staging terminal which was established in Wilhelmina harbor during 2020.

The main characteristics of the quays relevant for OW are summarized below in Table 2-8.

Table 2-8: Properties of quays in Port of Eemshaven available to OW-related port operations

		Beatrixhaven	Julianahaven (BUSS terminal)	Emmahaven	Wilhelmina (BOW terminal)
Depth at channel / entrance	[m] MLWS	17			
Harbor entrance width	[m]	470			
Presence of lock/gate		-	-	-	-
Vertical clearance	[m]	-	-	-	-
Berth length	[m]	1200 / 220	1100 / 1200	135	220
Depth at berth (MLWS)	[m]	7.5	11.5	7.5	16
Load capacity (UDL)	[kN/m^2]	300 / 40-60	25 – 200	40-60	100
Strengthened seabed		Yes	No	No	No
Storage yard area	[ha]	40	33	17	10+12

Future plans

Port of Eemshaven still has undeveloped land in the logistic area to the west which is available to prospective investors.

Co-location

Eemshaven does not host any production facilities.

Key takeaways

- Underutilized port facilities can be successfully turned into installation ports which can be a springboard for O&M.
- Colocation of manufacturing facilities is not a necessity for successful OW port business

2.6 Benchmark Formulation

Based on general industry requirements (Section 2.2) and the specific case studies presented in Section 2.4, COWI has defined benchmark recommendations for installation (staging, marshalling) ports and O&M ports. As the OW industry is still rapidly evolving, experience from the past cases is reasonably extrapolated to match observed trends. Due to the high-level nature of this study, this benchmark should also be understood as a guideline and not as a rigid set of rules. In order to reflect this, the criteria are categorized as:

- *acceptable* Minimum (or maximum) values or hard criteria. Exceeding these thresholds could limit the intended functionality or required trade-offs that should be analyzed through detailed feasibility study
- *recommended* Values that provides better versatility, faster workflow and the ability to accommodate future trends

Benchmark for installation ports also assumes that the port can be used for staging of foundations (TPs, monopiles, jackets) although it does not cover some specific features typical for such use.

2.6.1 Fixed-Foundation Installation Port Benchmark

Based on survey of installation and O&M bases done in Section 2.2, any **distance** up to 200km will be acceptable for running installation campaigns. Distances up to 400km have been used in past but the increased distance would be a trade-off with other factors.

Depth at the entrance, in the channel or along the fairway should be 12.5m (chart datum) to allow access to all vessels at all tides (also assuming increase in size of future vessels). Having less available depth still allows operations but can pose a limit to larger cargo and installation vessels. Similarly, if a harbor if harbor can only be accessed and departed at high tides, this adds additional constraint to a critical activity, which is the efficient charter of installation vessel.

Entrance width should be sufficient to allow easy navigation in range of weather conditions. It should also be acknowledged that WTIVs are carrying blades stacked across the deck (length up to 100-110m). Based on recommendations of ref. [4] to allow one beam to the bank clearance (B=50-60m) on top of maneuvering lane (1.6 to 2 X B), recommended entrance width should be 300m (1.8 X 100m + 2 X 50m).

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. However, with WTIV, blades can be stacked across the deck, requiring clearance larger than their length (70-80m) Therefore, locks are not acceptable for installation port.

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 required an additional approx. 20m of clearance, which represents the lowest acceptable limit.

The key location and harbor properties for an installation port, together with the parameter values, are summarized in Table 2-9.

Table 2-9: Summary of key location and harbor properties for installation port

Property		Recommended	Acceptable
Distance to OWF	[km]	< 200	< 400
Depth at channel (entrance) at MLLW	[m]	12.5	9
Harbor entrance width	[m]	300	200
Presence of lock/gate		Not acceptable	Not acceptable
Vertical clearance	[m]	Unrestricted	120
Turning circle	[m]	300 m	240 m

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) and that two vessels can be moored simultaneously. Having two berths allows flexibility in scheduling the inbound and outbound vessels. It is also recommended to allow a reserved berth for WTIVs during a load-out, as has been done in the ports of Rønne, Grenaa, Bremerhaven and Cuxhaven.

Based on LOAs given in chapter 2.2.3 and recommendation for the length of berth equal to 1.25 X LOA (ref. [4]), recommended berth length is 400m.

The terminal should be designed as 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 TPs which are shipped from fabrication yards elsewhere to be stored as well to allow foundation staging if needed.

If possible, providing a heavy load RoRo ramp could add additional flexibility as well.

The **Depth at berth** requirement is not much different compared to entrance requirement. Smaller under keel clearance accounts for difference.

Load capacity of areas depends heavily on use and type of transport. High load allowance does not need to be present throughout and case studies show several examples where general or container cargo quays have been adapted for storage or load-out. In case of suspended decks, this can be achieved using custom-built load spreaders to transfer the loads directly to the piles (rather than the deck). With embedded wall quays, a construction of load relief platform on driven piles can efficiently take the loads away from the wall itself and onto the bearing stratum below. Certifying (or upgrading) 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 50 kN/m^2 is enough to allow both transport and storage of elements such as nacelles, blades and tower segments.

Having a UDL of 100 kN/m^2 allows unhindered running of all components using SPMT (including monopiles and TPs) and staging TPs on quay side (in close proximity).

Some operations require a higher UDL allowances. Tower foundation packs or heavy load areas where elements are erected and pre-commissioned require bearing capacity of 150 - 200kN/m^2. It is considered most economical to limit this to a dedicated area. Similar goes for other similar uses such as heavy load pads or cradle foundations for monopiles.

The same recommendations apply for yard. If the load is not affecting the quay (or retaining wall at the back of the suspended pile wharf), providing high load areas is not as costly. If the fill is already compacted, it is sufficient to a well compacted gravel layer (up to 1m) to achieve uniform distribution of loads (and further settlements).

It should be again stressed that UDL in this case is uniformly distributed load over the entire (or large) area. Loads under the crane tracks are typically much higher but act over the limited area. As a rule of thumb UDL of 50 kN/m^2 should be sufficient to match peak load under the tracks of largest cranes seen in such ports (Liebherr 11350).

A **strengthened seabed** is recommended to ensure that WTIV can **jack-up** immediately next 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

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 should be carefully considered and if possible, avoided for quays that are intensively used for installation.

Also, with sufficiently competent seabed, jacking-up can be possible without strengthening or penetration.

About 15-20 ha of **yard area** and storage space is sufficient to achieve staging and loadout of both foundations and turbines (as these operations do not have to occur simultaneously) for a single project (≈500 MW capacity).

Granular overlaying stone pavement (crushed rock, gravel) is preferred over heavy-duty concrete blocks. Speed of transport is usually low and granular efficiently distributes peak loads from the crane tracks.

There are no requirements for fixed cranes for installation base ports.

If there are intentions to develop an installation port into offshore hub over a period of time, there should be consideration for future co-location of production facilities. Therefore, if possible, the OW installation terminal, particularly if it is a new development, should be located near unused land area. This can be achieved by opting for location in extension to the present terminal footprint but within a sheltered harbor.

The key berth and yard properties for an installation port, together with the parameter values, are summarized in Table 2-10.

Table 2-10: Summary of key berth and yard properties for installation port

Property		Recommended	Acceptable
Berth length	[m]	400	200
Depth at berth	[m]	12	8
Load capacity (UDL)	[kN/m^2]	100	50
Strengthened seabed		yes	*
Yard area	[ha]	15-20	10
Co-location potential	[ha]	100 ha	**

* acceptable without but should be carefully considered

** co-location is not necessary for installation process itself but rather for allowing the growth of symbiotic functions if pipeline of OW projects is strong

In addition to the properties discussed above, various other considerations could play a role in port-planning with OW services in mind. One of them may be the presence of land-based traffic connections. Good road connections are key requirement if supply chain is dependent on the transport of components from hinterland. It is not commonly seen that freight trains are used for transport of components to installation bases.

Proximity to other modes of transport such as airport could also be advantage if crew rotation is planned out of the installation base.

2.6.2 Floating Foundation Installation Port Benchmark

At this time, the formulation of a port requirements benchmark for floating foundations is quite an uncertain exercise, as the technology is not yet mature, there are still several viable designs and most importantly there is no track record for commercial deployment.

Compared to the bottom-fixed foundations, the most important distinction is absence of the WTIV with requirements for uninterrupted installation schedule (so smaller entrance width and potentially shorter berth).

Key driver of the process would be the production cycle of the floaters (dock, yard. Etc.) which should be the entry point into any kind of more detailed planning process.

Based on sizes of current demonstrator projects, the indicative requirements for port properties are described below and are shown in Table 2-10 assuming mostly activities of joining turbine and floater.

The size of **storage** is unclear as joining of turbine and floater is a continuous process governed mostly by the rate of floater production. In that sense, the size of the yard can be as low as to allow for one shipload of components to be available for installation but also as high as for fixed foundations.

Load capacity allowance is governed by the largest component storage on quay (nacelle) and tracked cranes required for lifting (possibly dual lift). It is considered that requirements are similar as for bottom-fixed foundations.

Depth at berth and entrance can be larger than for bottom-fixed foundations. While barge-type floaters have comparable draught to vessels shown in chapter 2.2.3, semi-sub require larger draught for maximal stability.

Table 2-11: Summary of indicative port properties for floating wind

Property		Recommended	Acceptable
Depth at channel (entrance) at MLLW	[m]	20	12
Harbor entrance width	[m]	200	150
Presence of lock/gate		Not acceptable	Not acceptable
Vertical clearance	[m]	Unrestricted	Unrestricted
Turning circle	[m]	300 m	240 m
Berth length	[m]	200	150
Depth at berth	[m]	20	11
Load capacity (UDL)	[kN/m^2]	100	50
Yard area	[ha]	15	5

It must be noted that technological changes and the natural maturation process can significantly alter this benchmark in the coming years.

2.6.3 Operation and Maintenance Port Benchmark

For operations based on CTV requirements for O&M port are far less demanding than for installation bases. Assuming vessels with LOA of 15-30m basic set of port parameters is given in Table 2-12.

As the loads for equipment and spare parts are not considerable, any of existing quays can function as berth for service vessels. In case of CTVs, access to the vessels is very often difficult from fixed berths due to small freeboard. In such cases, it is quite common to provide a dedicated pontoon berth for small vessels. Recommended properties for CTV based maintenance ports are shown in Table 2-12.

O&M facility should ideally have 0.75 to 1.5 ha of available area, adjacent to the berthing to allow for construction of the onshore facilities (offices, storage, accommodation, workshops).

Table 2-12: Summary of key location and harbor properties for CTV based O&M port

Property		Recommended	Acceptable
Distance to OWF	[km]	< 50	< 100
Depth at channel (entrance) at MLLW	[m]	4	3
Harbor entrance width	[m]	15-20	12
Presence of lock/gate		No	Tolerable
Vertical clearance	[m]	> 10m	> 10m
Turning circle	[m]	60	40
Depth at berth	[m]	4	3
Adjacent area	[ha]	1.5	0.75

Compared to CTV's, SOV would typically require deeper and longer berth. As the vessels return to port less frequently, berth can be shared with other vessels and as some functions are available on the vessel, less area could be needed on shore.

Table 2-13: Summary of key location and harbor properties for SOV based O&M port

Property		Recommended	Acceptable
Distance to OWF	[km]	< 100	< 200
Depth at channel (entrance) at MLLW	[m]	7	6
Harbor entrance width	[m]	25	20
Presence of lock/gate		No	Tolerable

Vertical clearance	[m]	> 40m	> 40m
Turning circle	[m]	150	100
Depth at berth	[m]	7	6
Adjacent area	[ha]	1.5	0.75

In addition to the above listed location and infrastructure properties, one of key requirements for O&M base is local availability of qualified workforce and hinterlands that can support activities.

2.7 Port design as a driver for local value and job creation

Offshore Wind Farms represent very large investments and sustained economic activity over an extended period of time. As such, there is a considerable focus on internalizing as great a part of this economic activity as possible within the region seeking to establish the OWF. Creating the optimal conditions for co-location of manufacturing, assembly, staging, operation and maintenance and decommissioning is always in focus to internalize as much of the value creation from OWFs as possible. This points to port design as a critical parameter: does the port facilitate all links in the OWF value chain?

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

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 co-location evolving over time and in anticipation of a continued pipeline of OWF projects.

3. Timing of the pipeline of OWFs may also be a factor in co-location of manufacturing. If the pipeline is concentrated within a short timeframe, co-location will likely be less attractive. It is costly and takes time to move manufacturing and when the pipeline runs out, the new location may not be better situated than the original location.

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

Based on these insights the expected impact on local content creation from port design may be summarized in phases as follows:

- 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 content even when the developer may be international. Staging and shipping requires a large amount of skilled labor: welders, crane operators, maritime crew to name a few. Providing space for co-location of manufacturing is not likely to impact local content in the short run. The local impact is to a higher degree determined by the long-term pipeline and the existing local manufacturing

industry in the country. Co-location is more likely to occur when the expected pipeline is large.

- During O&M of OWF: Port design and more importantly port proximity to the OWF may impact local content creation. O&M contractors will be more likely to utilize the port if it is located close to the OWF.

In summary, the local content generation for a new OW port comes from all three activities listed above. The O&M, in particular, can be highly localized with a stable perspective. When a visible pipeline is established, it may be possible to entice OW manufacturers to co-locate at the port, but this does not in itself increase local job creation unless the manufacturer is international. Whether this is successful also depends upon many factors beyond the port's control.

2.7.1 Job Creation in Danish Ports

Although it was not possible, to gather information on the individual economic impact of the ports profiled in Section 2.5, job creation during OWF construction and O&M in Denmark has been the subject of detailed study [9].

Table 2-14 summarizes the job creation from OWF construction and O&M in full time equivalents (FTE), which is the number of persons employed full time for a year (sometimes also called man-years).

Table 2-14 Employment Effects in Danish Ports [9]

Case study ports:	Port transformation investments	OWF project (role of the port)	Employment effect generated by the OWF
Esbjerg	DKK 1.8 bil (288 mil USD)	Thor Wind Farm Horns Rev I Horns Rev II Horns Rev III Multiple other WF (All functions)	5.234 FTE* (800-1000 MW) 2.729 FTE* (406 MW)
Grenaa	DKK 150 mil (24 mil USD) +100 mil infrastructure outside port (16 mil USD)	Anholt Wind Farm (Installation and O&M port)	101-500 jobs**
Rønne	DKK 500 mil (80 mil USD)	Kriegers Flak Arcadis Ost (Installation port)	3.221 FTE*** (600 MW) TBD (2022)

* it is estimated that 666-1,084 FTE and 347-565 FTE, respectively will be local to Esbjerg port
** Only local jobs
*** It is estimated that 14-129 FTE is local to Rønne port

Based on the results shown in Table 2-14 for the Thor and Horns Rev III wind farms, job creation during construction is expected to be in the range 5200-6700 FTE/GW. These estimates are based on a quite aggressive assumption about the development in FTE/CAPEX. It is assumed that technological development means that fewer hands are required for the construction of OWFs.

In 2013, the Danish think tank AE estimated the FTE from the 400 MW OWF Anholt to 7500 FTE corresponding to 18750 FTE/GW. In addition, salary levels in Denmark are 2-3 times higher than in Korea [10]. Consequently, FTEs are expected to be higher in Korea as the Korean employment induction coefficients are approximately 3 times higher than the Danish coefficients.

3 Assessment of the current port infrastructures in Korea

3.1 Methodology

This chapter outlines the current port infrastructures of the Korean ports which could be utilized for supporting offshore wind farm construction project. The study mainly depends on public data. During the preparation of the report, COWI communicated with the port authority to request some additional information.

Korean ports, as seen in Figure 2-3, are classified into four categories in accordance to the Harbor Act, Act No. 15134 based on its functions;

- National trade port: a hub harbor for domestic and overseas inland and marine transportation networks;
- Regional trade port: a harbor mainly for handling cargos necessary for regional industries
- National coastal port: a harbor mainly for evacuating ships in an emergency critical
- Regional coastal port: a harbor mainly for providing convenience and supporting local transportation of cargos and passengers

National trade port

Figure 3-1 Map of Korean Ports [11] (Magenta; National trade port, blue; Regional trade port, yellow; national coastal port; black, regional coastal port)

3.1.1 Shortlisting

All ports in Korea are listed in the 3rd National Port Master Plan [11]. In order to choose which of the ports on this list would be profiled in this study, it was necessary to apply some criteria to produce a "short list."

In agreement with KEA, two criteria have been applied for shortlisting the ports. The first criterion of the port category is selected because it represents the level of port infrastructure. Offshore windfarm supporting port will handle international cargos. Therefore, the ports in the category of national trade ports are the only ones likely to fulfill most requirements for an offshore windfarm integrated port. The figure below shows the international trade ports of Korea.

Figure 3-2 International trade port of Korea [12]

The second criterion is the distance to the proposed offshore windfarm areas. This is because the distance will heavily impact the performance of the project implementation, both in terms of time schedule and economics. In summary, the following shortlisting criteria were applied to the full list of Korean ports:

- Port Category: national trade port
- Distance to planned OWF: 200 km

These criteria are met by eight ports:

- Western coast: Boreong, Daesan, Janghang, Gunsan, Mokpo
- South & Eastern coasts: Ulsan, Busan, Pohang

Although the port of Janghang is an international trade port, its overall infrastructure is relatively weak, and the port of Gunsan is in close proximity to the port. Therefore, the port of Janghang will not be further considered in this study. The port of Boreong is also excluded because it is exclusively used to supply nearby coal power plants, and there is no publicly operated wharf available. Finally, the following six ports will be investigated and profiled in this study:

- Western coast: Daesan, Gunsan, Mokpo
- South and Eastern coasts; Busan, Ulsan, Pohang

3.1.2 Profiling

Profiles were compiled for these six ports, primarily using public information from the following sources:

- The 3rd National Port Master Plan, Ministry Public Notice No. 2011.07.29 [13]
- The 2nd New Port Development Master Plan, Ministry Public Notice No. 2019-122, 2019.08.02. [14]
- National Maritime Information [15]
- Amendment on the Port Master Plan – (Busan, Daesan, and Mokpo), Ministry Public Notice No. 2018-34, 2018.04.13 [16]

The profiles cover all of the benchmark parameters for fixed-foundation installation ports, formulated in Section 2.6.1, as well as other relevant information for understanding the current situation of the ports. Out of the three benchmarks formulated in Section 2.6 (fixed-foundation installation, floating foundation installation and operation and maintenance), it was chosen to proceed with the fixed-foundation installation benchmark for the remainder of this study. This is because the benchmark for floating foundation is only indicative (as the technology has not yet been deployed at commercial scale) and carries a significant amount of uncertainty. Regarding operation and maintenance ports, the requirements for these types of ports are much less stringent in comparison to the requirements of installation ports.

3.1.3 Gap analysis

The gap analysis is an assessment of the status of the port infrastructure for identifying the differences in the infrastructures between the benchmark port and the selected ports.

For the reasons given in chapter 2, it is considered that benchmark for floating wind is illustrative only and cannot be applied to preselection process. Therefore, the port infrastructure information has been collected focusing on the key parameters for fixed-foundation installation port shown in Table 2-9 and Table 2-10. It is understood that the ports on the eastern coast are seen as best candidates to service floating wind due to proximity. The port infrastructure study and gap analysis have been also conducted for the eastern port which is informative purpose for further study.

Several fixed-foundation type of OWF are proposed in the western sea. In this study, the Jeonbuk Southwest site has been considered as a reference site for measuring the distance to OWF for the profiles, as it is scheduled to start before Sinan. According to the results of the gap analysis, two good candidate ports were chosen for the later roadmap analysis.

3.2 Port Profiles

In the following sections, the information gathered on each port is presented as a profile.

The distances to the offshore wind farm have been referenced from the two major sites of Jeonbuk South West(2.4GW) and Ulsan (6.0GW) for the western ports and the south and eastern ports. Refer to Figure 1-1. The channel depth is based on A.L.L.W (Approx. Lowest Low Water), Datum Level. A.L.L.W corresponds roughly to LAT. Available depths referenced to A.L.L.W will therefore give additional reserve compared to benchmark that is referenced to M.L.L.W.

3.2.1 Port of Daesan

Overview

The port of Daesan is the only international port located in Chungcheong province. After its opening in 1991, the port has mainly been used for private oil companies; Hyundai Oil Bank, Hanwha Total. Then, the port has equipped one and three public berths in 2006 and 2010, respectively. It has a total of 31 wharves which can handle 13,512 thousand RT/year. The Wharf No. 3 has the biggest berthing capacity of 30,000 M/T.

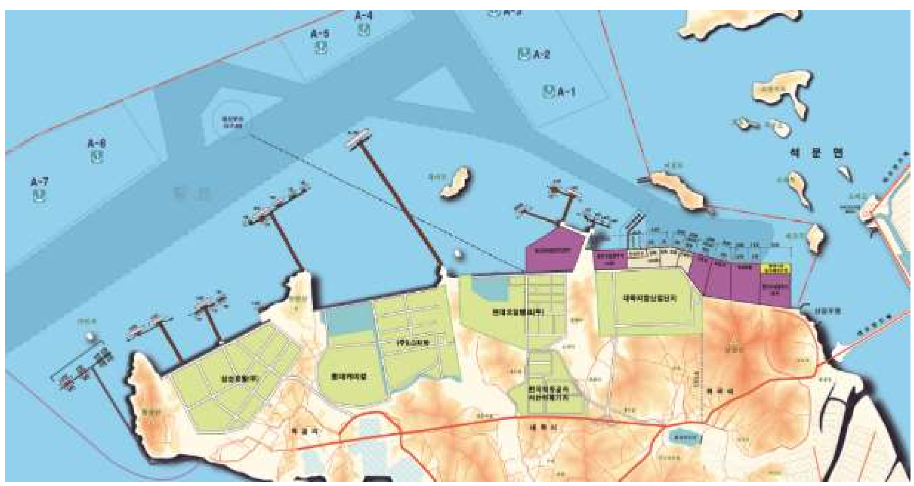


Figure 3-3 The port of Daesan [16] (Magenta: Being developed, Yellow; Planned port area)

Navigational Characteristics

The navigation channel depth is greater than 14 m in general. There are twelve anchorage areas, and the radius of the turning area is about 450 m which can cover heavy ships. There is no navigation restriction. However, the port may need to complete additional dredging to ensure the navigation requirement.

Infrastructure access

Although the nearest highway interchange, Songak I/C is about 41 km long, the four-lane road, Road No. 38, provides a good access to the port from the interchange.

The port has no direct access to the railway. The 3rd national railway development plan(2016~2025, [17]) introduces the plan to build a railway to the port of Daesan. The railway connection is planned at the Asan Industrial complex, and the railway from the main railway line to Asan Industrial complex is now in design stage. At this moment, the connection line to the port of Daesan is a desk planning stage with no detailed implementation plan available.

The key location and harbor properties of Daesan port are summarized below in Table 3-1.

Table 3-1: Key location and harbor properties for installation port – Port of Daesan

Property		Daesan port
Distance to OWF Jeonbuk Southwest site (ca.)	[km]	180
Depth at channel (entrance) at MLLW	[m]	>20
Harbor entrance width	[m]	>300
Presence of lock/gate		No lock/gate
Vertical clearance	[m]	Unrestricted
Turning circle	[m]	>300

Wharves

There are four public wharves whose PORT-MIS codes are MB1-01, MB2-02, MB3-01 and MB4-01, respectively. The first wharf is the international passenger terminal to China, and the other three wharves are being used for public purpose where max. 30,000 DTW size of ship can berth. The three quays are operated by the TOC (Terminal Operating Company).

Since there is no available quay at this moment, the eastern area shown in Figure 3-4 could be developed to accommodate the additional wharf, where a total 490-meters long wharf is being planned.

Figure 3-4 Planned new port facility [16](Red circled area)

Backup area

The public backup area is about 12.3 ha behind the public wharves, where there is little available space. Meanwhile, in the port area, COWI notes that there are two port areas under construction: western and eastern port facility area which are 15 ha and 20 ha, respectively. The western area is being used for spoiling the dredged material generated from the channel maintenance. Meanwhile, the eastern area is being reclaimed using sand. Therefore, the eastern area could be used as the backup area if completed.

Figure 3-5 Backup area of the proposed new wharf – Eastern Area (Redline depicts the proposed new quay)

Co-location potential

There is no co-location area available because the proposed wharf area is adjacent to a large hill. The backup area of about 20ha is greater than the min. required backup area. Therefore, the port could be considered as having a fair co-location potential.

There is an industrial area, Daejuk Industrial Complex, just behind the port area. It is being developed by several chemical companies and has no yard available. Sukmon Industrial Complex, shown in Figure 3-6, is the nearest industrial complex which is 20 km from the port. The area of the complex is about 452 ha, and there is 250 ha available area.

Figure 3-6 Sukmoon industrial complex

The berth and yard properties of Eastern Area in Daesan port are summarized below in Table 3-2.

Table 3-2: Summary of key berth and yard properties of the proposed quay in Daesan port

Property		Daesan Port	Note
Quay length	[m]	490	If developed
Depth at berth	[m]	New	If developed
Load capacity (UDL)	KN/m^2	New	If developed
Strengthened seabed		New	If developed
Yard area	[ha]	20	If developed
Co-location potential	[ha]	None	*

Summary

Although the port has limited available capacity, COWI notes that Daesan port may have a good potential to be OWF supporting port considering the following advantages;

- New wharf can be built on the Eastern Area where the reclamation is ongoing
- Fair backup area and co-location potential

At the same time, however, COWI also notes that the distance to the Jeonbuk Southwest project site is somewhat farther away than the other western ports studied in this report. The port could be a good candidate for OWF project in offshore area of Gyeonggi-bay (Incheon).

3.2.2 Port of Gunsan

Overview

Port of Gunsan is located near the Geumgang river estuary, which is at the center of the western coast of the Korean peninsula. The port serves as a gateway into the midwestern region of Korea. There are seven quays in total.

Figure 3-7 Port map – Gunsan port [16] (Yellow areas are planned port areas)

Navigational Characteristics

At the mouth of the port, the channel depth of 11 meters (Approx. LLW) is generally kept. Note that the water depths have been taken from Ocean map information service [12] where the depth is based on Approx. LLW. There are five anchorage areas where max. 50,000 GT size of vessel can be anchored.

Infrastructure access

The port of Gunsan has fully developed infrastructure; direct access to the railway and the four-lane road, Road No. 21, to the nearest I/C about 30km from the port.

The location and harbor properties of Gunsan port are summarized below in Table 3-3.

Table 3-3: Key location and harbor properties for installation port – Port of Gunsan

Property		Gunsan port
Distance to OWF Jeonbuk Southwest site (ca.)	[km]	60
Depth at channel (entrance) at MLLW	[m]	>11
Harbor entrance width	[m]	>400
Presence of lock/gate		No lock/gate
Vertical clearance	[m]	Unrestricted
Turning circle	[m]	>300

Wharves

Currently, all wharves are operated by Terminal Operating Companies, and there is no public wharf available. Figure 3-8 shows two planned port areas in detail. The first one is in between Wharf No. 74 and 79, and the other one is in between quay no. 4 and no. 6. The planned port area No. 1 could be a good candidate for OWF dedicated wharf. When developed, the new wharf will be about 890 m long. When developed, the new wharf will be about 890 m long and be backed up by 40 ha laydown area.

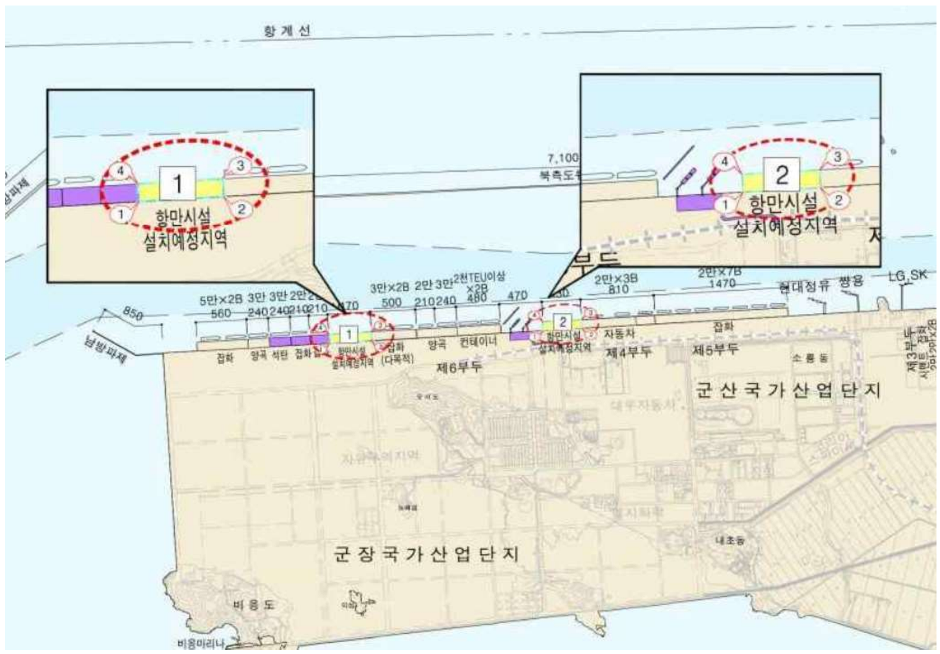


Figure 3-8 Planned New wharf location (Marked as "1")

Backup area

The proposed backup area for would be about 40 ha, which is greater than the requirement and the area can also be used for co-location for manufacturing facility. The area has been reclaimed by the soil from the channel maintenance dredging. The port master plan indicates that the area is a designated port area where a new quay will be constructed. However, there is no action plan for the construction. Also, note that the ground comprises of soft clay having very low strength. Therefore, the area needs improvement before use.

Figure 3-9 Backup area, marked in yellow (source: Google Earth)

Co-location potential

The proposed backup area is about 40 ha which is above minimally recommended value. Therefore, parts of the backup area could also be considered as co-location potential.

Saemangum industrial complex is being developed, which is just near the Port, just 3 km south from the port. The complex, connected with the Gunsan Industrial Complex, will be the largest industrial complex when completed. The project area is about 18.5 km².

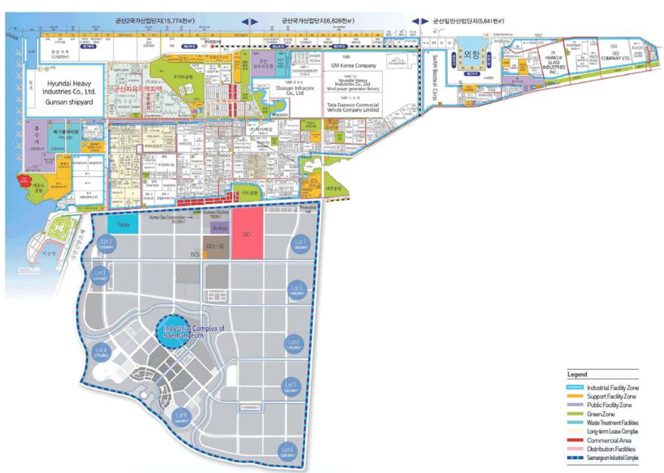


Figure 3-10 Location of Saemangum industrial complex being developed (blue dashed line)

The berth and yard properties of Gunsan port are summarized below in Table 3-4.

Table 3-4: Summary of key berth and yard properties for Gunsan port

Property		Gunsan port
Quay length	[m]	Up to 890
Depth at berth		New
Load capacity (UDL)	[KN/m^2]	New
Strengthened seabed		N/A
Yard area	[ha]	40
Co-location potential	[ha]	Good considering the backup area

Re-Purposing Existing Wharf

While it is not within the scope of this study to examine re-purposing existing wharves, a Gunsan port the local government has shown interest in developing the 7th Quay for offshore wind, using the quay no 71 and 72. Quay 71 and 72 can cover 50,000-ton size of ships each, and its total length is 560 meters long. The laydown area is about 32 ha. There is no further co-location area. However, the adjacent yard owned by Hyundai Heavy Industry could be developed to setup manufacturing facilities, if agreed. Therefore, it may be interesting to investigate this option in future studies.

Summary

The port of Gunsan is an excellent candidate due to its close proximity to the wind farm area, meaning that it could easily serve as both installation port and O&M port. The possible quay length of 890m and backup area of 40 ha are almost twice as much as benchmark recommendations.

3.2.3 Port of Mokpo

Overview

It is in the southwestern end of the country; the port of Mokpo is located in Jeollanam-do. The sheltered port on the delta of the Yeoungsan-gang handles various kinds of material, such as dry and liquid bulk, container, steel, vehicles, etc. In 2019, its material handing was about 4.7 Mil. R/T which ranked top 9th port in Korea.

The port is comprised of five main quays; Samhak, Daebul, Yongdang, Northport and New Port, where the New Port is being developed to expand its capacity. The quays of Samhak, Daebul, Yongdang and Northport may be inappropriate because of its limited material handling capacity. Accordingly, the New Port is investigated.

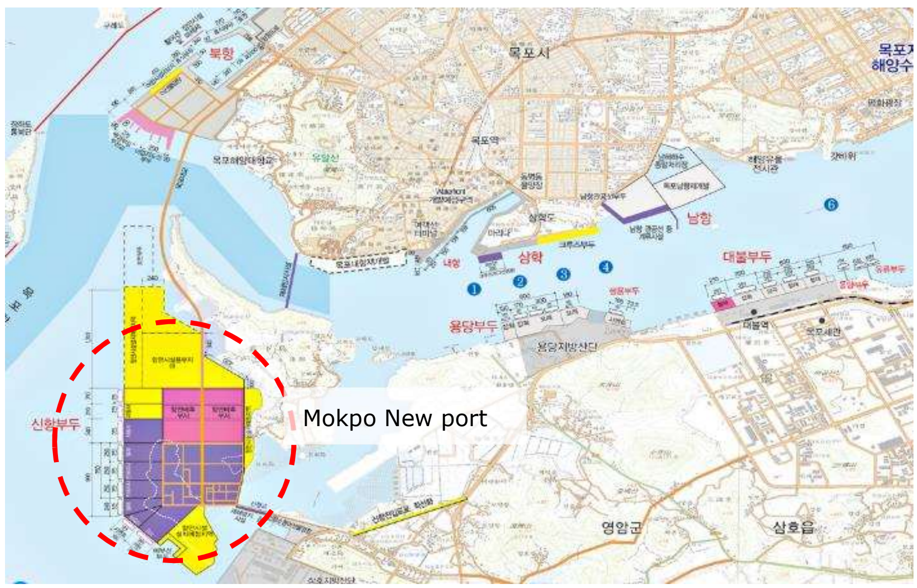


Figure 3-11 Mokpo New Port [13]

Navigational Characteristics

The port is equipped with five anchorage areas in total, where max. 50,000 G/T size vessel can be anchored and where the water depth is greater than 12m. The available navigation depth of the New Port is greater than 13m (Approx. L.L.W.).

There are many islands in the province and several bridges are being constructed or planned at the moment. Figure 3-12 shows major road and bridge projects nearby. The navigation clearances of the bridges are generally lower than 50m. This means that the WTIV must choose a detour route which increases transport to the proposed sites. The detour navigation route is illustrated in Figure 3-13 as blue line. Smaller O&M vessels would not need to detour around the bridges.

Figure 3-12 *Navigation clearances of the sea bridges (Image taken from http://gj.nocutnews.co.kr/news/5155960 originated by Mokpo regional office of Oceans and Fisheries)*

Figure 3-13 *Navigation channel to the port of Mokpo for heavy vessels (image taken from http://www.nbnnews.co.kr/news/articleView.html?idxno=292230 originated by Mokpo regional office of Oceans and Fisheries)*

Infrastructure access

There is an industrial railway network which ends at Daebul Industrial Complex located in 12km from the port. It is known that the railway will be connected to the New port. However, the construction schedule has not yet been prepared. The distance to the nearest highway interchange is about 19 km.

The location and harbor properties of Mokpo port are summarized below in Table 3-5.

Table 3-5: Key location and harbor properties for installation port – Port of Mokpo

Property		Mokpo port
Distance to OWF Jeonbuk Southwest site (ca.)	[km]	120 for small O&M vessel without detour 200 for heavy vessel with detour
Depth at channel (entrance) at MLLW	[m]	>13
Harbor entrance width	[m]	580
Presence of lock/gate		No lock/gate
Vertical clearance	[m]	Unrestricted
Turning circle	[m]	> 300

Wharves

There are 35 wharves in total with different berthing capacities. The multipurpose wharf (Code No. MBO-02, 03, and 04) and the steel wharf (MOB-01) in the New port provides maximum berthing capacity of 30,000 G/T with the water depth of 12 meters. The New port is the most promising quay from its availability perspective.

The New Port Development Plan (2019. 08, Public Notice No. 2019-122) states that the port of Mokpo is considered as one of offshore wind supporting ports. The proposed location in the planned port area as shown in the Figure 3-14.

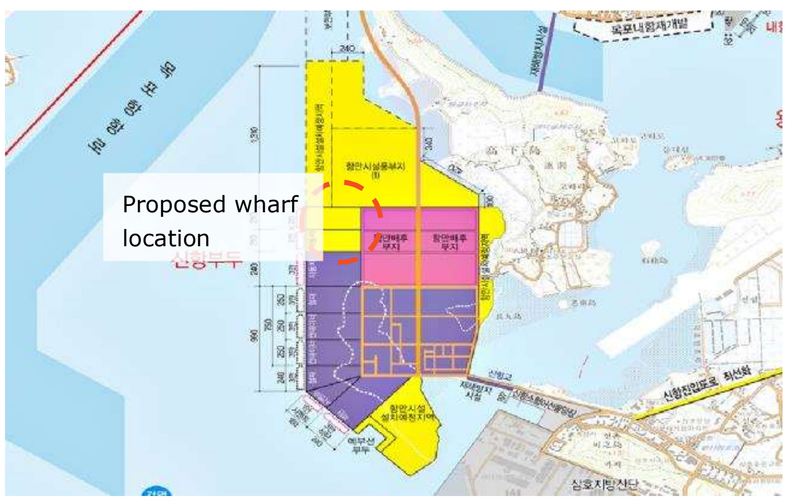


Figure 3-14 Proposed wharf location, circled in red [14]

The area is a designated port area which is reserved for future planning. The site is selected because of its good potential for backup area and co-location area, 40 ha in total. If developed, the wharf will be 400 m long.

Backup area

The proposed wharf has a total of about 39ha of backup area just behind the wharf area. It is under construction and planned for completion within the first half of 2021. The design bearing capacities of the backup area vary from 10 kN/m^2 to 50 kN/m^2 at the New port.

Figure 3-15 Backup area – proposed wharf of Port of Mokpo

Co-location potential

The proposed wharf could share part of the available yard (40 ha) with prospective manufacturing facilities in the future. In addition, land that is being reclaimed to the north could be used in the future for locating production facilities.

Daebul industrial complex is located relatively near the port of Gunsan, about 12 km. This industrial complex with a size of 446 ha has only limited free space of about 20ha which is much smaller than recommended. Furthermore, transport corridor goes through Mokpo downtown area which should be considered as deterrent when planning for transport of large components at slow speed.

The berth and yard properties of Mokpo port are summarized below in Table 3-4.

Table 3-6: Summary of key berth and yard properties for port of Mokpo

Property		Mokpo
Quay length	[m]	400
Depth at berth	[m]	New
Load capacity (UDL)	[kN/m^2]	New
Strengthened seabed		New
Yard area	[ha]	40
Co-location potential	[ha]	up to 60ha if area immediately to the north is reclaimed

Summary

The port generally meets the recommendations, though the need for heavy vessels to take a detour around bridges in increases the distance to OWF. The quay length is adequate, and the yard area is generous.

3.2.4 Port of Busan

Overview

The port of Busan is the largest port in Korea, located in the city of Busan. It is comprised of four major ports- North Port, Gamcheon and Dadaepo Port, and New Port. Public wharves are in North Port. The port aims to be the leading container hub port in east Asian region. In 2019, the port of Busan handled 22,000 Thousand TEU, which is top 6 in the world.

It is known that the two ports of North Port, Gamcheon and Dadaepo Port are under operation at almost their full capacity. In addition, the South Container port in the New Port, which is a dedicated container port, is also fully operational, and there is limited available berthing capacity and backup area. In the western side of the New Port, another new container port, so-called West container port (2-5 Stage), is under construction, and it will be opened in 2022. According to the port authority (Busan Port Authority), they are preparing a tender for making a long-term renting contract with maritime companies.

Figure 3-16 Port of Busan

Navigational characteristics

The channel depth in the New Port area reaches to -17m thus making it navigable for 24,000 TEU class container ship.

Infrastructure access

The New Port is supported by strong infrastructure. The port equips a railway access, and there is a highway interchange locating about 15 km from the port.

The location and harbor properties of Busan port are summarized below in Table 3-7.

Table 3-7: Key location and harbor properties for installation port – Port of Busan

Property		Busan port
Distance to OWF Jeonbuk Southwest site (ca.)	[km]	480 (130 to Ulsan site)
Depth at channel (entrance) at MLLW	[m]	>17
Harbor entrance width	[m]	≈1300
Presence of lock/gate		No
Vertical clearance	[m]	Unrestricted
Turning circle	[m]	>300

Wharves

In 2022, two container terminals will be opened, Stage 2-4 and Stage 2-5. Those two wharves will not be available for OWF supporting purpose because they were designed to handle containers only.

The only possible new wharf location for OW is the southern part of eastern new port, where two new multi-purpose wharves with total length of 480m are being constructed. Figure 3-17 indicates the wharf location. In order to utilize the wharf for OWF, the port operation policy must be amended, as the wharf is already planned for another purpose. In addition, although the site can be considered having enough backup area, the backup area is designed as container handling area. Therefore, it is foreseen that the site will be very congested.

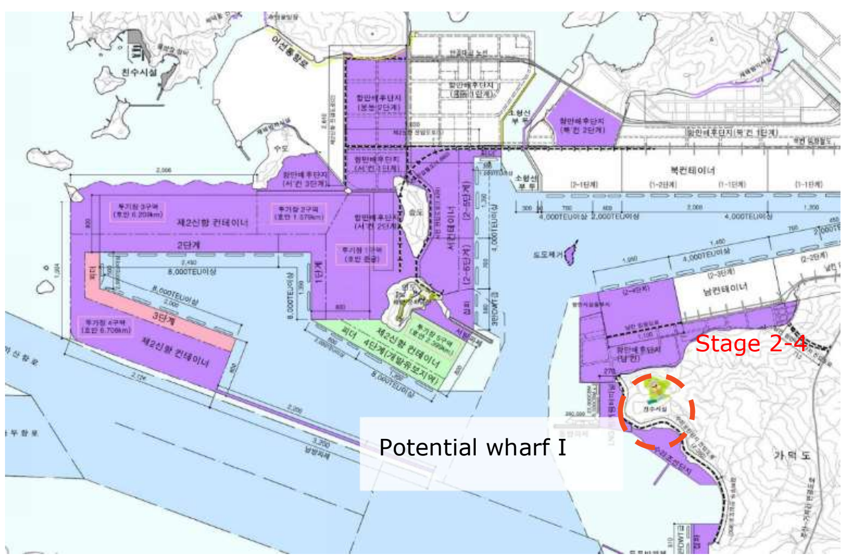


Figure 3-17 Potential OW wharf location

Backup area

There is a 38ha size of backup area behind the suggested wharf area. However, the actual availability will be very limited and could be lower than 10ha because the area will be mainly used for handling of container cargo.

Figure 3-18 Backup area – potential OW wharf of port of Busan

Co-location potential

The new port of Busan has been built in the sea by reclaiming. Therefore, the port has no co-location area, and only the planned backup yard would be available.

Busan new port can be supported by two industrial complexes, "international logistic industry complex" and "Mium industrial complex" which are about 10 km long from the port and provides a total of 100 ha available land.

Figure 3-19 Industrial areas nearby Port of Busan

The berth and yard properties of Busan port are summarized below in Table 3-8.

Table 3-8: Summary of key berth and yard properties for Busan port

Property		Busan port
Quay length	[m]	480
Depth at berth	[m]	15~17
Load capacity (UDL)	[kN/m^2]	20
Strengthened seabed		No
Yard area	[ha]	<10, considering expected congestion
Co-location potential	[ha]	Available area will be limited

Summary

The multi-purpose wharves under construction on the east side of the South New Port area will be the good candidate. The site has good navigation and berth of sufficient length. However, the backup area might be inadequate due to congestion and limited area.

3.2.5 Port of Ulsan

Overview

Port of Ulsan is a port complex comprising of four ports: Main port, Onsan port, Mipo port and New port. Together, these ports have a total of 116 berths and wharves with capacity for general cargo vessels of up to 50,000 tons. It handles coal, general cargoes, grain, automobiles, LPG, chemical and oil products.

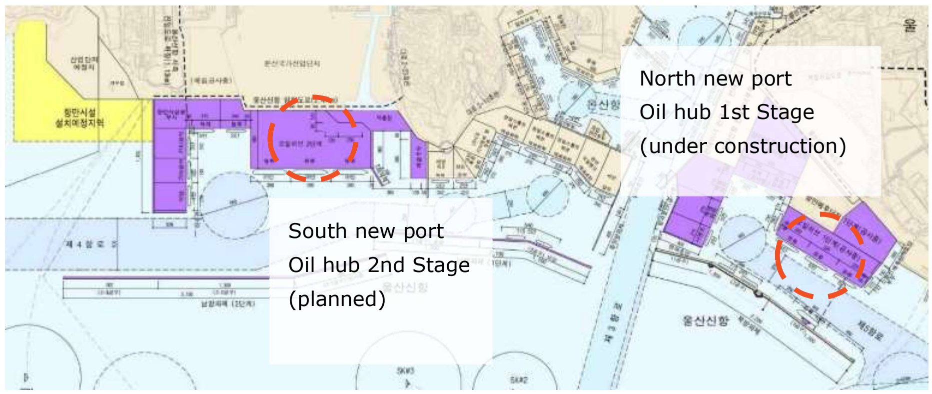


Figure 3-20 Port of Ulsan (New port area only) [18]

Navigational Characteristics

The port provides a total of five navigation channels. The min. channel width is 300 meters at the second channel where the channel depth is about 12 m.

Infrastructure Access

The infrastructure of the port of Ulsan Port is well-organized. It has direct railway connection and good highway access within 10 km.

The location and harbor properties of Ulsan port are summarized below in Table 3-9.

Table 3-9: Key location and harbor properties for installation port – Port of Ulsan

Property		Ulsan port
Distance to OWF Jeonbuk Southwest site (ca.)	[km]	550 (70 to Ulsan site)
Depth at channel (entrance) at MLLW	[m]	12~14
Harbor entrance width	[m]	≈650
Presence of lock/gate		No lock/gate
Vertical clearance	[m]	Unrestricted
Turning circle	[m]	>300

Wharves

A total of 116 ships can be moored in the port. The Main port has 30 wharves including 10 private wharves, where there is no wharf suitable for OWF supporting function. Yongyeon Pier located in the North New port is the only suitable wharf, which is 500 m long and allows access to vessels with DWT of max. 30,000 t.

Figure 3-21 Yongyeon Wharf

The wharf, however, would not be good for OWF support because of its limited backup area.

Alternatively, the planned south port area shown in Figure 3-22 could be used, where a breakwater is under construction. Note that the area filled with light purple is a planned port area, and the area will be reclaimed. If developed, the new wharf can be about 510m long.

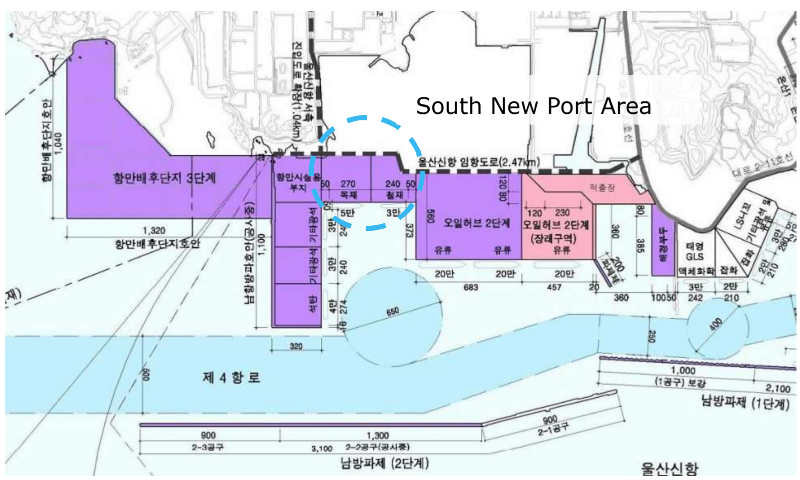


Figure 3-22 Alternative location of OWF wharf (blue circled area)

Figure 3-23 Proposed new wharf site along the coast

Backup area

The proposed wharf area has 39 ha size of a backup area which is shown in Figure 3-23 filled with yellow. Note that the site must be improved.

Co-location potential

The backup area of about 39ha is wide enough to allow additional industrial facilities. However, the

The berth and yard properties of Ulsan port are summarized below in Table 3-10.

Table 3-10:Summary of key berth and yard properties for Ulsan port

Property		Ulsan port
Quay length	[m]	360 available
Depth at berth		New
Load capacity (UDL)	New	New
Strengthened seabed		New
Yard area	[ha]	The actual availability is unclear. It depends on the port operation scheme, but could be up to 39.
Co-location potential	[ha]	Availability is unclear

Summary

The port of Ulsan is being operated at its full capacity, and there is limited available backup area and co-location area. The Yongyeon port area which is being developed could be utilized for support OWF. The proposed wharf location is shown in Figure 3-23.

3.2.6 Port of Pohang

Overview

The port is comprised of three ports; Yeongilman port, Old port and New port. The old port is small fishery harbor, and the New port is for steel industry port. The Yeongilman port is a container terminal port where six ship of 20,000 DWT can be moored, where two wharves are for general purpose. Yeongilman port is being operated by Pohang Yeongil New Port Corporation.

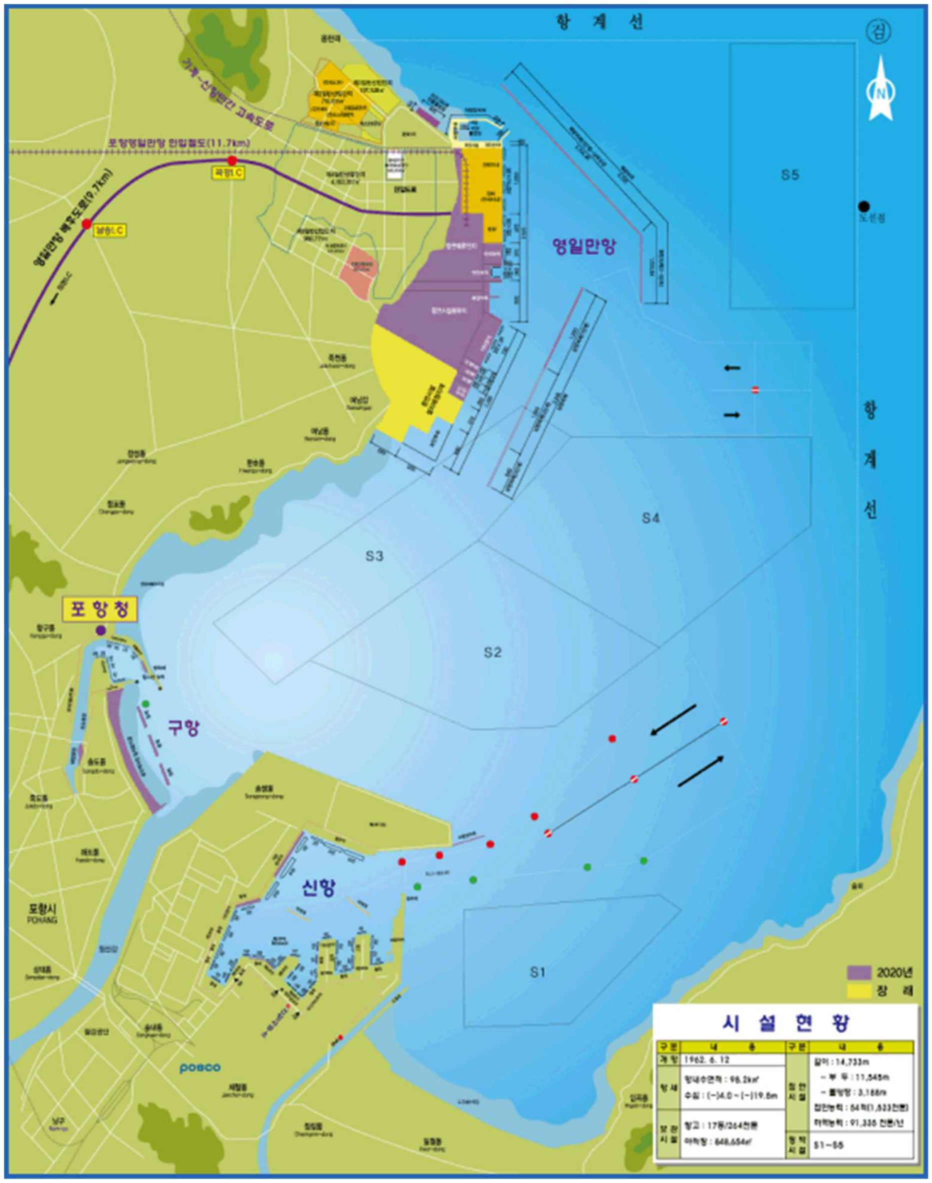


Figure 3-24 Port of Pohang

Navigational characteristics

The Yeongil port has a good navigation condition, 20 m deep and 900 wide on the mouth of the port.

Infrastructure access

The port provides good infrastructure access: a direct railway connection and 13 km from the nearest highway interchange.

The location and harbor properties of Pohang port are summarized below in Table 3-11.

Table 3-11: Key location and harbor properties for installation port – Port of Pohang

Property		Pohang port
Distance to OWF Jeonbuk Southwest site (ca.)	[km]	650 (130 to Ulsan site)
Depth at channel (entrance) at MLLW	[m]	20
Harbor entrance width	[m]	900
Presence of lock/gate		No lock/gate
Vertical clearance	[m]	Unrestricted
Turning circle	[m]	>300

Wharves

The general-purpose wharf is 420 m long in total, and its water depth is 12 m deep.

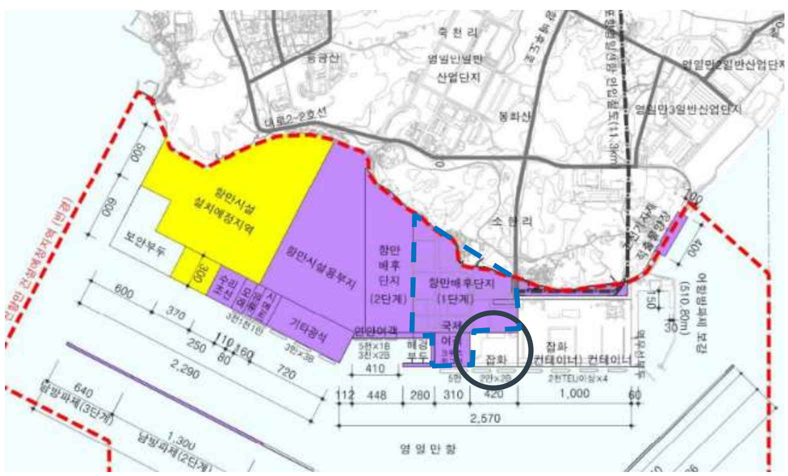


Figure 3-25 Suggested wharf on Yeongilman port

Backup area

The laydown area behind the multipurpose wharf is about 10 ha. At this moment, however, the backup area is almost fully used for containers and other materials. The availability during construction is unclear.

Co-location potential

The Yeongilman port is being developed. Especially, the blue doted area in Figure 3-25 has been reclaimed, and its total area is about 50 ha. It shall be noted that the area has its own designated use. To utilize the area, the port masterplan should be revised.

The planned Yeongil bay Industrial complex is located relatively short distance, 3 km, where about 15 ha is available.

Figure 3-26 Proposed co-location area (Yeongil bay industrial complex)

The berth and yard properties of Pohang port are summarized below in Table 3-12.

Table 3-12: Summary of key berth and yard properties for Pohang port

Property		Pohang port
Quay length	[m]	420
Depth at berth	[m]	11
Load capacity (UDL)	[kN/m^2]	20
Strengthened seabed		No
Yard area	[ha]	<10, considering congestion due to other operations
Co-location potential	[ha]	50 ha potential, actual availability expected to be less

Summary

The port of Pohang meets the navigation requirement, and it could handle the additional logistics for OWF project. However, there are clear limitations; limited backup area and not enough co-location area.

3.3 Gap Analysis of Selected Korean Ports

In this section, the information which was gathered on the Korean ports is summarized and the port properties are compared to the benchmark parameters for fixed-foundation installation ports, formulated in Section 2.6.1. In addition to this benchmark, the current availability of the port was added to the gap analysis, as this factor is relevant from a time and cost perspective.

Table 3-13: Gap analysis of selected ports in Korea

		Benchmark for fixed-foundation port		Korean Ports					
		Recommended	Acceptable	Daesan	Gunsan	Mokpo	Busan[C]	Ulsan[D]	Pohang
	Availability	-	-	New wharf must be constructed	New wharf to be constructed	New wharf to be constructed (New Port)	Under construction (South container terminal)	New wharf to be constructed (New port area)	Multipurpose wharf could be utilized[E]
Location & harbor	**Distance to OWF Jeonbuk Southwest site** (km, ca.)	< 200	< 400	180	60	200[B]	480	550	650
	Depth at channel (entrance) at MLLW (m)	12.5	9	>20	>11	>13	>17	12~14	20
	Harbor entrance width (m)	300	200	>300	>400	≈580	≈1300	≈650	≈900
	Presence of lock/gate	Not acceptable	Not acceptable	No lock/gate	No lock/gate	No lock/gate	No lock/gate	No lock/gate	No lock/gate
	Vertical clearance (m)	Unrestricted	120	Unrestricted	Unrestricted	Unrestricted	Unrestricted	Unrestricted	Unrestricted
	Turning circle (m)	300	240	>300	>300	>300	>300	>300	>300
Berth & Yard	**Quay length** (m)	400	200	490 available	890 available	400 available	480	360 available	420
	Depth at berth (m)	12	8	New[A]	New[A]	New[A]	15~17	New[A]	11
	Load capacity (UDL, KN/m2)	100	50	New[A]	New[A]	New[A]	20	New[A]	20
	Strengthened seabed	Yes	-	New[A]	New[A]	New[A]	No	New[A]	No
	Yard area (ha)	15-20	10	20	40	40	<10	Up to 39	<10
	Co-location potential (ha)	100	-	None	Good, 40ha backup area	Up to 60ha if area immediately to the north is reclaimed	Available area will be limited	Availability is unclear	< 50 ha, actual availability will be limited

Notes:

A) It is assumed that a newly constructed wharf will be made to meet the recommendation
B) For heavy vessel, measured along the detour navigation channel
C) Under construction, West side of South New Port Stage 2-4. Wharf operation policy would have to be amended to enable use
D) To be newly constructed on the New port area.
E) To utilize the existing wharf, the port operation scheme has to be amended and to be agreed by the stakeholders.

Legend:

Currently meets recommended values.	Between the recommended and minimum acceptable values or is not yet constructed.	Does not meet minimum acceptable requirements or is significant barrier to use.

The followings conclusions can be made based on the gap analysis;

- All Korean international trade port satisfies the navigation requirement. And no additional navigation channel dredging work might be required, except regular maintenance dredging works.
- Although there are many existing quays, many of them are operating at almost full capacity and have limited capability to take on OW business. To utilize the existing quays, strategical decision should be made on the port operation policy by the port authorities.

The selected ports have mostly been designed with 10-20 kPa of vertical load bearing capacity, so that the backup yard must be improved to meet the functional requirement.

3.3.1 Selection of Ports for Roadmaps

Based on the gap analysis performed in Section 3.3, two ports were selected for which to perform case studies on the necessary upgrade works and economic impact.

From the gap analysis, it can be seen that the ports of Busan, Ulsan and Pohang all have significant barriers to use, for various reasons. This leaves the ports of Daesan, Gunsan and Mokpo. Of these three ports, Daesan is slightly less preferable due to its smaller yard area and lack of co-location potential. Therefore, COWI has chosen to proceed with Gunsan and Mokpo for the remainder of this study.

At this point, it must be noted that this selection is based on a high-level analysis with the goal of providing some reasonable examples of how the port upgrades could be done and their expected benefits. Most decisions regarding OW projects are made on a project-specific basis, which is also true of which port to use. Therefore, it may well be the case that a different port, possibly even one not covered in this study, is the best choice for a certain project.

The roadmaps for the upgrades of these two ports should be understood as case studies with the purpose of communicating the scale of investment and corresponding benefits.

4 Roadmap for upgrade of Port of Gunsan to OW staging port

4.1 Introduction

This chapter presents a roadmap for development of Port of Gunsan into a turbine installation staging port. Port could potentially service the installation of:

- Jeonbuk Southwest site, 2.4GW,
- Sinan site, 8.2 GW

It is assumed for the purposes of this study that each of these projects have a first stage of 400 MW, due to start in next two years with the remainder of available capacity to be developed until 2030.

The scope of this brief roadmap is a high-level planning of the port terminal. The terminal area is assessed based on potential throughput, which is compared to the OW projects in the pipeline.

Site information has been collected from public sources and supplemented with engineering assumptions based on the best available experience and practice. Therefore, estimate of engineering works required for this terminal should be seen as illustrative.

4.1.1 Assumptions

The overall layout of the Port of Gunsan, including navigation, has been shown in Section 3.2.2.

As stated in Section 3.3.1, this roadmap is for the development of the proposed wharf at Gunsan, between Wharf No. 47 and 79, to serve offshore wind turbine staging and installation.

Development of a brand-new terminal is costly and time consuming and cannot be financed by servicing a single (or several) projects. However, it also presents an opportunity to develop a tailor-made solution for OW installation activities that will allow for streamlining of operations and minimization of the downtime for WTIVs.

The plot has dimensions of 880m (waterfront) X 560m (giving a total of 49 ha) and is located along the waterfront. Future berth line is planned to be continuous with adjacent terminals, both north and south. The area has been reclaimed with cohesive soil from the maintenance dredging and left to consolidate over the past 5 years. The existing level of reclaimed land is approximately +7.00m surrounded by rock embankment along the perimeter at level of +9.00m.

The plot has an area which is approximately twice the size and berth length which is recommended by the benchmark in Section 2.6.1 for installation of single project (approximately 500 MW).

This roadmap proposes fictional division of the plot in two symmetrical halves, Gunsan Offshore Wind Terminal (OWT) 1 and 2. Port planning is done for Gunsan OWT 1 and it is discussed what could be different possibilities for GOWT 2. This division will allow more flexibility in discussion of different possibilities for the terminal.

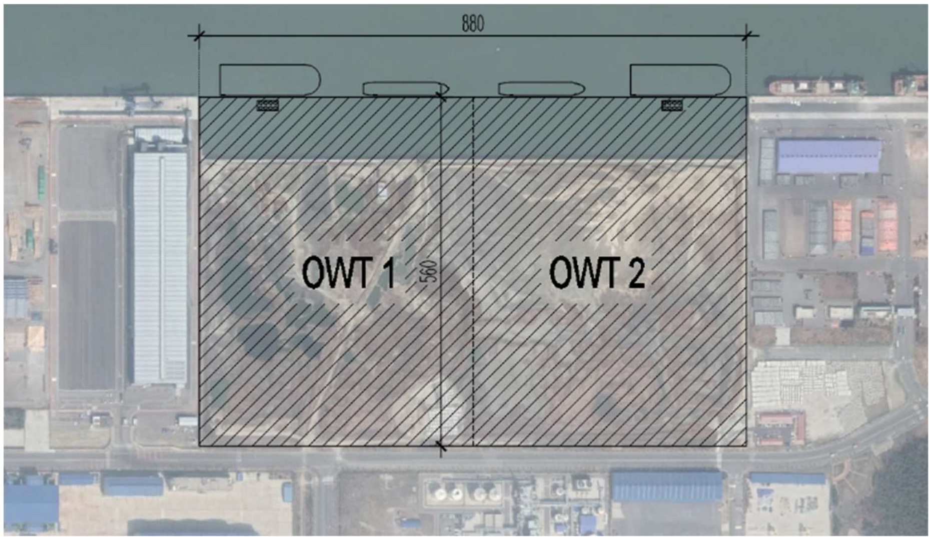


Figure 4-1 Gunsan OWT 1 and OWT 2 – overall layout

O&M operations will not be explicitly considered as a part of this roadmap (see chapter 4.3.4). However, O&M facility can be built within the same port with negligible investment (compared to this terminal) and without rigorous infrastructure requirements.

4.2 Site conditions

4.2.1 Tidal range

Based on the publicly available info and Table 5-1 of the ref. [19] tidal water levels in Gunsan are:

Extreme H.H.W. (including weather)	+8.12m
Approx. HHW	+7.46m
H.W.O.S.T. (spring tide)	+6.64m
M.S.L.	+3.62m
L.W.O.S.T. (spring tide)	+0.61m
Approx. LLW	+0.00m
Extreme LLW (including weather)	-0.69m

4.2.2 Weather conditions

Both coasts of Korea are prone to typhoons, with the season lasting from June to October (peak in August-September). Typhoons in Korea are less severe than in Southeast Asia. It is considered that weather conditions do not have an impact on the general layout of the OWT site.

According to a seismic zoning map of Korea (1987), Gunsan belongs to zone I with peak ground acceleration coefficient of 0.11 for 475yr return period event.

4.2.3 Bathymetry

Bathymetry has been taken from MIKE C-Map sea charts and shown on Figure 4-2.

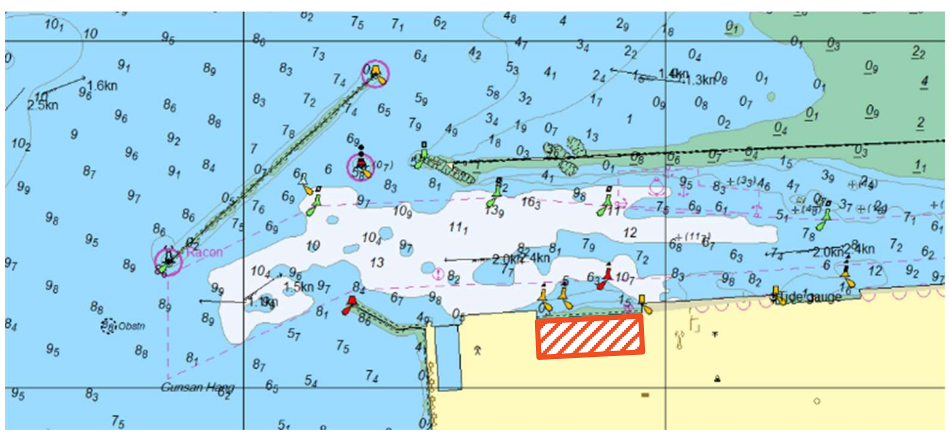


Figure 4-2 Bathymetry of Port of Gunsan. Depths are in reference to ALLW

It is assumed that existing seabed is at approximate level of -8.00 to -9.00m (A.L.L.W) which is the depth of surrounding berths and approach channel.

4.2.4 Geotechnical conditions

Based on experience from previous projects in Gunsan area, it is assumed that seabed is made of soft clay with N < 5 (N - SPT blow count). This top layer extends to approximately 5-10 m depth. Below this are sand deposits with average N ≈ 12. Soft or weathered rock could lie at a depth of up to 30m below the seabed. It is assumed that send deposits are not liquefiable for design driving seismic motions.

The existing site has been reclaimed with spoils from maintenance dredging (soft cohesive material) over a period of 5 years and left to settle by itself.

4.3 OW installation port masterplan

4.3.1 Use of areas

Use of areas for GOWT 1 is shown on Figure 4-3 and explained in text below. The recommended sizes of different areas and facilities are provided for GOWT 1, which is one half of the full site. Offshore Wind Terminal is developed as marginal berth, much like neighboring general cargo and container terminals. The total length of waterfront is 880m (both GOWT 1 and 2) which allows for 4-5 vessels to be moored simultaneously, depending on the size.

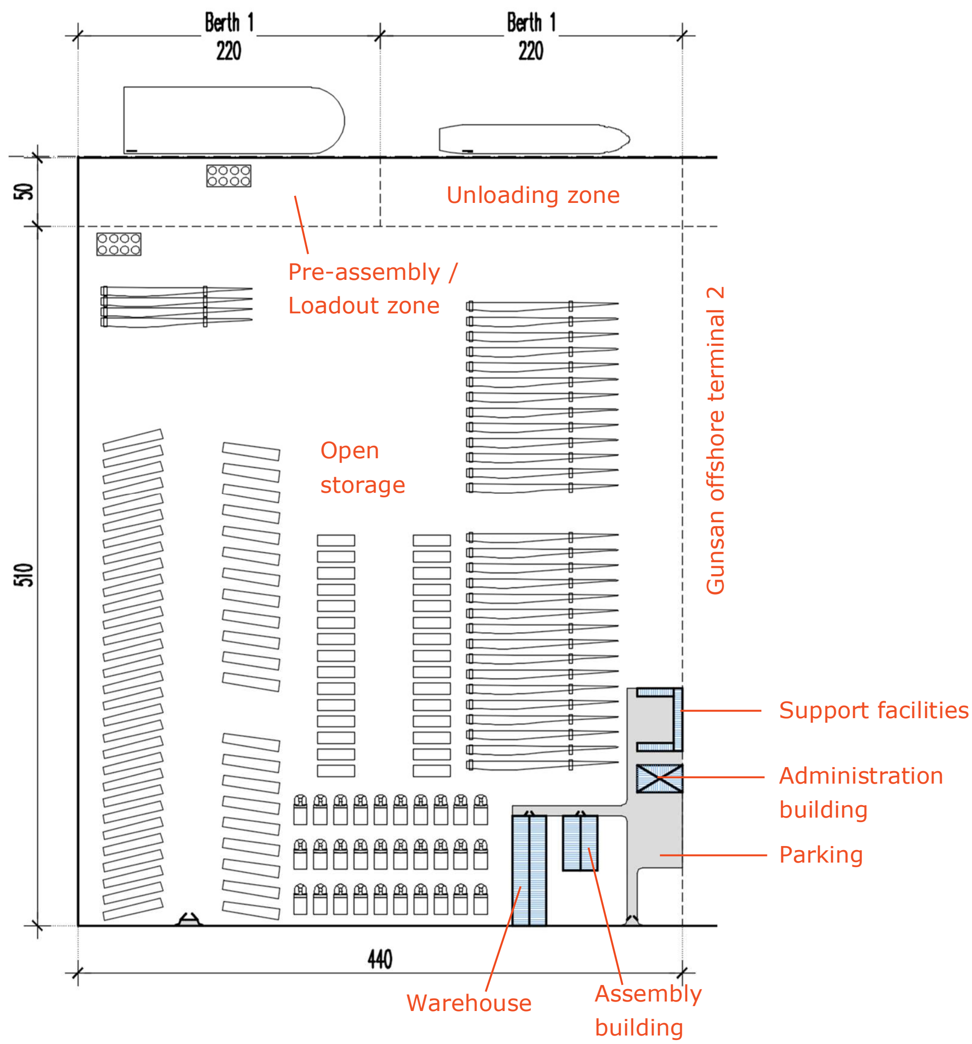


Figure 4-3 Gunsan OW terminal 1 –indicative masterplan (measurements in meters)

The parts of GOWT 1 shown in Figure 4-3 are described below.

Unloading zone	The unloading area is a 50m wide apron behind a 220m long berth. The unloading zone is placed at the inner side of OWT1 (towards OWT 2) to allow more flexibility and possibility to have more smaller vessel (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: *220m, min. water depth -12.00*

Area: *220 X 50m = 11,000 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 line foundations to be assembled to full height and pre-commissioned. From there, they are loaded by WTIV's crane fully assembled. Other components (blades, nacelles, etc.) arrive by SPMTs 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:* *220m, min. water depth -13.00* *Area:* *220 X 50m = 11,000 m²*
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). Transportation of components within the OWT is done using SPMT or trailers (for blades). *Area:* *≈190,000 m²*
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 m²*
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 m²*

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*

Another possible use of the terminal is the staging of foundations (jackets or monopiles + transition pieces). This stage precedes installation of turbines so it would be possible to use the terminal for both purposes for a single project. UDL of 100 kN/m^2 is assessed sufficient to allow for storing of the transition pieces or jackets on the quay. This would require shallow foundations along the quay similar to those provided for staging of towers which is a minor cost.

Staging of foundations is not always required (see chapter 1.4.1) and does not pose stricter requirements on the port facilities than turbine installation. Unloading and load out of foundations can be performed using SPMT, on-land crawler cranes or vessel cranes on jack-up vessels or barges. It is assessed that the concentrated loads from loadout by crawler cranes can fall within above design UDL by using moveable load spreading mats.

4.3.2 Requirements and supporting infrastructure

Depth and seabed

The basin in front of the quay should have a minimal depth of -13m ALLW to allow for mooring of the largest installation vessels in all tidal conditions.

In front of the load-out berths, stone-beds with thickness of 5m are provided to allow jacking up without leg penetration

Load requirements

The open storage, unloading and load-out zones should all be designed to allow for a UDL of 100 kN/m^2.

Tower pre-assembly foundations should be designed for a UDL of 150 kN/m^2.

Terminal operation

In general, operations at the terminal should be possible 24 hours a day and 365 days per year and should provide a level of security for the terminal that restricts access.

All areas should have storm tie-down provisions in case of typhoon.

Pavement

Selected areas such as roads, parking and paths can be paved. The load and storage areas are finished with compacted 0-32mm crushed rock layer. including a rainwater drainage system.

Power and light installations

The overall lighting requirement for the terminal is minimum 5-10 lux (or local regulation) which is achieved by 30m lighting towers at suitable spacing of approximately 60m. Masts should not be placed along the quay.

Security and communications

A perimeter fence should be installed around the site. Security cameras should be installed as a minimum at strategic points.

There should be two sets of gates, one each for both light and heavy vehicles.

Equipment

Staging port should be equipped with the following equipment types:

- Heavy crawler crane (such as Liebherr LR 11350)
- SPMTs
- Reach stacker
- Trucks and terminal tractors
- Cherry picker

Exact number and type of equipment and vehicles are subject to further studies and operator preferences.

4.3.3 Throughput

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 (ref. [20]).

An indicative throughput of GOWT 1 would be 60 turbines over a period of 3-4 months, assuming that two WTIVs are working simultaneously. This corresponds to a 500MW OWF, assuming an 8MW turbine. This fits well with the Jeonbuk Southwest site, for which a first phase of 400MW is assumed for the purposes of this study.

With the vessel installation rate acting as a time schedule driver, the required production rate of the terminal would be 3.5 turbines per week. It is considered that this is realistically achievable.

With a monthly throughput of 15-20 turbines, the storage area should allow for laydown of least twice that volume to ensure sufficient buffer in case of transport or production delays.

Available storage area is checked based on the generic turbine components footprint (chapter 2.2.2), assuming 10-12 MW turbine size. A spatial factor is assumed in the range of 1.3 to 1.6 to account for access to components. Blades can be laid separately or stacked up to three blades vertically on top of each other. Varying these parameters in an analysis gives a range of required storage area between 9 and 20 ha. Stacking of the blades produces largest impact. Still, even with the most conservative assumptions, available storage area is assessed as sufficient to store 30 turbine sets.

Development of the full terminal (GOWT 1 and GOWT 2) would allow for the throughput to be more than doubled if the entire terminal would be used for staging of single project larger than 1 GW.

Due to its size, this terminal is very flexible and there are several other ways to use it. For example, GOWT1 and GOWT2 could be used for staging of turbines for a single OEM supplying turbines to multiple projects. Or, they could be used possibility is hosting two different OEMs.

4.3.4 Co-location

The size of the plot could theoretically allow for production activities to be hosted on the site, but these activities could limit or reduce the throughput of the terminal.

Production of the foundations requires approximately 15-20 ha. Production of blades requires even more due to the large laydown area which is needed to store the stock.

As viable alternative, production of turbine components could be located in one of the neighboring plots or Seamangum industrial park (4 km to the south). With short transport distance and large available areas locating production facilities, there would be synergy with the terminal that would be used both as feeder port (export of components) and installation base during later stages of nearby OW projects.

Another long-term opportunity is hosting the O&M base for Jeonbuk Southwest site. Being 60 km away and with no other ports in vicinity, Gunsan for both CTV and SOV-based approach (or both combined). O&M operations are much less demanding in terms of infrastructure requirements compared to the installation (see chapter 2.6.2). For this reason, O&M would not need to be located at GOWT but could be placed in the area further to the east to prevent reduction of throughput capacity for vessels with larger draught requirements.

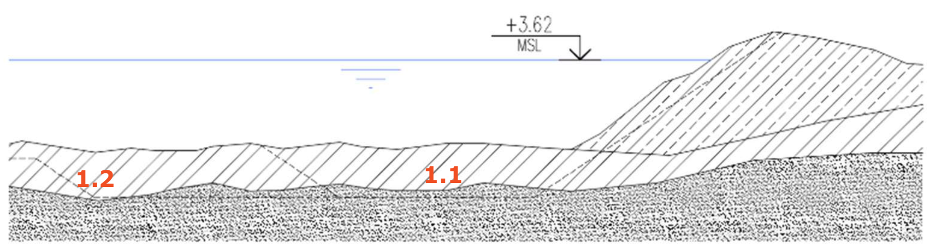
4.4 Terminal construction works

The terminal area has already been reclaimed so that is assumed as a starting point for the construction works for establishing a new terminal.

As the quays of surrounding terminals are executed using caissons, it is assumed that this method would be optimal for the GOWT.

4.4.1 Description of works

Construction works are listed below in approximate sequence of execution (shown by numbers) and illustrated with figures. Descriptions are given only for major civil works.

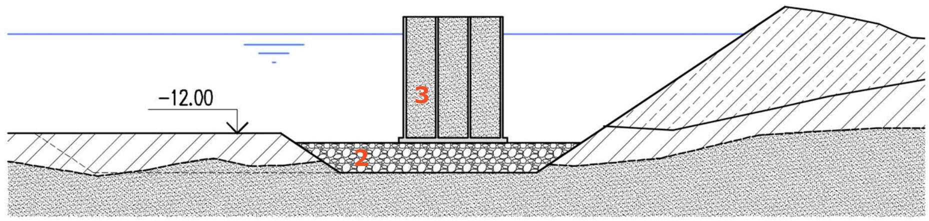


1 Dredging

1.1 Top layer consisting of weak cohesive soil is dredged out (assumed 5-10m depth). Width of the trench is such to allow spreading of the load from the caisson at 1:1 inclination to the layers below.
NOTE: Dredging of foundation trench at the ends will not be possible due to the risk of undermining the existing caissons. It is expected that local soil improvement will have to be done in these areas.

1.2 At places where jacking-up of WTIV is planned, foundation trench is extended to allow for forming of stone-beds that prevent the penetration of the foundation soil.

2 Trench is backfilled with rockfill (for example, 1-50kg stones) and finished with a screed layer (30-60mm gradation).

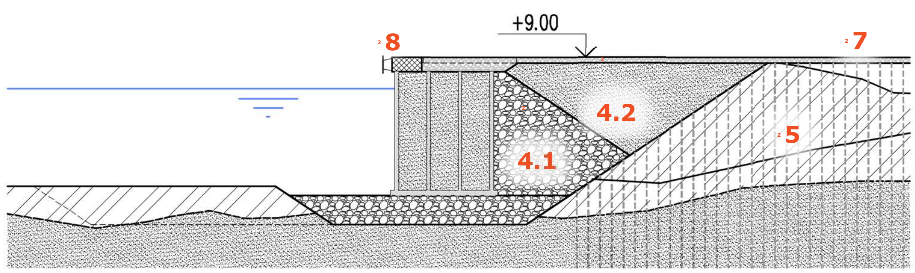


3 Caissons

3.1 Caissons are cast in the yard (or dock), launched and immersed at location.

3.2 Caissons are filled with hydraulically pumped sand.

3.3 Scour protection is installed to the front of the caisson in the length that is affected by propeller flow. Scour protection is assumed as concrete matrasses.



4 Reclamation

4.1 Zone immediately to the back of the caisson is filled with self-compacting rockfill (for example 1-500kg) and finished with filter layer (for example 0-50mm).

4.2 Area behind, to the slope of existing reclamation is filled with sand.

5 Soil improvement is carried out to improve bearing capacity and minimize settlement. Ground improvement by means of installation of rigid inclusions is thought to be a good compromise to achieve desired results, use wide range of equipment available. It is also possible to vary diameters, grid spacings and lengths as to achieve desired effect in changing ground conditions. A high production rate (up to 500-600 linear meters per shift per rig) also allows to optimize overall construction program and project schedule. For the considered level of loads (50-150 kPa) and typical

diameter of inclusions of 300-450 mm, preliminary grid spacing (square) is 1.2 – 2.5 meters.

6 Electrical works

6.1 Cabling and substations.

6.2 Light masts are installed on pad foundations.

7 Fill is finished with 1m thick crushed rock layer which is compacted by rollers and vibro-plates.

8 In-situ concrete and fixtures

8.1 Capping beam.

8.2 Quay fittings (fenders, bollards and ladders).

8.3 Tower pre-assembly foundations.

9 Buildings, parking and fencing.

4.4.2 Cost estimate

An indicative cost estimate is shown in Table 4-1. Costs have been calculated for the development of entire terminal area (OWT 1 and OWT 2) according to the assumptions given in chapters above. The cost estimate assumes double the estimated areas for buildings and parking that are given in chapter 4.3.1.

The accuracy of this cost estimate fits between class 4 and class 5, according to AACE Cost estimate classification system (concept screening / study). This gives an accuracy range of ±50%.

All unit prices used for the estimate have been based on best available knowledge on unit prices in Korea and is excluding any value-added tax or other taxation.

Table 4-1: Indicative estimate of development costs for Gunsan OWT 1 and 2.

Works	Cost [M USD]	Cost [M Won]
Dredging, reclamation and scour protection	53.9	59.883
Soil improvement	32.3	35.885
Reinforced concrete works and caisson installation	81.0	89.991
Quay furniture	2.6	2.889
Lighting and electrical works	6.2	6.888
Buildings, parking and fencing	5.8	6.444
Mobilization & demobilization (8%)	14.5	16.158
Total	**196.3**	**218.138**

Table 4-1 shows the total estimated costs for both GOWT 1 and GOWT 2. If only one of the two terminals are built, the expected costs will be about 50% of the total.

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

4.4.3 Estimated duration

Indicative duration of the works is shown on Figure 4-4. The diagram only includes major works which form the critical path.

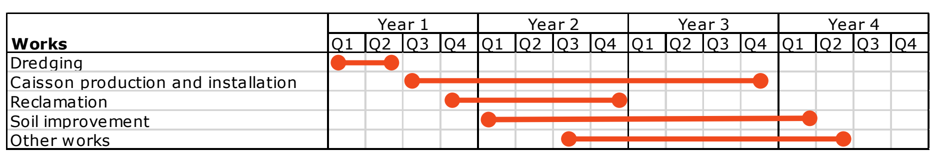


Figure 4-4 Indicative duration of works

Caisson production and installation rate has been assumed as 3 weeks per caisson (22m long). For this to be possible, casting of caissons must be done in casting yard with several production lines. Given that caissons are commonplace in Korea, it is assumed that such facility is already available and does not need to be constructed for this project.

Soil improvement duration has been calculated assuming that four drilling rigs are working simultaneously in two shifts 7 days per week.

Works have been assumed to be staggered with minimal delay to produced shortest time overall.

It is important to say that works can be further re-arranged so that GOWT 1 can be put to use while works on GOWT 2 are still ongoing. It is estimated that this could be done after approximately 2 years after starting of the works.

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

4.5 Roadmap summary

The starting point for COWI's estimate of the roadmap for Gunsan to service OW has been that a new terminal is going to be developed with primary purpose to facilitate a large-scale operation such as turbine staging and installation.

Development of a new terminal requires considerable investment and is estimated to take three years or more to deploy entire area and available berth length. It has been shown that available area is sufficient to service installation of nearby OWFs over the period of 10 years. However, feasibility of the terminal to service exclusively OW sector remains beyond the scope of this study as it depends on many factors and stakeholders.

A way forward could be a phased development where capacity of the terminal is developed in step with the rise in demand. Active approach where developers and OEMs are approached and engaged to understand their needs and forge strategic alliance based on mutual interest.

There could be a possibility to repurpose one of the existing terminals in the short term by upgrading of the bearing capacity and addition of other required features. Master plan presented in this roadmap can serve as a guidance regarding requirements for the area use and resulting throughput.

Gunsan has a viable potential to serve as an O&M base and retain a long-term OW related economic activity with high percentage of local content. This opportunity should be seen as parallel track to development of OW terminal for staging of turbines.

There should be a robust pipeline of OW projects to ensure that a new terminal can provide return on investment. Economic feasibility of the terminal should also consider a possible pessimistic scenario where OW turbine or foundation staging projects are not initiated in close succession.

5 Roadmap for upgrade of Port of Mokpo to OW staging port

5.1 Introduction

This chapter presents a roadmap for development of Port of Mokpo into a turbine installation base port. Development is aimed at servicing the same OW projects as those listed for Gunsan in chapter 4.1.

Site information has been collected from public sources and supplemented with engineering assumptions based on the best available experience. Therefore, estimate of engineering works required for this terminal should be seen as illustrative.

5.1.1 Assumptions

The overall layout of the Port of Mokpo, including navigation, has been shown in chapter 3.2.3.

As stated in Section 3.3.1, this roadmap is for Mokpo with the same basic considerations as given for Gunsan.

The plot has dimensions of 420m (waterfront) X 400m (giving a total of 17 ha) and is located along the waterfront, see Figure 5-1. Future cope line is planned to be continuous with adjacent terminals to the south. The area is currently unclaimed land and full land reclamation of the site is required. In the immediate hinterland to the east of the chosen site there is newly reclaimed land areas that currently is undergoing development. To the south of the site, a developed automobile wharf is in operation. Based on information on the existing automobile wharf the existing level of neighboring reclaimed land areas is assessed approximately +5.60m surrounded by rock embankment towards the site.

The plot has an area of 17 ha and 420 m berth length which matches the size and berth length which is recommended by the benchmark area given in Section 2.6.1 for installation of single project (approximately 500 MW).

Port planning is done for the plot with a discussion on possibilities for further expansion and development of neighboring areas.

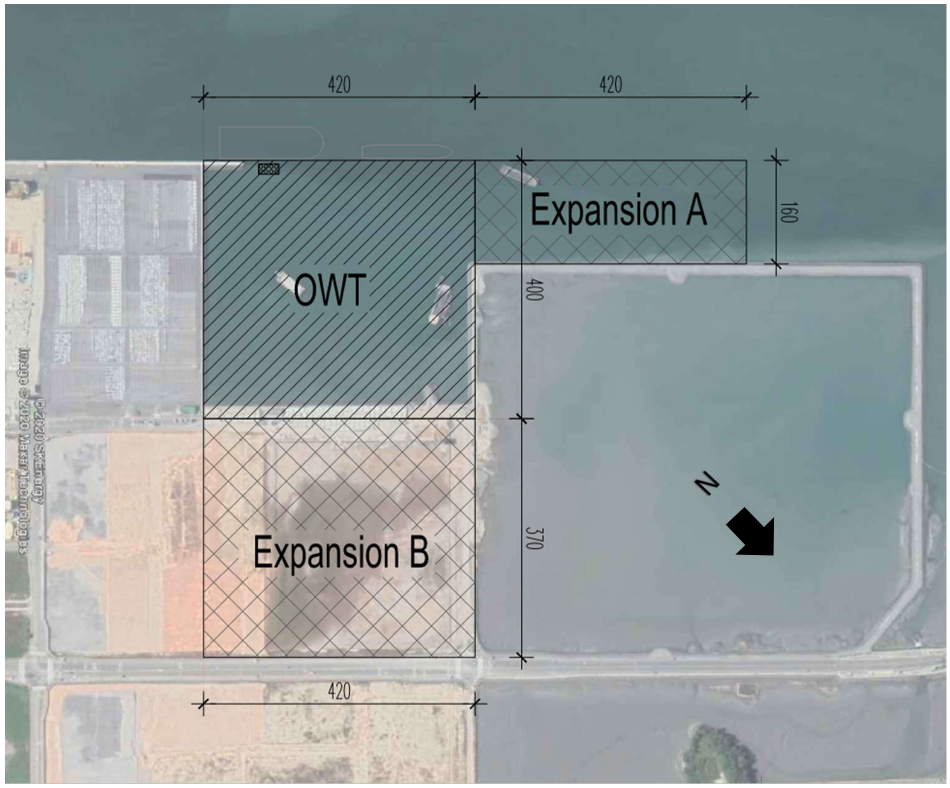


Figure 5-1 Mokpo OW terminal – overall layout (measurements in meters).

O&M operations will not be explicitly as a part of this roadmap (see chapter 5.3.4), but as the benchmark for operation and maintenance ports in Section 2.6.3 shows, it will also be possible to conduct O&M operations from this port.

5.2 Site conditions

5.2.1 Tidal range

Based on the available info from nearby automobile wharf the tidal water levels in Mokpo are:

Extreme H.H.W. (including weather)	5.50m
Approx. HHW	+4.86m
H.W.O.S.T. (spring tide)	+3.84m
M.S.L.	+2.43m
L.W.O.S.T. (spring tide)	+1.02m
Approx. LLW	+0.00m

5.2.2 Weather conditions

As in the port of Gunsan, Mokpo is subject to typhoons, with the season lasting from June to October (peak August-September). Typhoons in Korea are less severe than in South East Asia. It is considered that weather conditions do not have an impact on the general layout of the OWT site.

According to seismic zoning map of Korea (1987), Mokpo belongs to zone I with peak ground acceleration coefficient of 0.11 for 475yr return period event.

5.2.3 Bathymetry

Bathymetry has been taken from MIKE C-Map sea charts and shown on Figure 5-2.

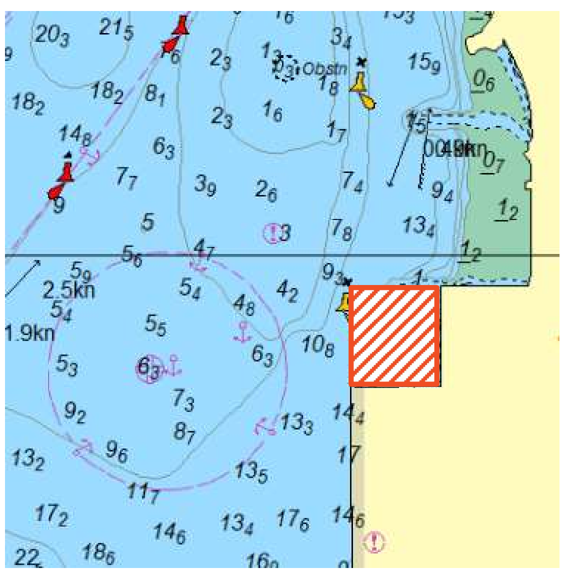


Figure 5-2 Bathymetry of Port of Mokpo. Depths are in reference to ALLW (±0.0m)

It is assumed that existing seabed is at approximate level of -9 to - 10m. It shall be noted that reduced water depth of up to approx. -3m is observed to the west of the proposed berth.

5.2.4 Geotechnical conditions

Based on experience from the neighboring automobile wharf, it is assumed that seabed is made of soft clay with N < 5. This top layer extends to approximately 2-12 m depth. Below this are soft rock deposits. Backfill is for the Mokpo site assumed to be sand as it is not considered that spoils from the dredging would match the volume needed for reclamation.

5.3 OW installation port masterplan

5.3.1 Use of areas

Use of the area is shown on Figure 5-3 and explained in text below. Offshore Wind Terminal is developed as marginal berth, much like neighboring general cargo and container terminals. The total length of berths is 420m which allows for 2-3 vessels to be moored simultaneously, depending on the size.

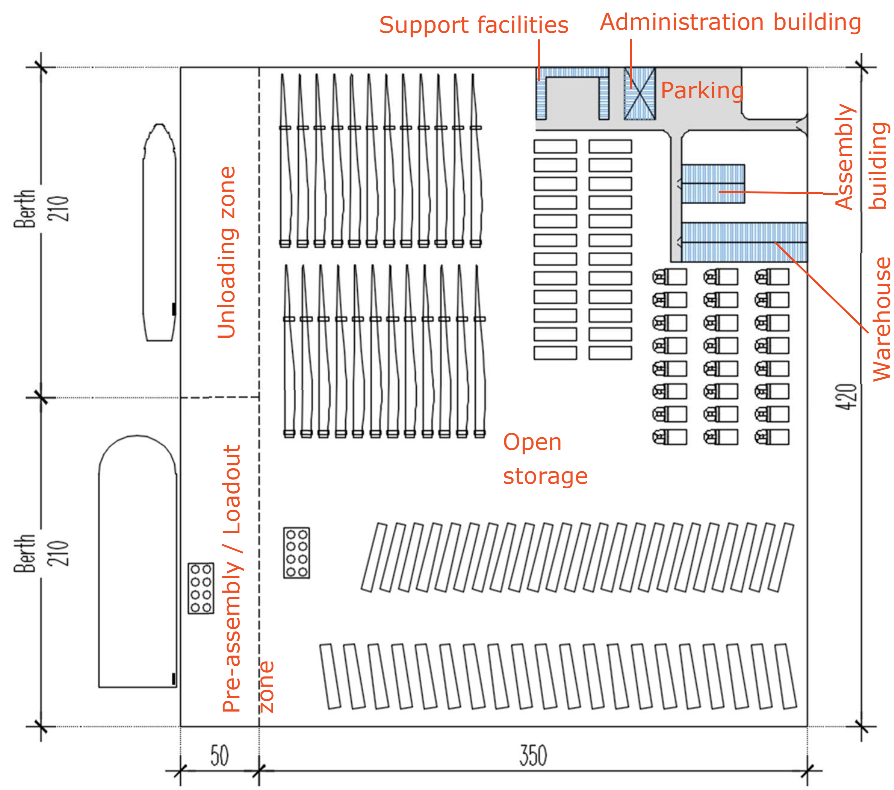


Figure 5-3 Mokpo OW terminal – indicative masterplan (measurements in meters)

The parts of Mokpo OWT 1 shown in Figure 5- are described below.

Unloading zone	The unloading area constitutes 50m wide apron behind a 210m long berth.

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: *210m, min. water depth -12.00 m*

Area: *210 X 50m = 10,500 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 line foundations to be assembled to full height and pre-commissioned. From there, they are loaded by WTIV's crane fully assembled.

Other components (blades, nacelles) arrive by SPMTs from open storage and are loaded on deck using WTIV's crane.

WTIV's is jacked-up in front of the quay to achieve full crane capacity and eliminate movement.

Berth length: *210m, min. water depth -12.00 (m)*

Area: *210 X 50m = 10,500 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).

Transportation of components within the OWT is done using SPMT or trailers (for blades).

Area: *≈140,000 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 m²*
Assembly building	The assembly building is an insulated and airconditioned hall which serves the pre-assembly and storage of electrical components such as power and transformer units.	
	Area:	*40 X 25 m = 1000 m²*
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	Parking area with 80 spaces for small vehicles.	
	Area:	*2000 m²*

As with Gunsan, the terminal area can be used also for foundation staging.

5.3.2 Requirements and supporting infrastructure

Requirements for the specific areas of the terminal are the same as those given in chapter 4.3.2.

5.3.3 Throughput

Based on the throughput calculated and storage requirements calculated in chapter 4.3.3, it is considered that area of 14 ha is sufficient to store 30 turbines. However, blades will have to be double stacked.

By expanding to the north of the site with additional 420m (waterfront) x 160m shown as expansion A on Figure 5-1 the berth capacity gets doubled in order to double the unloading and preassembly/load out capacity. To get sufficient storage area capacity to balance the throughput of the doubled berth capacity a further expansion of the hinterland area to the east of the site shown as expansion B on Figure 5-1 should be included. This gives a total capacity of 840 m berth and approx. 330,000 m^2 storage area. By expanding the site with expansion A and B the full terminal would allow for the throughput to be more than doubled if the entire terminal would be used for staging of single project larger than 1 GW.

As alternative, terminal could be used for staging of turbines for a single OEM supplying turbines to multiple projects.

Third possibility is hosting two different OEMs.

5.3.4 Co-location

The reclaimed land area to the east of the site on both sides of the main road currently undergoing development would be suitable as co-location areas, see Figure 5-4. Assuming that expansion A and B has been utilized for OWF staging port facilities the remaining potential co-location area is approx. 32 ha.

Figure 5-4: Co-location areas at Mokpo OWT (measurements in meters).

Production of the foundations requires approximately 15-20 ha. Production of blades requires even more due to the large laydown area which is needed to store the stock.

Another long-term opportunity is hosting setting up O&M base for Sinan site (60 km distance) or Jeonbuk Southwest site (120 km distance for smaller O&M vessels). Distance to the site allows for both CTV and SOV-based approach (or both). Same considerations apply as for Gunsan OW terminal.

5.4 Terminal construction works

The terminal area is currently water area which needs to be reclaimed as land area.

As the quays of surrounding terminals are executed using caissons, it is assumed that this method would be optimal for the OWT. Backfill material is assumed as sandy material based on information of used material for nearby terminals.

5.4.1 Description of works

Construction works are listed below in approximate sequence of execution (numbers) and illustrated with figures. Works are similar to those described for Gunsan and are not repeated here in detail. Illustration of indicative cross section is shown on Figure 5-5.

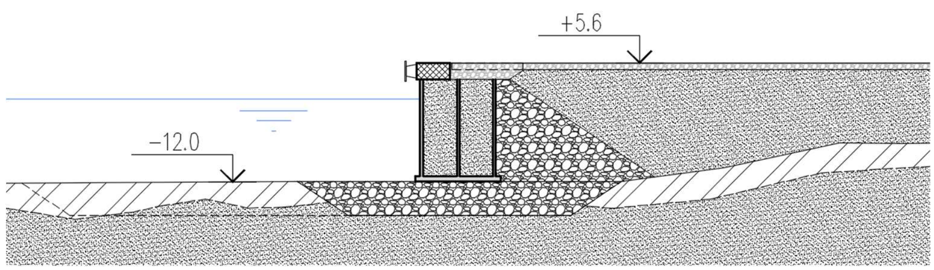


Figure 5-5: Typical cross section for Mokpo terminal

In case of Mokpo, the use of sand is assumed for reclamation. As the sand is a frictional fill, settlements are expected to occur immediately. To accelerate the settlements of the soft deposited soil, reclaimed area is pre-loaded in segments. The exact height of preloading or any other measures such as vertical drain are not assumed without better information of the geotechnical conditions.

Fill is finished with 1m thick crushed rock layer which is compacted by rollers and vibro-plates.

5.4.2 Cost estimate

Indicative cost estimate is shown in Table 5-1. Costs have been calculated for the OWT site not including the expansion possibilities according to the assumptions given in chapters above.

The accuracy of this cost estimate fits between class 4 and class 5 according to AACE Cost estimate classification system (concept screening / study). This gives an accuracy range of ±50%.

All unit prices used for the estimate have been based on European prices and adjusted to what is assumed to be applicable for Korea and is excluding VAT.

Table 5-1: Indicative estimate of development costs for Mokpo OWT.

Works	Cost [M USD]	Cost [M Won]
Dredging, reclamation and scour protection	64.1	71.215
Reinforced concrete works and caisson installation	22.1	24.553
Quay furniture	1.3	1.444
Lighting and electrical works	5.2	5.777
Buildings, parking and fencing	3.0	3.333
Mobilization & demobilization (8%)	7.7	8.555
Total	**103.5**	**114.989**

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

In comparison to the cost estimate for Gunsan, the cost estimate for Mokpo is significantly lower. This is mainly due to the size difference between the terminals: both Gunsan terminals together are more than twice the size of the Mokpo terminal. One additional point to note is that the dredging, reclamation and scour protection works are much higher. This reflects the higher cost of reclaiming the Mokpo terminal entirely from the sea, which Gunsan only needs small additions.

5.4.3 Estimated duration

Indicative duration of the works is shown on Figure 5-6. The diagram only includes major works which form the critical path.

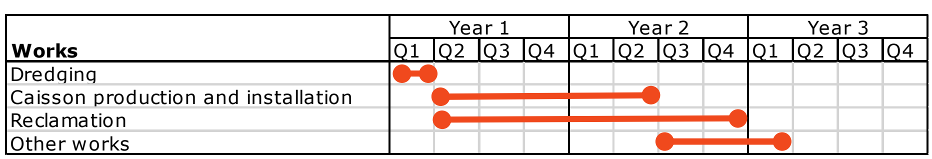


Figure 5-6 Indicative duration of works

The same assumptions apply for estimate of duration as for Gunsan.

The estimated duration for Mokpo is approximately a year shorter than the estimated duration for Gunsan, primarily due to the fact that Gunsan has more than twice as much area.

5.4.4 Roadmap summary

As for Gunsan, starting point for estimate of the roadmap for Mokpo to service OW has been that a new purpose-built terminal will be constructed to facilitate a large-scale operation such as turbine staging and installation.

Development of a new terminal is assessed to take slightly more than two years. It has been shown that available area is sufficient to allow the growth in the throughput that follows expected construction of nearby OWF over the period of 10 years. However, feasibility of the terminal to service exclusively OW sector remains beyond the scope of this study as it depends on many factors and stakeholders.

The same considerations as described for Gunsan apply here as well. Should OW pipeline remain strong following initial commercial projects, the port of Mokpo should pursue OW-related offer of specialized services and production through co-location, which in this case can be in immediate vicinity.

6 Estimation of Impact on Local Economy and Job Creation

6.1 Methodology

The purpose of this model is to calculate the direct and indirect impact on gross domestic product (GDP) and employment of the investments in 1) preparing a port to accommodate the installation and O&M of an OWF and 2) during construction and O&M of an OWF.

The calculation of the GDP and employment effects is based on Leontief multipliers derived from input-output tables (IO tables) for Korea provided in English by the Asian Development Bank [21] and employment induction effects from the Ministry of Employment and Labor of the Republic of Korea [10].

The IO tables outline how activity in one sector contributes to the production in other sectors. The IO table that the multipliers are based on includes 34 sectors. In order to use the multipliers to assess the impact of an investment, a primary sector is identified. This is the sector which will typically be the central sector during implementation of the investment.

The primary sector chosen for the investments are summarized in Table 6-1.

Project investments		Primary sector
1	Gunsan Port	Construction
2	Mokpo Port	Construction
3	OWF	Construction
4	O&M	Construction/Water Transport

Table 6-1 Main sectors of the three phases of the project

The primary sector for O&M activities is more complex than for the construction works. Given the limited choices provided by the sectoral split in the input output tables, there is no perfect match for all the activities comprised within O&M. O&M involves a substantial component of water transport. The operation and maintenance itself involves many different skillsets, but most of them can be found within construction. Hence, the impact of O&M is measured as a simple average between the sectors Water Transport and Construction.

The direct effect is the increased activity, created by the investment itself. This will include tasks such as supervision, installation and construction work. The direct effect on GDP is simply the total investment. The direct effect on employment is calculated as the total investment times the employment induction coefficient for the primary sector.

The indirect employment effect is the increased demand for labor, which occurs as a result of procuring goods and services, and the effect this has with the supplier.

The calculation of the indirect employment effects includes the following steps:

- The investment sum is divided among different sectors, based of the draw on resources generated by the primary sector in other sectors.

- The indirect effect in each sector is then calculated by multiplying the investment in each sector, with the employment induction effect for the sector in question.

- The total indirect effect is the sum of the indirect effects in all the sectors.

6.2 Assumptions

In Sections 4 and 5 of this study, capital expenditures (CAPEX) was calculated for each of the ports: USD 196.3 million for Gunsan and USD 103.5 million for Mokpo. The CAPEX of the OWF is assumed to be the average CAPEX from the QBIS report [9] of 2.65 mEUR/MW (3.14 mUSD/MW) for the development of the WF to the installation and grid connection. The operating expenditures (OPEX) of the wind farm is similarly assumed to be the average OPEX of the QBIS report [9] of 0.048 mEUR/MW/year (0.057 mUSD/MW/year).

Activity	Value	Expenditure Type
Gunsan Port construction	USD 196.3 million	CAPEX
Mokpo Port construction	USD 103.5 million	
OWF for a 500 MW OWF	USD 3.14 million/MW	
O&M of a 500 MW OWF	USD 0.057 million/MW/year	OPEX

Table 6-2 Assumptions of CAPEX and OPEX for used in the model

The local content, in terms of the local jobs created, depends on the capabilities of the country or region of the OWF project. If the country is capable of designing the project, producing the parts, and transport, install, operate and maintain the OWF completely the share of local jobs created will be higher than if it is necessary to outsource parts of the process.

As noted in section 2.7, the local job creation can, to some extent, be linked especially to the port's location and facilities. Local job creation potential will also differ between each of the three scenarios being addressed: port construction, OWF construction and O&M of an OWF.

The following assumptions are made, highlighted in Table 6-3:

- During port construction, it is assumed that Korea has all the necessary expertise. Hence local job creation will be 100% of the total FTE created.
- During OWF construction, it is assumed that Korea would seek international assistance to a limited degree. This analysis assumes that local wind turbines are used, as there are active manufacturers in Korea. Other manufacturing for OWF already exists in Korea, but development of the early OFW would require international assistance – especially for

development and specialized ship operations. Development and ship operations comprise roughly 10%-20% of CAPEX [22]. Based on this, the share of local job creation is assumed to be 90% of the total FTE in Korea at least for the planned 2.4 GW in Jeonbuk Southwest site. Over time and with a consistent pipeline, the local content may increase.

- During O&M, the proximity of the ports to the OWF is critical, and the ports in this study have been selected partly for their proximity. Hence there is a high likelihood that these ports will be selected as base ports for O&M. This leads to a high share of local job creation regardless of the nationality of the O&M contractor. It is assumed that the local job creation will be 95% of the total FTE.

Phase	Local content share
Construction of port	100%
Construction of OWF	90%
O&M of OWF	95%

Table 6-3 Local Content Share of the three phases

6.3 Results

Figure 6-1 and Figure 6-2 illustrate the impact on GDP and employment from investments in ports and OWF and from O&M. Impacts from OWF construction and O&M are based on a 500 MW wind farm.

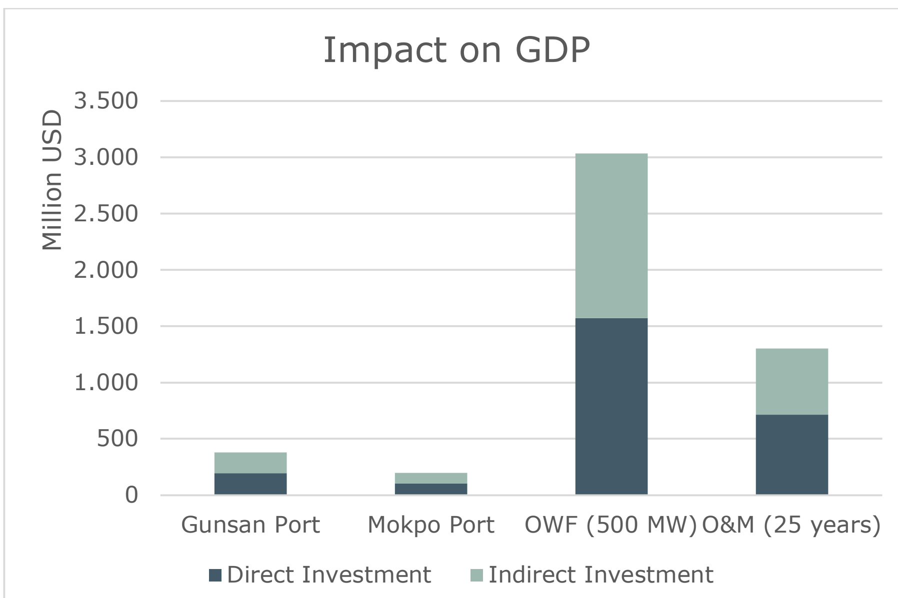


Figure 6-1 Impact on GDP shown for each phase

As the investment in the Gunsan port is larger than the investment in the Mokpo port, the impact on GDP and employment is larger for the Gunsan port than the Mokpo port, as well. The impact found for the construction of a 500 MW OWF is substantially higher than the impact found with the construction of the ports. As the typical lifetime of an OWF is 25 year the total potential O&M accumulates to a large impact as well, though it does not surpass the impact of constructing the

OWF itself. Total impact on GDP from a 500 MW OWF is expected to be 3 billion USD, whereas the total impact on GDP from 25 years of O&M on the same 500 MW OWF is expected to be 1.3 billion USD, see Table 6-4.

	Direct Investment (mUSD)	Indirect Investment (mUSD)	Total impact on GDP (mUSD)
Gunsan Port	196.3	182.8	379.1
Mokpo Port	103.5	96.4	199.9
OWF of 500 MW	1,570	1,462	3.032
O&M of 500 MW OWF (Yearly)	28.5	23.5	52
O&M of 500 MW OWF (25 years)	712.5	588.4	1,300.9

Table 6-4 Impact on GDP for each phase

By applying the employment induction coefficient, the total employment effect from investing in a 500 MW OWF is estimated to be 25,700 FTE and 25 years of O&M on the OWF is expected to sum up to 8,900 FTE. This includes both direct and indirect effects. The direct effect of O&M per year is estimated to be 357 FTE.

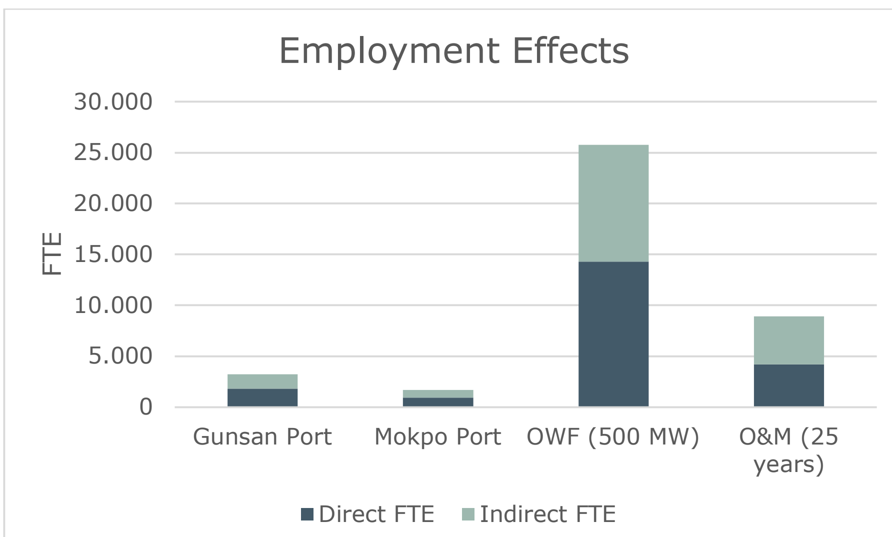


Figure 6-2 Employment effect shown for each phase

The estimated FTE in Table 6-5 are as expected high compared to the FTE referenced in section 2.7. As commented in section 2.7 this is expected as the employment induction coefficients in Korea are 3 times higher than the Danish coefficients.

	Direct FTE	Indirect FTE	Total FTE
Gunsan Port	1,788	1,432	3,220
Mokpo Port	943	755	1,698
OWF of 500 MW	14,303	11,452	25,755
O&M of 500 MW OWF (Yearly)	168	189	357
O&M of 500 MW OWF (25 years)	4,195	4,734	8,929

Table 6-5 Global Employment Effect

Table 6-6 below, combines Table 6-5 and Table 6-3 to provide an estimated of the local content, i.e. the expected FTE in Korea from the investment.

	Direct FTE	Indirect FTE	Total FTE
Gunsan Port	1,788	1,432	3,220
Mokpo Port	943	755	1,698
OWF of 500 MW	12,873	10,307	23,180
O&M of 500 MW OWF (Yearly)	159	180	339
O&M of 500 MW OWF (25 years)	3,986	4,497	8,483

Table 6-6 Local Employment Effect

The estimated FTE in Table 6-5 and Table 6-6 are very high in a Danish context, which is due to the difference in the employment induction coefficients mentioned in section 2.7.

6.4 Summary

With the expected investments in the construction of the Gunsan port, the Mokpo port, a 500 MW OWF and the O&M of the 500 MW OWF, it is expected to have a positive impact on the GDP and employment in Korea. The investments, O&M costs and total local employment effects are highlighted in Table 6-7.

	CAPEX	Total local employment effect
Gunsan Port construction	USD 196.3 million	3,220 FTE
Mokpo Port construction	USD 103.5 million	1,698 FTE
Construction of a 500 MW OWF	USD 1,750 million (USD 3.14 million/MW)	23,180 FTE
O&M of a 500 MW OWF (yearly)	USD 28.5 million/year (USD 0.057 million/MW/year)	339 FTE

O&M of 500 MW OWF (25 years)	USD 712,5 million	8,483 FTE

Table 6-7 Summary table of investments and local employment effects

In the short term, the GDP and employment effects are expected to be linear, e.g. a doubling in investment will double the impact on GDP and employment. However, a consistent and sustained pipeline of OWF projects in Korea will lead to efficiency gains and cost reductions such that OWF construction and O&M of the OWF requires less FTE in the future.

As the OWF pipeline and the installed capacity in Korea grows, COWI expects the share of local content to grow. As more local knowledge and expertise is accumulated, there will be less need for international support for the development and construction projects. It will be difficult to say whether the decrease in the employment effect due to technological development or the increase in the local share will have the biggest impact, and what the overall effect will look like.

In terms of recommendations for designing the optimal pipeline, it is recommended to aim for a stable pipeline rather than a fast and immediate growth. If the pipeline is kept stable, the sector will also remain in work and the slow growth will have a more long-term effect on the economy, rather than a temporary effect of quick growth which then afterwards leaves the sector unemployed for longer periods of time. A stable pipeline will also increase the likelihood of sustaining a local supply chain and thereby a high share of local content.

7 References

[1] Korean Government, Offshore windfarm development plan, 2020.

[2] WindEurope, "Ports: a key enabler for the floating offshore wind sector," 2020.

[3] M. Hannon, E. Topham, D. MacMillan, J. Dixon and M. Collu, "Offshore wind, ready to float? Global and UK trends in the floating offshore wind market," Universitt of Strathclyde, Glasgow, 2019.

[4] C. A. Thoresen, Port Designer's Handbook, 2018.

[5] International Renewable Energy Agancy (IRENA), "Renewable Energy Benefits - Leveraging Local Capacity for Offshore Wind," 2018.

[6] LEANWIND, "Ports suitability assessment for offshore wind development-Case studies Report," 2015.

[7] WindEurope, "WindEurope home page," [Online]. Available: www.windeurope.org. [Accessed 28 Oct 2020].

[8] M. Ø. JOHANSEN, "Siemens scales down in the Port of Esbjerg," EnergyWatch, 17 09 2017. [Online]. Available: https://m.energywatch.eu/article/9908916. [Accessed 24 11 2020].

[9] QBIS, "Socio-economic Impact Study of Offshore Wind," QBIS, Copenhagen, Denmark, 2020.

[10] Ministry of Employment and Labor, "Guidelines for Evaluating Job Creation by Government Investment Project, 2020 (2020 년 재정사업 고용영향평가 가이드라인)," 2020. [Online]. Available: http://www.moel.go.kr/english/main.jsp. [Accessed November 2020].

[11] Ministry of Oceans and Fisheries, Amendment on the 3rd National Port Master Plan (2016-2020), Ministry Public Notice No. 2016-122, Korean Ministry of Oceans and Fisheries, 2016. 9. 29.

[12] National Hydrographic and Oceanographic Agency, "National Maritime Information," [Online]. Available: http://www.khoa.go.kr/oceanmap/main.do.

[13] Korean Ministry of Oceans and Fisheries , 3rd National Port Master Plan (2016-2020), Ministry Public Notice No. 2016-122, Korean Ministry of Oceans and Fisheries , 2016. 9. 29.

[14] Ministry of Oceans and Fisheries, "The 2nd New Port Development Master Plan (2019-2040) - Public Notice No. 2019-122," 2019.7.30.

[15] National Maritime Information, [Online]. Available: http://www.khoa.go.kr/oceanmap/main.do .

[16] Ministry of Oceans and Fisheries, "Amendment on the Port Materplan - Busan, Daesan, and Mokpo Port (Public Notice No. 2018-34)," Ministry of Oceans and Fisheries, 2018.04.16.

[17] Ministry of Land, Infrastructure and Transport, "The 3rd National Railway Master Plan, Public Notice 2016-374," 2016.6.27..

[18] Ministry of Oceans and Fisheries, "Amendment on the 3rd National Port Master Plan (Ministry Public Notice 2016-122)," 2016.

[19] "Korean Port Design Standard, Part 1," 2014.

[20] R. Y. J. D.-N. J. Lacal-Arántegui, "Offshore wind installation: Analysing the evidence behind improvements in installation time," Elsevier Ltd., 2018.

[21] Asian Development Bank, "Republic of Korea: Input-Output Economic Indicators," ADB Data Library, 2017. [Online]. Available: https://data.adb.org/dataset/republic-korea-input-output-economic-indicators. [Accessed November 2020].

[22] BVG Associates, "UK offshore wind supply chain: capabilities and opportunities," Department for Business, Innovation and Skills, 2014.

[23] COWI, Arkitema og Tredje Natur, "PF-GEN-RP-001, Besigtigelse," 2020.

[24] GL Garrad Hassan, "A Guide to UK Offshore Wind Operations and Maintenance," 2013.

[25] Korea Hydrographic and Oceanographic Agency, "Open database system," [Online]. Available: http://www.khoa.go.kr/oceanmap/main.do. [Accessed 15 Oct 2020].

[26] Korean Sea traffic information system, "Port-Mis," [Online]. Available: https://new.portmis.go.kr/portmis/websquare/websquare.jsp?w2xPath=/portmis/w2/main/intro.xml.

[27] Port of Gunsan, "Website," [Online]. Available: http://gunsan.mof.go.kr/content/view.do?menuKey=486&contentKey=157 .

[28] Port of Mokpo, "Website," [Online]. Available: https://mokpo.mof.go.kr/index.do.

[29] Ministry of Oceans and Fisheries, "Amendment on the 3rd National Port Materplan (Ministry Public Notice No. 2014-67)," 2014.

[30] Ministry of Oceans and Fisheries, "Amendment on the Port Materplan - Gunsan, Gwangyang, Goemun, Hoopo, Ulroong (Public Notice No. 2017-85)".

[31] Headquaters Department of the Army, "TM 5-850-1, Engineering and Design of Military Ports," 1983.

[32] W. G. No.34, "Seismic design guidelines for port structures," PIANC, 2001.

[33] Statistics Korea, "https://www.index.go.kr/main.do," 2020. [Online].

8 Appendices

Appendix A Distance between OWF and installation / O&M ports

				Installation		O&M	
OWF	Year	Capacity (MW)	Distance from shore (km)	Turbine	Distance from port (km)	Base port	Distance from port (km)
Amrumbank West	2015	302	35	Esbjerg	120	Helgoland	40
Anholt	2013	400	15	Grenaa	27	Grenaa	27
Arkona	2019	385	35	Mukran	49	Mukran	49
BARD Offshore 1	2013	400	101	Eemshaven	116	Emden	146
						Cuxhaven	185
Beatrice	2019	588	14	Nigg	93	Wick Harbour	25
						Buckie	64
Borkum Riffgrund 2	2019	450	56	Esbjerg	212	Norddeich	66
				Emden	92		
Butendiek	2015	288	32	Rømø	55	Rømø	55
				Esbjerg	68		
Dudgeon	2017	402	35	Vlissingen	260	Great Yarmouth	83
Gemini	2017	600	85	Eemshaven	85	Eemshaven	85
Global Tech I	2015	400	115	Bremerhaven	182	Emden	151
Gode Wind (phase 1+2)	2017	582	45	Esbjerg	185	Norddeich	50
Gwynt y Môr	2015	576	16	Mostyn	28	Mostyn	28
Hohe See	2020	497	90	Esbjerg	179	Emden	144
				Eemshaven	117		
Horns Rev 1	2002	160	18	Esbjerg	37	Esbjerg	37
Horns Rev 2	2009	209	32	Esbjerg	58	Esbjerg	58
Horns Rev 3	2019	407	20	Hvide Sande	44	Hvide Sande	44
				Esbjerg	58	Esbjerg	58
Hornsea 1	2020	1218	120	Able Seaton	217	Grimsby	131
Hornsea 2	2022	1386	100	Humberside	151	Grimsby	131
Kriegers Flak	2021	605	15	Rønne Havn	112	Klintholm	34
London Array	2013	630	20	Ramsgate	34	Ramsgate	34
				Harwich	39		
Meerwind Ost	2015	288	53	Cuxhaven	91	Helgoland	28
Nordsee 1	2017	332	40	Eemshaven	80	Norddeich	60
Nordsee Ost	2015	295	57	Bremerhaven	120	Helgoland	34
Northwind	2014	216	37	Oostende	43	Oostende	43
				Esbjerg	573		
Race Bank	2018	573	27	Eemshaven	405	Grimsby	71
Rampion	2018	400	13			Newhaven	24
Veja Mate	2017	402	95	Esbjerg	210	Emden	148
						Eemshaven	115
Walney Extension	2018	659	19	Belfast Harbour	168	Barrow	46
Westermost Rough	2015	210	8	Esbjerg	574	Grimsby	45
Wikinger	2018	350	35	Sassnitz	48	Sassnitz	48