leanwind

Logistic Efficiencies And Naval architecture for Wind Installations with Novel Developments

Project acronym: **LEANWIND**
Grant agreement nº 614020
Collaborative project
Start date: 01st December 2013
Duration: 4 years

WP Framework/Industry Challenges Report – Novel vessels and equipment

Work Package 3 - Deliverable 3.1

Lead Beneficiary: 27
Due date: 31st March 2014
Delivery date: 31st March 2014
Dissemination level: PU (Public)

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No. 614020.

Disclaimer

Document Information

Version	Date	Description			
			Prepared by	**Reviewed by**	**Approved by**
1	28/03/2014	**Name**	LR	MRTK/GDG/ UCC_HMRC	MRTK
2	25/10/14	**Name**	NTUA and LR		

Author(s) information (alphabetical):	
Name	**Organisation**
Azadeh Attari	GDG
Gabriel Olayinka Okuyemi	LR
Jan Goormachtigh	OWA
Jens Møller Christensen	A2SEA
Jesper Tang Kristensen	A2SEA
John Koch Nielsen	Force Technology
Jose Manuel Fernandez Hernando	ACCIONA
Marco Federico Beghi	LR
Martin Antrobus	AMS
Martin Layng	LR
Nuno Valverde	EDPI
Pierre Perrocheau	CESA
Rebecca Sykes	LR
Vincent de Laleu	EDF
Yves Rolland	EDF

Acknowledgements/Contributions:	
Name	**Organisation**
Ad Bus	LR

Definitions

Acronym	Description
BIMCO	Baltic International Marine Council
CESA	Community of European Shipyards Association
DECC	Department of Energy & Climate Change
EWEA	European Wind Energy Association
FID	Final Investment Decision
HLV	Heavy Lift Vessel
HSC	High Speed Craft
IACS	International Association of Classification Societies.
IMO	International Maritime Organisation
LCOE	Levelised cost of electricity
MCA	Maritime and Coastguard Agency
MODU	Mobile Offshore Drilling Units
NDE	Non-destructive examination / inspection
O&M	Operations & Maintenance
OCV	Offshore Construction Vessel
OEM	Original Equipment Manufacturer
OMS	Offshore Marine Services
OSC	Offshore Service Craft
SCV	Small Commercial Vessel
SOLAS	Safety of Life at Sea
TAS	Turbine Access Systems
TOC	Transfer of class between IACS member societies
WFSV	Wind Farm Service Vessels
WP	Work Package
WTG	Wind Turbine Generator
WTIV	Wind turbine installation and/or heavy lift maintenance vessel

Executive Summary

Electricity generated from offshore wind remains at an uneconomic level in comparison with that from conventional fuel sources in most parts of the world. Significantly increased costs have been incurred by the wind industry in the move from onshore development, with the associated ease of access and installation, to offshore sites. Now these are being further increased by the progression from inshore into deeper waters in search of greater resource and by the pressures of coastal development. This is driving a need for cost reduction.

Due to the relatively early state of the sector, there remain significant cost savings to be made through learning and technological innovation. “LEANWIND” (Logistic Efficiencies and Naval architecture for Wind Installations with Novel Developments) is an EU project under funded FP7 that aims to provide cost reductions across the offshore wind farm lifecycle and supply chain. The Lean aspect of the project aims to characterise the processes involved in the industry, identify value creating steps and reduce waste, thereby maximising value to the client. Technological improvements will be used to reduce the waste in the process.

One significant area of cost is in the installation and commissioning phase which was estimated at around £400 million, out of a total project capital cost of £1500 million for a typical Round 3 500MW wind farm in the Crown Estate's Guide to an Offshore Wind Farm [1].

The wind farm installation phase requires a number of vessel types including, but not restricted to, accommodation vessels, cable laying vessels, construction support vessels, diving support vessels, heavy lift vessels, jack up barge or vessel, multi-purpose project vessels, multi-purpose cargo vessels, service crew vessels, safety and standby emergency evacuation and response vessels, survey vessels and tugboats. While many do not necessarily require technological innovation to be effective for the industry, the increasing installation volumes, turbine size, water depth and distance from shore means that the anticipated shortage of supply can be fulfilled by vessels developed considering cost efficiencies for the industry. Confidence in terms of financial support for offshore wind and future substructure design would encourage their construction.

The industry has predominantly been reliant on jack-up vessels (or liftboats) for installation and large maintenance actions such as gearbox replacement. These barges and vessels have been increasingly adapted to become specific for the market and are now seeing investment by wind farm developers and OEM. However, the number of capable jack-up installation vessels required for the hundreds of 5-6MW turbines in the next generation of offshore wind farm developments is estimated to outstrip supply by 2020. This has been identified as an area that would benefit from technological innovation where potential cost reductions are closely linked to

- reduction of the time needed for the various installation operations
- extension of the weather windows in which the operations are feasible

Innovations to reduce total install time will not only reduce cost to the individual wind projects but also eases market demand on the more capable installation vessels. The cost reductions could be achieved by

- Decreasing use of offshore lifts requiring an increased amount of onshore pre-assembly
- Decrease operating constraints due to meteorological conditions
    - Improved vessel design for less restrictive weather limitations
        - Increased maximum jacking sea state
        - Increased max crane operating wind speed
    - Improved weather prediction
        - Improved weather monitoring and decision support system
    - Increased loading capability for cranes and components being lifted to increase number of usable weather windows
- Decreased transit time
    - Increased number of turbines loaded per trip
        - Increased deck payload
        - Increased useable deck area
    - Increased transit speed
- Decreased offshore operation duration
    - Increased jacking speed
    - Decreased leg-preload duration (by using 4- or 6-legs vessels)
- The use of component feeder vessels
- The use floating installation vessels

O&M activity accounts for approximately one quarter of the life-time cost of an offshore wind farm. As part of this, service vessels are required to transfer wind turbine maintenance crew to perform duties on the turbines with significant regularity. At current levels, a 1GW farm with 200 turbines rated at 5MW is expected to require around 3000 maintenance visits per year, with a disproportionate number of visits being required in the winter when the environmental conditions incur more unplanned maintenance. Delays in carrying out unplanned maintenance, when a fault has occurred and the turbine may no longer be operational, incur significant penalties in lost electricity generation and revenue. This loss is also more pronounced in the winter as the potential resource is greater. Innovations in condition monitoring and turbine design are being made to reduce visits, but even at the target of six per year a significant number of transfers remain.

Approximately 110 service vessels with wind experience are available in the market and demand is expected to exceed supply by 2017. By 2022 approximately 426 vessels are expected to be required to deliver maintenance crews to site [2]. To reduce lost revenue, access in sea states higher than the current typical limit of 1.5m significant wave height and 12m/s wind speed is considered necessary; vessels and access systems capable of transferring personnel in 3m is desired. A large number of current service vessels are not suitable for these conditions and in the UK are restricted to 60Nm from safe haven, rendering them unusable for farms to be located further from shore. For these sites duration of transit must also be reconciled against the length of the maintenance crews' working day.

Farm operators desire vessels whose characteristics produce fast transfer speeds, with large deck area, are fuel efficient and have a comfortable ride as sea sickness is a significant contributor to lost time. The transfer of technicians from vessel to turbine is also easier and safer when there is little vessel motion when station keeping. Both aspects are dictated by the working environment such as significant wave height, spectral shape, current conditions etc. together with hull form, weight distribution, presence of ride control systems and the expertise of the captain. In some cases the resulting design requirements may be in conflict, such as with longer sleeker hull forms which are faster and more efficient but more exposed to waves on the beam.

Technological innovations in the transfer of personnel from vessel to turbine have sought to improve accessibility. The bump and jump method, based upon a bow fender design creating a high friction force between bow and boat landing, remains the preferred access method but is limited to a 1.5m Hs. Active and passive crew transfer access systems have been developed to compensate for motion in more severe sea states. These remain unpopular due to their high cost and weight which is typically located towards the bow and may require additional hull strengthening.

With increasing farm size and distance from shore, purpose built wind farm maintenance vessels that are able to undertake lifting activities for component replacement will be developed. These may also act as a mother-ship providing accommodation and spare part storage functions, with smaller service vessels transferring crew to turbines in the farm. Uncertainty remains over the detailed functionality of the mother-ship and the safe and reliable transfer of personnel from crew boat to the mother-ship. Concepts including lift and stowage of the service vessels on the mother-ship are also being proposed.

Service vessel designs may also have recently been limited by the regulations resulting from SOLAS and the International Load Line Convention definition of a “Passenger"; vessels carrying more than 12 passengers must be in possession of a Passenger Ship Safety Certificate which incurs additional safety equipment and operational activities such as safety drills. Vessels with a load line length below 24m and fewer than 12 passengers are able to avoid the more stringent regulations under the Load Line Convention and most of SOLAS, therefore incurring less cost in the fit-out and operation of the vessel.

The main challenges for service vessels remain

- Reducing motion when transferring to increase accessibility in larger sea states
- Balancing fuel efficiency against transit speed
- Reduce motion which incurs sea sickness due to its detrimental effect on maintenance crew operational efficiency
- Establishing optimum vessel size and hull form type for varying distances from shore

The purpose of this report is to highlight the challenges in the industry regarding installation and maintenance and these will form the basis for the remaining activities in this project related to vessels. Solutions for these challenges will be sought through vessel and equipment design, analysis, simulation and physical test. The following stage of this project will refine the design requirements, such as maximum metocean conditions for operations, which will be used to create the designs. These will be considered in light of economic and technical factors and the lean principles on which the project is based. Design stages will follow and activities will include

- Global structural analysis for a number of loading conditions to verify the structural integrity of the vessel hulls

- Performance assessment of DP systems in terms of the increased functionality of vessels in being able to maintain station when undertaking installation and maintenance tasks
- Vessel motion will be assessed via sea-keeping and manoeuvring calculations; essential in the assessment of comfort and wind turbine access on service vessels

Marine operations and equipment functionality also require consideration to verify the design. This work package will also therefore consider the modelling of

- Seabed/spudcan interaction
- Motions minimization/compensation equipment
- Floating offload/loadout
- Jacking equipment
- Advanced personal transfer equipment

The designs and assessment techniques will be the functional results of the project. In addition, the parameters which are key to vessel design, layout, crane operations and access systems will be disseminated to the project.

Vessels perform a transportation function for the industry and can be optimised appropriately but the industry must be capable of sustaining their use to justify investment in their bespoke design. Identifying cost reduction through reduced operational time also requires a collaborative approach on farm design and operation. The cheapest foundation to design and construct may not be the cheapest to install due to sensitivity to precision in the installation, the weight or volume of the structure. This is accommodated in this project through interacting on foundation design in WP2, O&M procedures in WP4 and the economic and market assessment in WP8.

Table of Contents

1. Introduction and Background

1.1 Project Description

"LEANWIND" (Logistic Efficiencies and Naval architecture for Wind Installations with Novel Developments) is an EU funded project under FP7 which aims to provide cost reductions across the offshore wind farm lifecycle and supply chain. This will be achieved through the application of lean principles and the development of state of the art technologies and tools. The project is a collaboration of industry and academic partners from 12 member states to provide a diverse range of skills and experience for this to be achieved.

1.2 Scope of Work

The project comprises ten work packages of which this work on Novel Vessels and Equipment forms work package 3. This report is the first deliverable of this work package. This report is to be read in conjunction with the first deliverable report of work package 2, which outlines the industry challenges in Construction, Deployment and Decommissioning, and work package 4, which outlines the same for Operation and Maintenance strategies.

This work package focuses on the primary vessel types used for both wind farm installation and O&M, with the objective of making efficiencies in terms of innovations to existing vessels and designing new vessel concepts tailored specifically to industry requirements. The focus will be on the installation and service vessels used to build and maintain offshore wind turbines and their sub-structures.

Section 1 of this report describes the background and justification for the project.

The wind industry, offshore industry and shipping industry use differing and industry specific terminology. The Concepts and Definitions used in the document are described for reference in Section 2.

Applying lean principles to the offshore wind installation and O&M process requires a focus on client defined value. Identification of the current status of offshore wind farms provides a basis from which to define client value. Therefore Section 3 details the current process employed, with specific details of existing technology used. The present day fleet of installation vessels and maintenance vessels will be described. The risks associated with the maritime industry are controlled by national regulations and vessel class; those issues which relate to installation and maintenance vessels are also described in Section 3.

The future installation strategies and substructure types expected to be used for future developments remains an area of uncertainty, giving rise to uncertainty in future vessel requirements. Also, developments in deeper waters and further offshore presents increased difficulties for both wind farm installation and maintenance. Identification of these industrial challenges is a fundamental stage to providing waste elimination solutions. The challenges and novel vessel solutions proposed for wind turbine installation are described in Section 4. There are also challenges for the transit of maintenance personnel quickly and with minimal fatigue during the operational phase. These are also discussed in Section 4, together with the access systems anticipated to facilitate safe transfer to the wind turbine structures.

To be able to focus the project and refine the vessel designs, baseline scenarios have been developed based on site characteristics driving wind farm design; these are outlined in Section 5.

The penultimate section of this report, Section 6, describes the work which will complete the remaining parts of work package 3. It describes how this will be formed into the project tasks: defining the key design parameters and criteria related to installation and maintenance vessels design; their layouts, crane operations and access systems, the vessel and equipment selection approach for further analysis and optimisation and the simulation and demonstration of these systems.

The findings from this review are summarised in Section 7.

1.3 Lean Principles

LEANWIND is to build upon the principles of the Lean methodology. Lean is a technique for the efficient expenditure of resources to maximise customer value and eliminate wasteful stages in the process. Value is defined by the customer and constitutes as any action or process that a customer would be willing to pay for. Essentially lean is centred on preserving value on less work [3].

The methodology is derived from Toyota Production System (TPS), the term first coined by John Krafcik (Quality Engineer) is based on Toyotas original 7 waste reduction strategies to eliminate waste and improve customer satisfaction [4]. Toyota view that the focal point of lean is the reduction of 3 main types of waste: muda ("non-value-adding work"), muri ("overburden"), and mura ("unevenness").

Lean principles have been employed as a framework and implemented out of manufacturing in other industries. Employed in two main ways, primarily as a tool for the steady elimination of waste (muda); the premise being that waste elimination results in quality improvements. Another form of lean implementation is called "The Toyota Way", an approach that is concerned with the elimination of mura ("unevenness") in effect to achieve a smooth process by improving the flow of work.

LEANWIND (Logistic Efficiencies and Naval architecture for Wind installation with Novel Development) is set to implement the lean principles by (Strategos Inc, 2007):

1. Specifying value as defined by customer: with the client being the offshore wind industry and overall value defined as the reduction of LCOE.
2. Identify all the steps in the value stream eliminating whenever possible steps that do not create value: implemented by the analysis of current and state of the art technologies.
3. Making the value-creating steps occur in tight sequence so the product will flow smoothly toward the customer: evaluating the whole wind supply chain to provide improvement over each step streamlining the whole process.
4. As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste.

Effectively, the implementation of lean principles in the project is to encourage cost reduction within the whole supply chain by eliminating waste by technological improvement and streamlining the overall process.

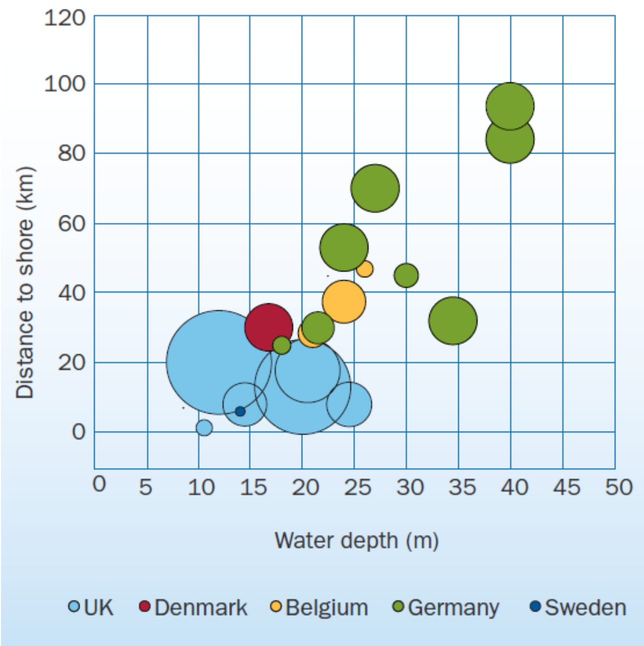
1.4 Current Status

There are currently 6.6GW of installed offshore wind capacity in Europe [5]; this is an increase on 2012 by the installation of 1,567 MW offshore in 2013. The total number of installed wind turbines is now 2,080, connected in 69 offshore wind farms in 11 countries across Europe [5]. Whilst the onshore market has decreased, offshore installations grew by 34%. This is an increase of 3.3GW over the 2010 figure of 2,946 MW [6].The countries with the highest installed capacities are the UK with 47%, Denmark with 22%, Germany with 15% and Belgium with 12%, with 72% of installations being in the North Sea.

Monopiles dominated the 2013 installations with 79% of offshore turbines being installed on this type of substructure, 14% were installed on tripods and 6% on jackets. Some newer substructures such as tripile and gravity based substructures (GBS) represent 1% and 0.2% of the installations in that year. However, it must be considered that the installations in any one year are not a true representation of what is a fast changing industry with construction periods over multiple years. In 2010, monopiles were also the most common substructures (65% of all installed turbines), followed by gravity (25%), jacket (8%) and tripile (1%). Ten projects, which are still under construction, will increase the total by 3MW when completed and grid connected. The average size of offshore turbines installed in 2013 was 4 MW, due to the dominance of the Siemens 3.6MW design.

Floating installations still remain in a research, development and demonstration phase with two experimental and two full scale floating substructures being deployed in 2013.

One of the key concerns regarding the transition to newer substructure designs is the depth of water. Figure 1 shows the range of water depths and distance to shore for the sites installed in 2013, showing that many of the larger sites were installed in approximately 15-20m of water but that sites with depths up to 40m were also developed. These farms are located up to 100km from shore.



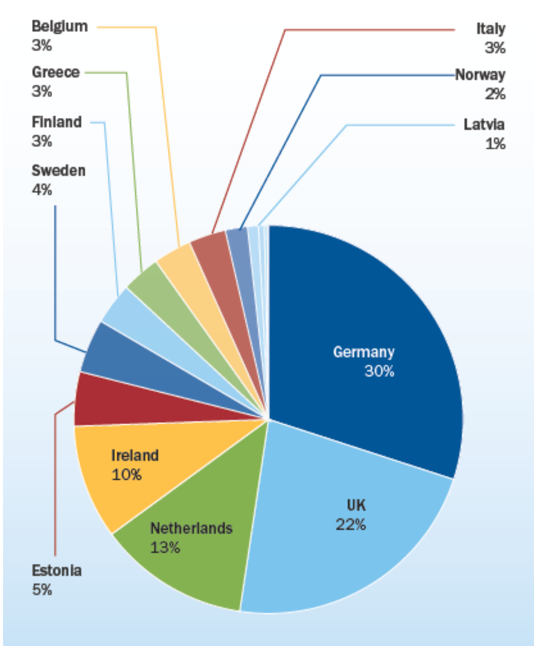


Figure 1 (left): Range of water depth and distance from shore for farms installed in 2013, where the size of the wind farm is indicated in the circle size Source: [5]

Figure 2 (right): Shared of consented capacity per European country

1.5 Future Trends

A number of sites remain in the development and planning process; EWEA have identified 22GW of consented projects in Europe that have yet to be constructed [5]. While the expected installation date for the near term projects is more certain, for others it is uncertain whether sufficient investment can be found and the engineering challenges can be overcome economically.

EWEA predicts that the European offshore wind market will reach an annual installation of 7.8GW by 2021 and 13.7GW by 2030. A range of wind turbine capacities are expected to be installed in the period up to 2030, increasing from the average 3MW turbines at the present day up to the 7MW in current development and demonstration, and potentially to the proposed 10MW. DONG Energy is testing up to two next generation offshore wind turbines including a Siemens 6 MW at Gunfleet Sands [6].

An increasing number of sites are also being leased at increasing distances from shore and moving into deeper waters, as shown in Figure 3. The substructures required to be installed to construct the deeper farms are likely to move away from monopiles due to the technical limitations of sufficient strength and decreasing stiffness with increasing size. Following the successful demonstration of the Beatrice and the Alpha Ventus projects in water depths of more than 30m, there is increased interest in jacket substructures and substructure design in general is expected to move towards jackets and tripile. Different substructures use a range of foundation methods, including piles and suction buckets. Suction buckets are being explored due to their reduced noise during installation and a reduction in installation time. Noise is a highly regulated issue in German waters.
For medium depth waters (up to 60m), the Carbon Trust launched an innovation competition. Four concepts were taken forward as finalists, which included a gravity base

foundation, a float out suction bucket, a twisted piled jacket and a self-installing wind turbine using 3 suction buckets.

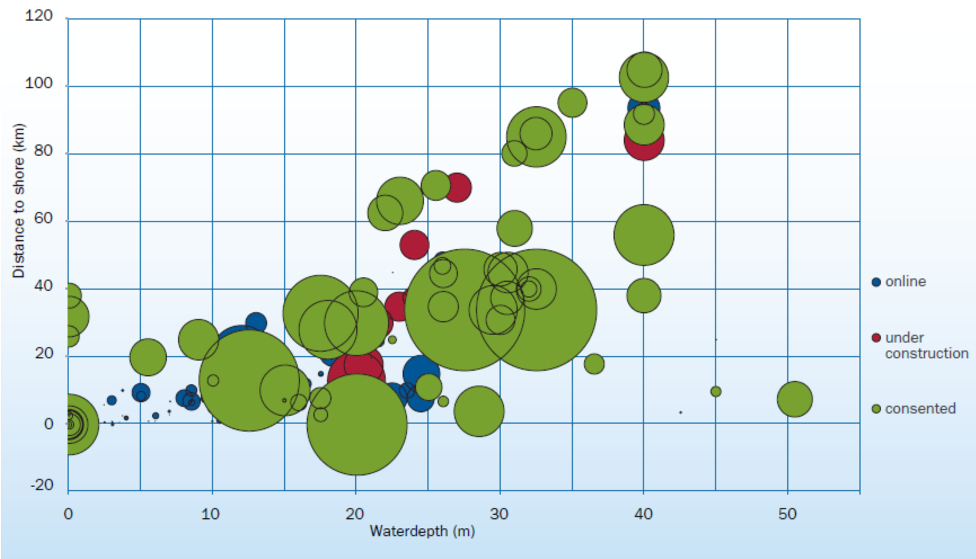


Figure 3: Average Water Depth and Distance to Shore of Online, Under Construction and Consented Wind Farms Source: [5]

A significant amount of offshore wind turbine market forecast data is quoted in rated turbine capacity since the leases are managed in this way; however, to obtain an estimate of the likely vessel activity requires an understanding of the number of individual turbines. Then the estimated number of installation operations and maintenance visits can be used to inform investment decisions and vessel design requirements, which are linked to investment.

Some indication of the individual number of wind turbine installations is available through analysis of data provided by Renewable UK for UK waters in May 2013 [7]. Estimated numbers of wind turbines are available for approximately 6625MW are included in [7] covering Round 1, 2, 3 Northern Irish and Scottish Territorial Waters. For those sites where the number of turbines and the rated capacity of the farm are suggested, the expected construction timelines give some indication of likely number of installations per quarter. This information is available for 34768MW of the 46625MW and the estimates are based on a constant installation rate over the installation period; the resulting time lines of annual and cumulative installations are included in Figure 3.

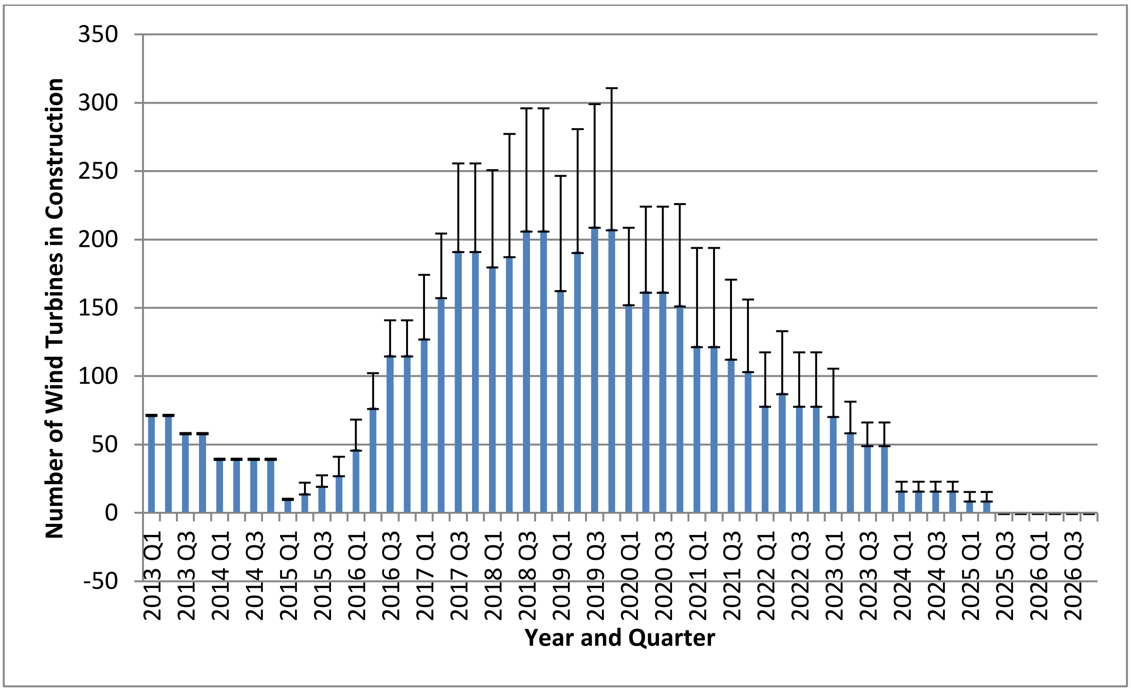


Figure 4: Estimated number of offshore wind turbines to be constructed in the UK per quarter based on data from [7] Note: the upper limit of the error bars indicates the upper estimate of the number of individual installations due to uncertainty in the individual turbine capacities to be installed

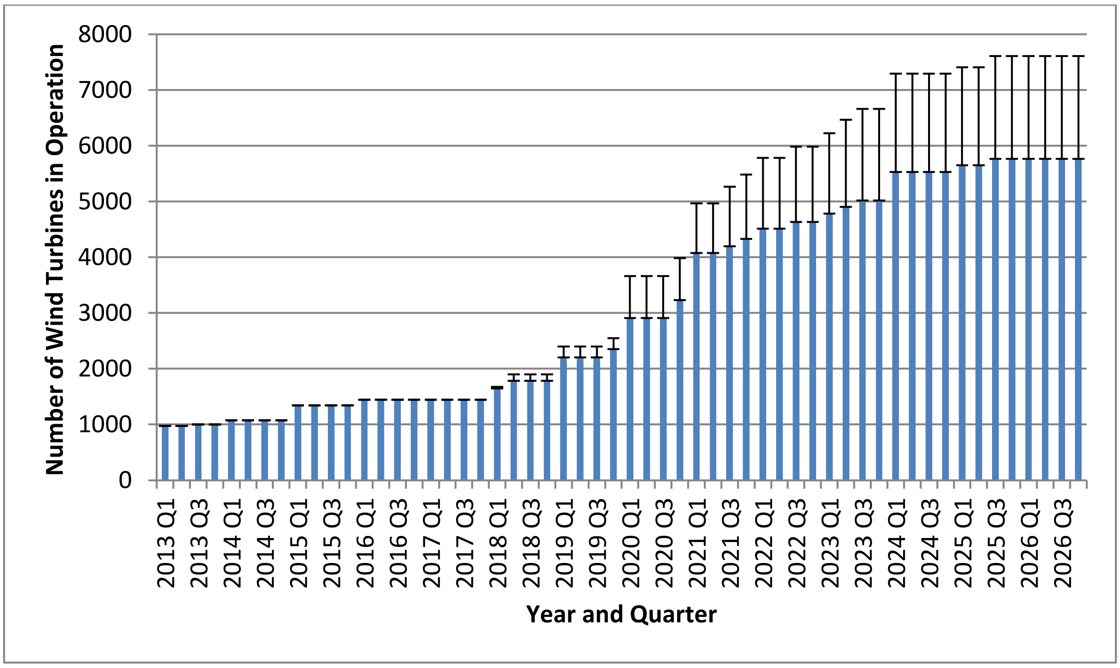


Figure 5 Estimated number of offshore wind turbines in operation in the UK per quarter based on data from [7] Note: the upper limit of the error bars indicates the upper estimate due to uncertainty in the individual turbine capacities

1.6 Cost Benefits and Reduction

The offshore wind industry aims to reduce its LCOE to become more economic. The UK department of Energy and Climate Change (DECC) Cost Reduction Task Force suggests that the current cost of around £140 per MWh will need to be reduced to around £100 per MWh in order to maximise the size of the industry (June 2012). However, the costs of the industry have increased from approximately £1.5m/MW in 2008 to approximately £3.5/MW in 2013. The installation and commissioning of balance of plant and turbines, including land and sea based activity costs around £400 million for a typical 500MW wind farm, this represents 27% of the estimated total project cost [1]. Costs are estimated to further increase with water depth as shown in Table 1.

Table 1: Cost increases as a function of water depth [8]

Water depth	10 - 20	20–30	30–40	40–50
Cost (EUR/kW)Turbine	772	772	772	772
Foundation	352	466	625	900
Installation	465	465	605	605
Grid connection	133	133	133	133
Others	79	85	92	105
Total cost (EUR/kw)	1 800	1 920	2 227	2 514
Scale factor	1.000	1.067	1.237	1.396

2. Concepts and Definitions

The wind industry, offshore industry and shipping industry use differing and often sector-specific terminology; the wind industry defines vessels based on their function to the industry; the shipping industry based on the vessel characteristics. A series of concepts and their definitions as used in this report are included below:

Term	Description
Accessibility	The proportion of time in a working year a turbine can be safely accessed from a particular vessel and transfer system. Accessibility is often limited by the vessel and transfer system capability in a given sea condition.
Ballast	Material used to provide stability and control buoyancy to a ship/boat. A ships ballast tank holds water and acts as a stabiliser by positioning the ballast tank below the water level to counteract the weight of the ship above surface level.
Barge unit	Surface type unit without primary propelling machinery
Bow	Forward part of the hull of a ship or boat
Certification	Compliance with the regulations of the relevant national authority. Generally prescriptive, based on requirements contained in recognized codes and standards.
Classification	The development and worldwide implementation of a set of published Rules and Regulations which set and maintain standards of quality and reliability. A unit is in class when the relevant Rules and Regulations have, in the opinion of the class society, been complied with, or when it has been granted special dispensation from compliance
Column-stabilised unit	A column-stabilised unit is a unit with a working platform supported on widely spaced buoyant columns. The columns are normally attached to buoyant lower hulls or pontoons. These units are normally floating types but can be designed to rest on the sea bed.
DP (Dynamic Positioning)	Computer-controlled system to automatically maintain a vessel's position and heading by automated control of propellers and thrusters.
Flag state	The administration with which the unit is registered
Floating unit	Hull structure and its integral marine systems together with propulsion system (where fitted) and essential machinery
Significant Wave Height (Hs)	This is the average of the statistical measure of wave height in a sea state.
Installation vessels	Installation Vessels are more generally termed Offshore Construction Vessels (OCV) due to their use in heavy lift maintenance activities. They are employed in the wind farm project installation phase.
Internationally recognized standards	Technical codes, specifications, recommended practice etc. issued by competent authorities and recognized by the Regulatory Authorities.
Liftboats	A liftboat is a unit with a buoyant hull (generally either triangular or pontoon shaped) with moveable legs capable of raising the

Term	Description
	hull above the surface of the sea and designed to operate as a sea bed-stabilised unit in an elevated mode. The legs may be designed to penetrate the sea bed, or be attached to a mat or individual footings which rest on the sea bed. In general, installation and maintenance activities would be undertaken in the jacked-up condition. These unit types are generally self-propelled
Plimsoll Line	The Load Line indicates the legal limit to which a ship may be loaded (relative to specific water types and temperatures). This is indicated by a graphical representation on the side of the ship.
MARPOL	The International Convention for the Prevention of Pollution from Ships is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes.
National authority	The specified controlling coastal state administration in whose territorial waters the unit will operate. These may include both marine and industrial administrations.
Notified Body	A Notified Body is a third-party, accredited body which is entitled by an Accreditation Body. Upon definition of standards and regulations, the Accreditation Body may allow a Notified Body to provide verification and certification services. These services are meant to ensure and assess compliance to the previously defined standards and regulations, but also to provide an official certification mark or a declaration of conformity.
Offshore construction vessel	An offshore construction vessel means a mechanically self-propelled or towed vessel, which is primarily engaged in offshore wind farm construction, assembly, maintenance, disassembly, demolition or similar activities and carrying crew and industrial personnel qualified to man the vessel and undertake the construction works.
Offshore Wind Farm Service Craft	Many vessels engaged in maintenance activities are more generally termed offshore wind farm service craft (OSC) as their function is generally in the transfer of maintenance technicians: Offshore service craft refers to a conventional relatively slow vessel or a high-speed craft that is used to transport industrial personnel who may not be working on board.
Self-elevating (or Jack-up) unit	Floating unit which is designed to operate as a sea bed stabilized unit in an elevated mode. These units have a buoyant hull (generally either triangular or pontoon shaped) with moveable legs capable of raising its hull above the surface of the sea. The legs may be designed to penetrate the sea bed, or be attached to a mat or individual footings which rest on the sea bed. Generally not fitted with a propulsion system.
Self-propelled	The unit is designed for unassisted sea passages and is fitted with propelling machinery in accordance with the Rules.

Term	Description
Service/Maintenance vessel	Also referred to as offshore wind farm service vessels. Mechanically self-propelled vessel which is generally used in the transfer of maintenance technicians.
Ship unit	Self-propelled surface type unit of ship shaped single or multiple hull form.
Statutory regulations	The international marine standards imposed by the flag state. The national authority and classification society may also have specific requirements concerning compliance with these standards
Surface type floating unit	Unit with a ship or barge-type displacement hull of single or multiple hull construction intended for operation in the floating condition.

3. State-of-the-art

3.1 Installation Vessels

The scope of the installation process is the transportation of the support structure, nacelle and hub assembly, blades, towers and array cables from construction port to site and then installation at site. This project is focussing on the transportation and installation of the support structure and turbine.

The tasks for an installation vessel are the transfer of support structures and turbines offshore, provision of bases for lifting and installation operations, provision of offshore access, and accommodation for ship crew and personnel during maintenance operations, loading, transporting and assembling failed turbine components in offshore environment if repair or replacement is required.

3.1.1 Foundation Installation and Transportation Strategy

The foundation installation and transportation strategy is determined by giving consideration to wind turbine foundation and turbine types, weights and geometry, water depth and distance from port, met-ocean conditions and weather windows. The turbine design and substructure is not constant across the farm.

Various possible configurations for transportation and installation of monopiles are as follows (Kaiser, Snyder 2010):

One Installation Vessel

One installation vessel is used for both transporting and installing the foundation. The vessel can transport and install all the foundations first. Then transport and install all the transition pieces. The second possible configuration is that the vessel transports both the foundation and transition piece, and installs them simultaneously and in sequence.

One Installation Vessel and One Feeder Vessel

In this configuration, a feeder vessel is used to transport the components onsite, where the installation vessel installs the foundation and transition piece. This will save the installation vessel several trips to the port.

Two or More Installation Vessels

In this configuration the two vessels can operate separately with each installing foundations and consequently the transition pieces, or they can work together, with the first vessel installing the foundations, and the second installing the transition pieces. While using two installation vessels reduces the overall installation time considerably, it usually does not half it. Therefore, the number of boat days per foundation in this configuration increases, but overall installation time for the farm decreases.

Turbine Installation and Transportation Strategy

Turbine installation requires relatively heavy components to be lifted to the hub height. This stage of installation is also the most sensitive to weather condition and wind speed. Onshore assembly of turbine components has the potential of decreasing the number of challenging offshore lifts; however, it will increase the number of required trips for transporting the assembled blades to the installation site. Therefore, the turbine weight, the hub height, and the installation and transportation strategy have considerable effects on the vessel requirements and vessel spread size and composition.

The installation vessel usually needs to be accompanied by another jack-up vessel for transportation of components. This way the lift operation can be conducted in a fully stationary condition, reducing the anticipated installation time. If a feeder vessel is to be utilised for turbine transportation, it is more likely a self-elevating vessel, equipped with dynamic positioning, rather than a combination of barge and tugs, considering the high sensitivity associated with the turbine transportation [9].

3.1.2 Vessels Used During Installation Activities

Jack-up Platforms

Jack-up platforms (JUP), also known as lift boats, are comprised of a buoyant hull, and a number of legs (3 to 6), which can penetrate and stabilise in the sea-floor, and then raise the hull above the water surface. The JUP can be positioned into location (self-propelled or by towing) with the legs raised and floating hull on the water. Once positioned, the legs are jacked down onto the seabed and preloading takes place. During preloading the weight of the barge and additional ballast water are used to drive the legs into the seabed, avoiding further penetration while operations are carried out. After preloading, the jacking system is used to lift the platform above the water to a safe and predetermined height. Jack-up platforms are often used for:

- Installation of offshore constructions
- Maintenance of offshore wind farms
- Offshore civil constructions
- Site investigation
- Decommissioning of oil and gas infrastructures
- Accommodation platform

Figure 6: (from left to right); Jack-up platform installing a wind turbine, Jack-up platform as accommodation platform next to drilling platform and Self-propelled jack-up platform

(OWA)

These types of vessels provide a stable base for lifting operations under adverse sea conditions by eliminating the vessel displacements due to surface waves and surges. Jack-up vessels can also provide accommodation for both the vessel and the technical crew, and are cost-effective options in sites with medium to high waves. However, the jacking operation can be time-consuming and limited by metocean conditions. Operability of jack-up vessels in deep waters is limited by the length of jacked legs. These vessels require feeder vessels for functioning, and they usually have limited operational speed of around 10 knots [10].

Leg-Stabilised Vessels

The leg-stabilised vessels use their legs to stabilise the hull, instead of raising it over the water surface. This makes them a more suitable choice for shallower water sites. Elimination of the jack-up operation also results in quicker installation and transportation capabilities when compared to jack-up vessels. However, they have a limited capability for lifting, since the hull remains submerged, and is still subject to some levels of wave-induced motion, rendering them as a less desirable option for the future developments [10].

Heavy-Lift Vessels (HLV)

Figure 7 (from left to right); Heavy Lift Vessel "Rambiz" and HLV lifting jacket from a barge

(OWA)

HLVs are equipped with cranes specialized in lifting heavy loads. They are specifically designed for offshore installation of pre-assembled modules, and therefore they have the highest capacity in crane operations. They provide a great flexibility for unusual and heavy cargo, and have favourable stability characteristics. Heavy-lifters are commonly utilised in the offshore oil and gas industry, and hence their availability in the offshore wind market is an issue and incur significantly high costs. Heavy lifters have slow mobilisation speeds, and might have problems for entering some of the ports, due to their size [10].

Platform Supply Vessel

A Platform Supply Vessel's (PSV) primary function is the transportation of goods to and from offshore platforms. PSV's are often used for transportation of jacket piles and monopiles.

Figure 8: Example of a Platform Supply Vessel

(http://www.nauticexpo.com)

Towing Tugs

Tugboats are powerful and highly manoeuvrable; they have very good positioning keeping capabilities. A tugboat's power is typically stated by its engine's horsepower and its bollard pull. Some tugs are also equipped with small cranes, to be used in anchor handling or other light transportations.

Figure 9: Kingdom of fife; Tug boat with 61 metres length, and maximum speed of 13.7 knots [11]

Tugboats can be used for:

- transport of non-self-propelled vessels (e.g. barges, first generation jack-up platforms,…) by pushing or towing them
- transport of floating wind turbines
- water, fuel, food and spare parts supply
- assistance in case of emergencies
- crew changes
- transport of waste (from platforms)

Barges and Pontoons

Barges and pontoons are used for transporting heavy components, such as jackets, jacket piles, transition pieces and monopiles; they are often not self-propelled and need to be towed or pushed by tugboats.

Figure 10: Jacket transport by barge and tugboat supporting vessels

(http://www.owectower.no)

They are also used in the construction of gravity based foundation, where the structure is fabricated on deck, see Figure 11.

Figure 11 Foundation construction and transport, Karehamn [12]

Completed structures can be towed to the installation location; this is done by support tugs, and since often these barges are non-self-propelled. When at the final location, a vessel with crane capability lifts each GBS from the barge for installation. This is not suitable for heavy GBS (i.e. 10.000 tons), due to the barges' limited payload weight and the resulting large lifting capability required at site.

Crew Boats

Crew boats are also referred to as wind farm support vessels. Their main application is for personnel transfer and utility work, such as enforcing safety zones, conducting environmental studies, or providing support for the shallow water divers. Crew boats range from small-sized rigid hulled inflatable boats to catamarans of 20 to 25 metres length.

Multicats

Multicats are 12 to 30 metres long, and are multipurpose but their main application in this industry is for anchor handling. They can also be used for light transport duties, since they are equipped with a small crane and an open deck providing a good storage space, divers' support or as a tug boat.

Figure 12 (from left to right); The Forth Trojan Multicat and The Forth Jouster; 26 m long Multicat [11]

During all stages of offshore installation, support vessels with various sizes and compositions are required. Other classes of vessels that can also be employed depending on the scope of installation stage include: crew boats, multicats, tugs, dive support vessels and dredging/scour vessels.

3.1.3 Designing for the Functional Requirement

Vessels should be selected depending on the project's economic and technical requirements. Technical demands vary greatly depending on parameters such as the ground condition and water depth, but also depending on the particular stage of the offshore installation being conducted, e.g. foundation, turbine or cable installation.

Foundation Installation

Foundations design has typically focussed on monopile, gravity based structures and jackets. The installation of foundation and substructures usually needs to be completed using a jack-up vessel or heavy list vessel (HLV), and is less likely to be completed with low crane capacity vessels.

The most important requirements in the selection of a suitable vessel for foundation installation are the crane capacity and operational water depth. Although in some cases crane capacities lower than the weight of substructure can be used, e.g. when using specialised pile gripping devices for installation of monopiles. The maximum speed of vessel and the maximum height for the crane lift are not as critical. In many cases, the foundation is transported onsite using an auxiliary vessel, and not the same vessel that is used for installation.

Turbine Installation

Turbines can be installed using most jack-up vessels; however, they are unlikely to be installed by HLVs, due to the required height of the associated lift. HLVs are, however, suitable for lifting and installation of fully-assembled turbines, such as the case in Beatrice demonstration project.

Figure 13: Heavy lift vessel 'Rambiz' installing a fully-assembled turbine; Beatrice demonstration project (www.eurotrib.com)

A number of parameters affect the design requirements for installation vessels. These influence the chosen vessel for a site and the strategy employed and thus the installation time:

- Substructure size and weight
- Turbine size, weight and component acceleration limits
- Distance from shore
- Installation strategy regarding combination of feeder vs. installation vessels

Soil profile at the construction site has a large impact on the speed of piling operations. Impenetrable layers of soil hinder usual driving procedure, and in some cases drilling might be required, causing delays in the planned timeline of the project. If the soil profile adjacent to the piles is erodible, scour protection becomes necessary, which adds to the requirements for vessel spread and installation time. The ground conditions also affect the vessel selection as the leg penetration depth affects the ability of a jack-up to operate in certain water depths.

Water depth greatly impacts the weight and type of support structure, and hence influences the requirements for deck strength and maximum crane capacity. The hull height and air gap should also be large enough to provide for the water depth and accepted wave conditions at the construction site.

Vessel Design Aspects

There are a number of critical factors in choosing the appropriate turbine installation vessel. The following parameters can be mentioned:

- The variable load: this parameter dictates the maximum weight of turbine components that can be carried.

- The crane height: this is one of the most important parameters considering the fact are usually installed in heights much more than that required by the oil and gas industry. The leg length and boom length when combined should provide enough height for installation of the nacelle and blades at the design hub height.

- Leg length: this parameter affects the maximum operational height, and also determines the maximum operational water depth at the construction site.

- Crane lift capacity: the limiting weight of installation vessel determines the turbine installation strategy, the number of lifts required, and hence the extent of pre-assembly of turbine components that can be conducted onshore.

- Deck space: it determines the number of turbines that can be carried and installed in one trip, and also the degree of onshore pre-assembly.

Current Design Solutions

The operational pattern together with requirement for deck area is governing present designs:

- There is a need for large deck area
- There is need for a stable platform for crane to work from.
- There is a need for a stable platform for jacking condition.

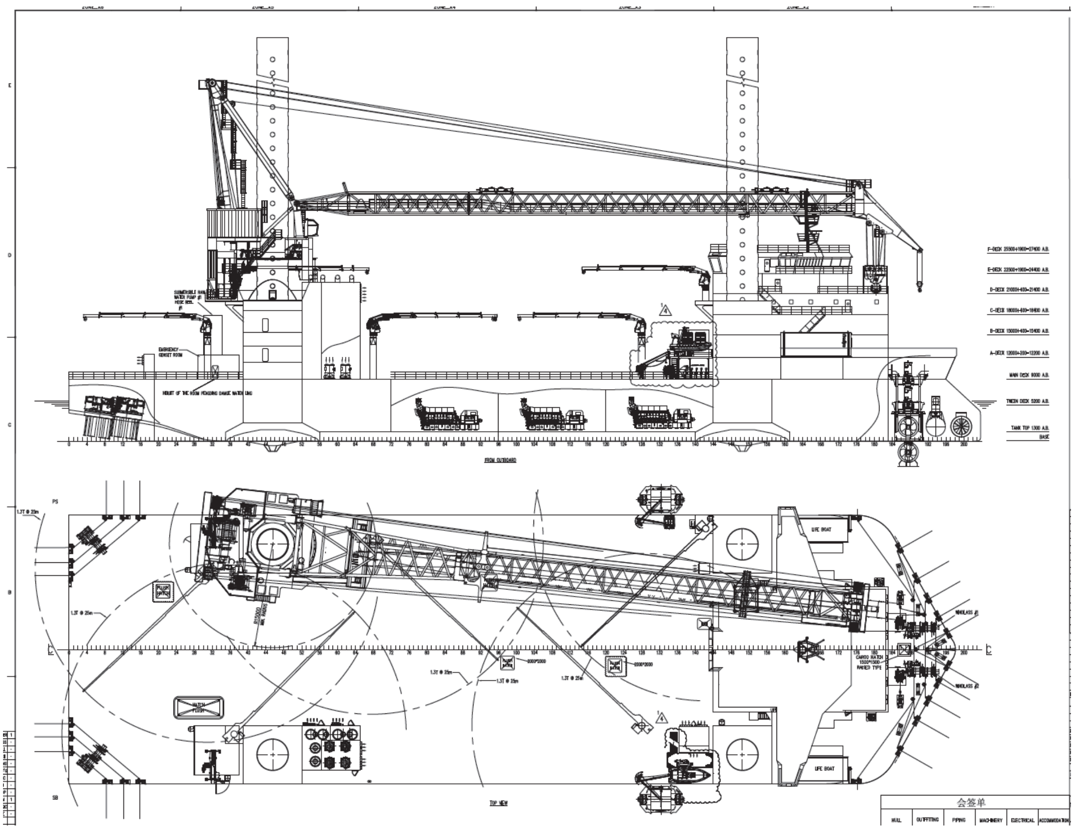


Figure 14: Elevation and plan of 2nd generation installation vessel

(A2Sea)

The above drawing shows the elevation and plan view of a typical 2nd generation installation vessel with crane located aft and stowed on top of accommodation. The integration of crane and leg maximises deck space.

Jack up system leg constructions are divided into build-up/rolled sections and lattice construction. The legs are fitted with jack-up systems, such as rack and pinion or similar. The system operates on hydraulic/electric drive and operation is normally performed in sea states up to Hs = 2 m. The design follows the requirements for operating water depth and strength and stability when jacked-up. Once a vessel is jacked up (out of the water), it is considered that wave height is then not to be a limiting factor.

Dynamic positioning (DP) technology is commonly employed. Installation vessels employing jack-up systems will use DP when approaching the designated position for installation. The DP-system maintains vessel position during the jacking process.

Heavy lift vessels also use DP although they are not equipped with jacking systems. In foundation installation, in shallower waters they use anchor systems to maintain position. In deeper water subsea installation of equipment, DP is used due to the depth. The heavy lift vessels not utilizing jacking during operation rely on the stability in floating condition during the cargo handling operation.

Installation vessels may combine propulsion and manoeuvring systems. The requirement for station keeping ability and manoeuvrability especially at lower speeds governs the layout of the propulsion type utilized. Normal type diesel driven propellers supported by bow and perhaps stern thrusters will not be able to respond with sufficient low response period. The propulsion system layouts are therefore based on usage of VOITH-drives, Azipod or Azimuth systems or similar systems.

Figure 15 (from left to right); typical foreship, VOITH propulsion unit [12], azimuth thrusters [13]

The benefit of a propulsion system based on VOITH or Azi-type propulsion units is that the manoeuvrability at lower speed is excellent. This is needed when approaching a wind park or under manoeuvres within the wind park area, where there are strict regulations on speed. The transit vessel speed for a typical installation vessel is abt. 12 knots or less.

Crane Configuration

The main crane has different modes depending on the purpose of the vessel and also the job in hand. This will influence lifting capacity and lifting height of the crane. Three of the main scenarios are:

Installation of wind turbine

This requires both lifting capacity and the same time sufficient lifting height above deck.

Installation of foundations

The passage of the cargo through the splash zone requires relatively high capacity on the crane due to the cyclic loads to which the crane is exposed. Gripper arms are used to hold monopoles during installation. Also for novel XXL-monopiles, there are requirements for very high end lifting capacity.

Sub-sea equipment lifts

In the execution of sub-sea operations, the control of the cargo submerged requires a crane designed for these tasks. These jobs are often at depth exceeding the limitations of jack-up vessels. Hence anchoring or DP-operation is necessary.
A critical operation is a lift through the splash zone and lifts on/off the seabed. In both cases wave-vessel interaction is critical and a limiting factor, the vessel response to sea state becomes important and there may be a need for heave compensation systems.

Operational limits on crane operations

Normal standard for limit on crane operation is about 20 m/sec. wind speed. This however varies from crane to crane and maybe lower for the component being lifted.

Figure 16 Crane on an installation vessel. It shows how there in this case is a requirement for lifting height (A2Sea)

When specifying heavy lift cranes for wind farm installation vessels, there is a compromise between the required stability during a heavy lift of the maximum capacity, the motion characteristic of the installation vessel and transit speeds [14].
The design issues for installation vessel cranes are as follows:

- Lifting height
- Operational minimum radius
- Load control
- Crane tail swing
- Weight of crane: lighter cranes are required to lower total load of installation vessel.
- Occupied deck space: cranes can occupy much needed deck space.
- Crane maintenance: minimal maintenance and highly reliable crane are needed to minimise delays in wind farm installation offshore
- Wind and weather resistance
- Appropriate control systems and drives: the need of crane using one control system rather than multiple is desired

3.1.4 Summary

Summary of the important operational factors depending on the installation stage under consideration is provided in Table 2.

Table 2: Important operational requirements depending on the work type

	Water depth	Crane capacity	Crane height	Deck space	Variable load	Vessel draft	Turntable capacity
Foundation	✓	✓					
Turbine	✓	✓	✓	✓	✓		
Cable						✓	✓
Substation		✓					

Most of the existing jack-up vessels have been optimised for offshore oil & gas industry, where their jack-up capacity operates marginally above water in deeper waters. When employed for installing wind turbines, the jack-ups should lift to far greater heights than their standard operating range to accommodate the large lifting heights required. These results in considerable delay associated with the time required to raise the jack-up to the target height, and lower back once the installation in finished.

Having been developed for the offshore oil and gas industry, most jack-up vessels are not the cost-effective options for installing wind turbines. Their costs are usually high during the favourable seasons, when they are also in demand by the oil industry. Many of the jack-up barges are also still unable to move in wave heights over 1m.

The above-mentioned shortcomings have shifted the developers towards utilising modified and purpose-built vessels suited for offshore wind applications. These custom vessels should be able to move from site to site as fast as possible. The storing capacity should be high enough to carry a number of turbines at the same time, to reduce the number of transportations to the port. They should also be designed for lifting operations in heights that are suited for turbine installation.

3.2 Maintenance Vessels

3.2.1 The Need for O&M Vessels

O&M activity accounts for approximately one quarter of the life-time cost of an offshore wind farm. Over the next two decades, offshore wind O&M is going to become a significant industrial sector in its own right. Based on the UK Government's projections for the deployment of offshore wind, the O&M of more than 5,500 offshore turbines could be worth almost £2bn per annum by 2025 – an industry similar in size to the UK passenger aircraft service business today. Maintenance accounts for by far the largest portion of O&M effort, cost and risk.

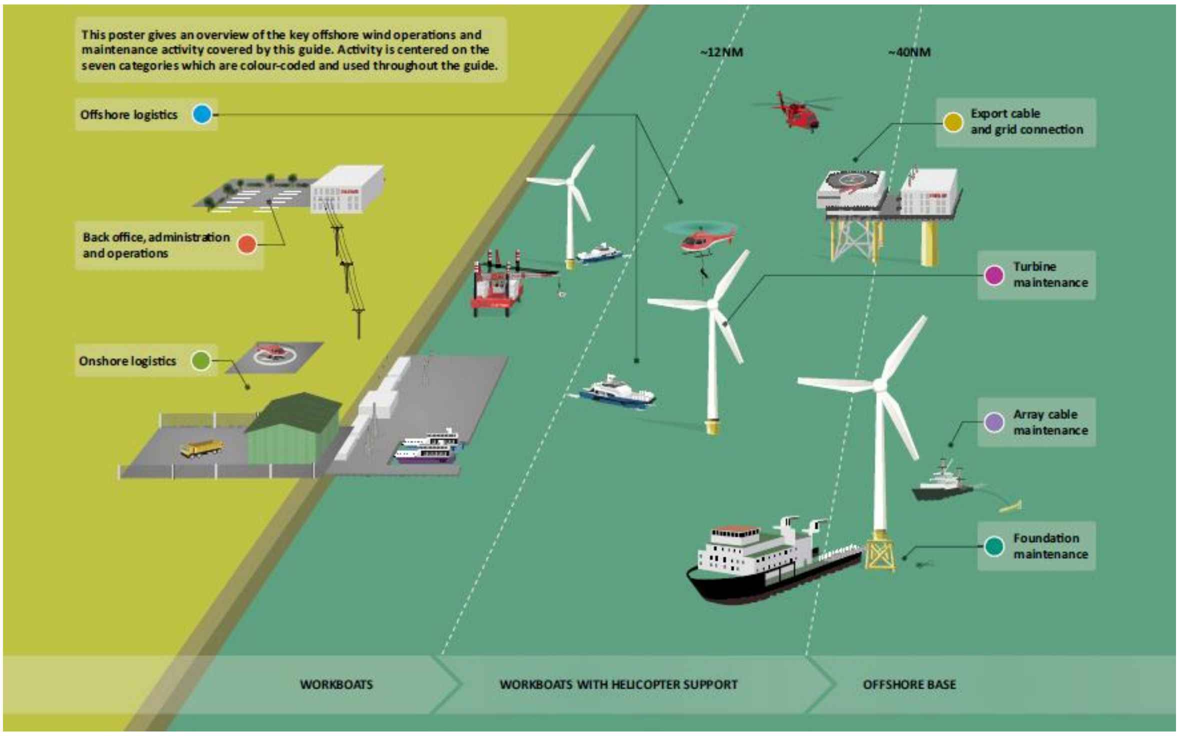


Figure 17: Overview of offshore wind O&M activities [15]

Maintenance activity can be divided into preventative maintenance and corrective maintenance. Corrective maintenance includes the reactive repair or replacement of failed or damaged components. It may also be performed batch-wise when serial defects or other problems that affect a large number of wind turbines need to be corrected. Preventative maintenance includes proactive repair to, or replacement of, known wear components based on routine inspections or information from condition monitoring systems. It also includes routine surveys and inspections. The aim is to keep the availability of the farm at the highest level, to extend the life time of the various equipment of the farm (turbine, foundation, etc.), and to decrease the number of failures. Preventive maintenance should be scheduled according to the maintenance strategy developed for the specific wind farm.

One of the key priorities for offshore wind farm operators is to limit the total downtime of the turbine which can be divided into four parts as illustrated below.

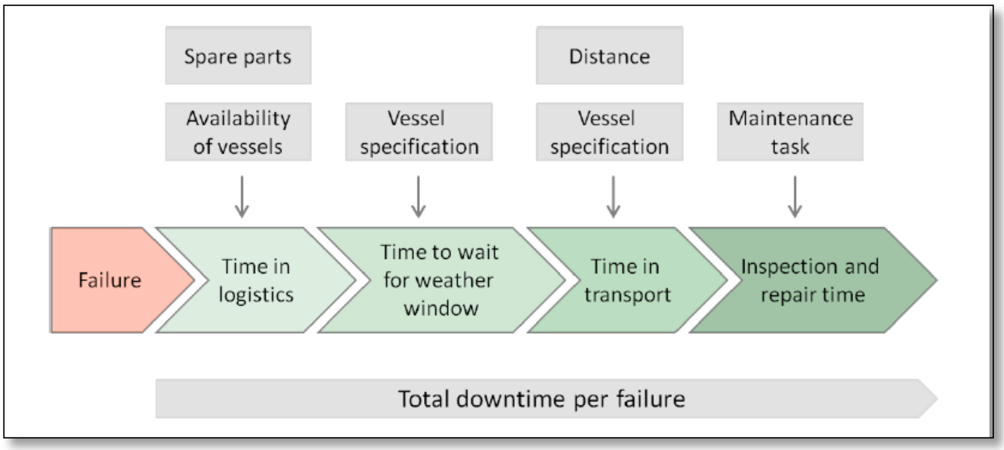


Figure 18: Factors influencing the downtime when a failure occurs [16]

When a failure occurs, contracting the right vessels and spare parts can take time. Once the required vessels are in place, the crew and maintenance team have to wait for an appropriate weather window, and this waiting time will depend on the specifications of the vessel. The distance from the O&M port to the offshore wind farm and the vessel speed will determine the transfer duration. Once the vessel is located at the turbine, the maintenance task can be executed, provided the sea state condition allows the maintenance team to access the turbine and the time required will vary according to the type of failure.

It is therefore key for farm operators to set up corrective maintenance strategy taking into account failures mode assessment, sea state condition forecast, total cost of downtime and availability and capability of maintenance vessel fleet.

For planning purposes, the distinction is usually made between scheduled or proactive maintenance and unscheduled or reactive maintenance. After the paramount safety of personnel, the second most important consideration when operating and maintaining an offshore wind project is the financial return. The objective of maximising the output of valuable electricity for sale – at least cost – can be thought of as driving all decisions by project owners about planning and carrying out O&M [15].

For further information on maintenance strategies please see LEANWIND Deliverable 4.1 Chapter 2.

3.2.2 Current Vessel Solutions to Enable Maintenance

Maintenance operations will require up to three different activities:

- Transportation of maintenance personnel and tools,

- Shipment of larger spare parts and equipment
- Lifting activities.

Each of the activities will require a specific vessel type:

- Service Crew Vessel - Also known as offshore service craft or personnel transfer vessels are designed to transport maintenance crews comfortably and safely between port and turbine. Vessels typically range between 15 to 25 meters and vary in hull forms; monohull, catamaran or SWATH. Vessels normally come equipped with storage areas, WC, small cranes. The Service Crew Vessel can be used to provide support during both the construction phase and O & M phase of an offshore wind project.
- Jack-Up Vessel or barge - Generally the most commonly used vessel for the replacement of major components. Jack up vessels are a type of self-elevating platform that consist of a hull fitted with a number of movable legs capable of raising the hull over the surface of the sea. There are different kinds of jack up vessels available; first generation vessels with heavy lift capacities are not self-propelled and need to be towed to location, second generation barges are designed with a large working deck, storage space and accommodation, third generation jack ups are ship shaped self-propelled vessels purpose build for wind turbine installation vessels with DP technologies. Jack up vessels used for installation can be sizeable and expensive for maintenance operation such as component replacement. Smaller, more affordable jack-ups are generally preferred for maintenance operations where other service vessels are limited by lifting capacities.
- Tailor made O&M vessel - As many offshore wind installations are heading further offshore, finding smart O&M solutions for offshore wind fleets has been identified as key issues to be overcome by turbine OEMs and offshore wind farm operators. Offshore maintenance services may include substantial repair work and turbine overhaul, both of which require larger, more capable vessels than service crew vessels. Jack-up, typical wind farm installation vessels, may be used for this activity but day rates are too expensive for use in an O&M basis also availability is limited by competition of these vessels with the oil and gas industry. As a result, the notion of building smaller, and a result, cheaper vessels is welcome.

3.2.3 Service Vessels

These vessels offer a number of functions including personnel transfers carriage of maintenance equipment, survey work; but personal transfer remains their major function.

Personnel Transfer

Current service vessels transfer personnel from shore to turbine to carry out routine and reactive wind turbine maintenance tasks. The work consists of technical breakdowns and regular checking of equipment from a preventative perspective. Greasing and oil changing work has to be completed along with testing of electrical systems, safety equipment, foundations and cables.

At some sites, vessels operate for 24 hours per day and each shift for crew and technicians is normally 12 hours. Some crews stay extra time or arrive early to complete routine vessel maintenance. Some of the wind turbine maintenance tasks do not take very long and technicians are taken to multiple turbines during the working day. It is therefore possible that the vessel can complete as many as 60 transfers of the same personnel in one shift. Therefore, the amount of transfers a vessel can complete in a 12 hour period is dependent on the tasks that are being completed by the technical engineers but the significant number required to be carried out at present are restricted by environmental limits on being able to transfer personnel.

Accessibility and transit time are largely dependent on wind farm location; sites further from shore typically have sea states with larger Hs and longer Tp, although this is site depth dependent. Transferring maintenance personnel from vessel to wind turbine safely and effectively in various sea states is one of the key challenges in offshore wind O&M. In order to overcome these varying scenarios, different methods are currently used to transfer personnel onto turbines:

Direct vessel transfers, known in the industry as “bump and jump”, is where vessels push against turbines backed by the force of the engines, some at full throttle whilst a maintenance crew jump across, from vessel to turbine and vice versa.

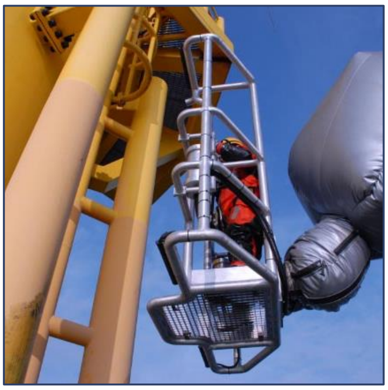
The force applied due to the vessel’s thrust, in conjunction with a specially designed bow fender and rubber contact points, increases the friction between the boat landing and the fender minimising the motion enough for maintenance crew to step over onto the ladder. Innovation in rubber materials and fender shape has improved friction to reduce relative motion.

The bump and jump method is limited by the ability of the vessel to remain motionless during transfer; however large waves, especially when coupled with strong currents can cause the vessel to lose its fixed position. The current technology and first generation vessel designs are limited to sea conditions of 1.5m significant wave heights. This limitation severely affects the economic viability of wind farms located in areas where >1.5m significant wave heights are seen on a more regular basis.

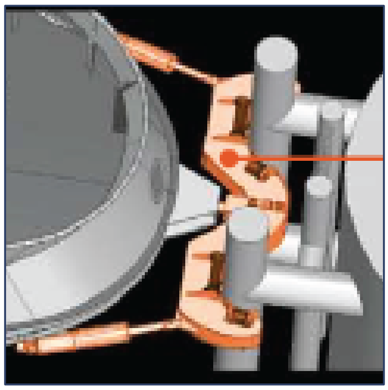
Further development of vessel technology, while increasing the sea worthiness and stability, will make currently inaccessible wind farm sites more economically viable [17].

Some transfers are assisted by motion compensating systems, where maintenance vessels are fitted with damping systems, using either passive or active systems, that aim to reduce vessel motion and hence, in theory, enabling transfer operations in harsher conditions and larger wave heights. These systems use technologies that can monitor vessel accelerations due to wave motion in real time and compensate reducing the relative motion between the boat landing and the vessel. Theoretically, motion compensating platforms aim to widen the crew transfer weather window to include significant wave heights above 1.5m.

MaXccess



MOMAC MOTS 500



MOBIMAR Grippers

Figure 19: Examples of different transfer technologies Source: [18], [19] and [20]

Such systems include the MaXccess, Momac, Amplemann and Houlder TAS systems, with different systems suiting different vessel sizes. The challenge in their inclusion in vessel design is the large weight and required deck space at the bow. The time taken to deploy also varies and should be a consideration in this project.

Carriage of Maintenance Equipment

Some consideration has been presented for vessels to carry small shipping containers that hold spares and equipment for use in the farm. Generally the space requirement is larger than most vessels can offer and can cause an issue with visibility when stored on the foredeck. An enhanced level of stores available would assist with increasing efficiency of O&M function.

Additional Functions

Additional functions may be able to be fulfilled by these vessels, including provision of power at the wind turbine for commission or the carriage of fuel for generator located at the wind turbine. They may also carry survey functions given their frequent turbine visits; this may assist in the monitoring of scour for example.

3.2.4 Service Vessel Design Characteristics

Hull Form

Vessel design plays a large part in enabling the turbine to be accessed safely. Essentially how the vessel responds to wave conditions affects vessel movement at the transfer piece. The vessel may encounter waves from port, starboard, bow or stern and even quarters. This siting of the ladder for each monopile typically considers wind and wave with intent to increase accessibility. The vessels response to waves is determined by hull form and weight distribution.

There are numerous vessels types and designs that fall within the SCV codes currently servicing offshore wind farms, and so each have their own sea keeping behaviour. The main hull forms which have the greatest effect on sea keeping behaviours are instead discussed below.

Monohulls

Monohulls are a single water displacing body whose hull form spreads across the beam of the vessel. They are characterised by resistance to motion at high speeds and poor sea keeping behaviour in severe sea states. Stationary monohull vessels are prone to a rolling motion when stationary.

Twin Hull/ Catamaran

Catamarans are comprised of a pair of hulls reinforced by the vessel superstructure. They offer reduced resistance to motion hence reducing engine power requirements and thus reducing fuel costs and emissions. Due to the large ratio of length to width, they are able to travel at high speeds whilst maintaining excellent lateral stability and reduced vertical motion. They can suffer poor roll characteristics when on station however. This hull form gives a good sized working platform for the vessels length. The beam of catamarans also lends itself to a large surface area for the transfer fendering. Almost all WFSV working are catamarans, including designs now employed by South boat, Turbine Transfers, Fintry and Alicat.

Small-Waterplane-Area-Twin-Hull (SWATH) Vessels

It is known that wave excitation drops exponentially with depth, hence by reducing the volume of a hull at the surface of the sea and achieving a large proportion of the vessel's buoyancy beneath the waves, the vessel can be very stable even in rough seas at high speeds. Much like catamarans, SWATH vessels normally have a twin-hull arrangement.

SWATH's are entering into the market place with large organisations such as A2SEA and Fred Olsen including vessels of this type in their fleets.

The features of SWATH's are:
Torpedo shaped hull sections that minimise the contact area of the hull with the water and to improve efficiency. The hulls are ballasted by water to give the vessel 2 modes these are; Catamaran and SWATH mode.

Current vessels employing SWATH forms typically have the following characteristics:

- Average speed 22 knots
- 18 – 20m length
- 8 – 10m beam

The advantages are:

- Greater sea keeping capability
- Efficiency
- Shallow or deep draft
- Comfort for passenger
- Operable at significant wave height of 2.5 m maximum

Disadvantages

- Increased cost due to more complex hull shape
- Sensitive to weight
- Engine maintenance difficult

Vessel Length

Larger vessels may have a more favourable response to waves during transit and transfer due to their greater length with respect to the wave period. Bridge deck height and tunnel width in catamarans also allow for many more waves to pass through the hull form with less effect.

Error! Reference source not found. shows a large bow design with an opening that allows ater to be released from the bow reducing accelerations while steaming and pushing on to turbines. It also demonstrates length alone isn't always a good indicator. Both these vessels are at the top of the industry but the Windcat 101 is 28m and the Eden Rose is 20m. Bow height of both vessels is around 3m from the water line. Vessels between 17 and 24m have much more capability for the safe transfer of personnel and will be able to transfer in conditions outside of the 1.5m Hs, potentially negating the need for motion compensating access systems. Smaller vessels have more need for motion compensating access systems but are not typically capable of carrying the increased weight.

Bow design

Bow and fender designs are an important part of the vessel being able to remain in contact with the boat landing during direct transfer. There is no standard in the dimensions of the landing stages between manufacturers of turbines; although many landing stages are roughly compatible with 1 or 2 exceptions. Fenders would normally be used on vessels to stop scratches and protect the vessel. They have evolved to try and fulfil their new function and provide increased friction with the boat landing. Through trial and error, the vessels' fender materials are also becoming more technical in the current generation of vessels. The rubber D type fenders have now been superseded by more technical and advanced shapes and materials, including T shape fenders which have increased friction and therefore the ability to remain stationary for longer. The pressure at the bow due to the contact and shear forces must be considered during structural design.

Propulsion and Transit Speed

Current maintenance vessels generally are configured with 2 engines and either propellers or water jets. Recent vessels entering the market have been configured with 4 engines in line. The thinking is that the vessel can operate with engines running when in the farm region and utilise the 4 engines to achieve a good sprint speed when transiting from shore, however implications on fuel efficiency and carbon footprint need to be assessed. It is also argued that the maintenance of 4 smaller engines is easier and the possibility of downtime is minimalized as it is possible to carry out maintenance on duty with one engine shut down.

Transit speed in favourable conditions is typically around 20 knots. Many vessels have top speeds of around 27 knots with a few achieving 30 knots. Theoretically transit speeds can be increased but the crew comfort and the level of safety equipment required increases when speeds over 27 knots are used in other than very calm waters. There is therefore an economic balance to be struck between reduced transit time with associated increased maintenance time and increased cost in the vessel manufacture.

For the vessel to be able to grip the turbine during bump and jump transfers, it must be able to gain traction via mass and thrust. Lightweight vessels generally have to push very hard as their presence in the water is minimal. Larger vessels in normal conditions do not push too hard and may not require any additional thrust from the engines in some conditions.

Conventional pitched propellers and controllable pitched propellers offer the most common and simplest method of vessel propulsion. Vessels speed and performance is directly linked to propeller design and some understanding of the intended use of the vessel is taken into account by designers. The propeller will have a zone of maximum efficiency and this is normally optimised for its cruising speed. The only other vessels that are designed to push against structures are tug boats. In this instance the design choice is made to maximise thrust from the propellers at the point of pushing. Speed is sacrificed for thrust. With wind farm vessels thrust and speed are both required. Some operators have experimented with variable pitch systems which mean the propeller performance can be adjusted between cruising speed and thrust against the turbine. Some builders have encountered problems with these systems due to the lag between instructing a change of pitch and the system reaction.

Water jets draw water from an inlet in the last third of the vessels hull and eject the water at speed from a jet and buckets on the transom. Buckets are used for steering and even for reversing making it is very manoeuvrable system of propulsion. Water jets are an efficient method of propelling vessels at high speed; at their best performance they can reach speed of above 25 knots. Some smaller vessels have suffered with problem using water jets. When pushing hard onto the turbine they become wedged between the propulsion in the aft and the turbine on the fore. As waves move through the vessels hull form it is possible for the intake to become exposed to air. Unless proper prevention methods are in place the engine will have no resistance and over-rev possibly damaging the engine.

A common opinion of waterjets is they are good for working in shallow water, which they are. When working in shallow water for a considerable period they can become damaged by the suspended matter that is concentrated in shallow water. Scouring of the chamber can cause a loss of performance and increase maintenance. Waterjets generally tend to be more expensive than a CPP system.

Personnel Capacity

Almost all vessels are 12 person vessels with 2 or 3 crews; this is a result of the banding of safety issues by PAX under the statutory regulations resulting from SOLAS. A number of larger capacity vessels have now been developed including the Windcat 101 with a capacity of 45. Some vessels have sleeping accommodation for passengers and crew allowing greater range and working duration.

Range

Range is determined largely by fuel capacity and any sleeping arrangements. Range is also limited by safety requirements through regulations. The majority of service vessels under 24m are under MCA category 2 which restricts vessel to a safe haven of 60Nm; in this instance it is not necessary for the vessels to carry a large fuel load. Typical vessels have enough fuel for 2 or 3 days.

Increasing the MCA category requires an increase in safety provisions on-board. Some vessels are under category 1 which restricts them to 150 Nm from a safe haven. These vessels may have the capability to achieve large range but do not operate with full fuel capability when working as day vessels. There is cost attached to carrying fuel when not bunkering at every opportunity. As fuel is often excluded from the contract and bought and supplied direct to the operators then they have a minor interest in saving fuel by taking bunkers more regularly.

Crane Lifting Capacity

Many of the larger vessels are equipped with cranes with a typical size of 5Tm; some have 2 cranes located on each stern and bow. Cranes are seen as a useful for self-loading when in port, but are not generally used. Tools and equipment are often carried in plastic 1m^2 cubes and flexible bags. The loading of this equipment with the aid of a crane can save time for both crew and technicians.

Cargo Capacity

Cargo capacity varies with the size of the vessel, the fuel load and the vessel design. The following would be typical cargo capacity after taking into consideration a full fuel load and crew and passenger:

- Under 15m - 3 tonnes
- Under 20m – 5 tonnes
- 20m and over 10 tonnes

Load requirements on current vessels are rarely more than 3 tonnes. This may change if tasks currently undertaken by installation vessels are completed by service vessels.

Deck Space

Deck space is very important for the store of passenger equipment and giving a good dedicated space at the transfer point. There is a compromise with vessels designs as the fine entry hull forms are often sensitive to weight in the forward end. This can mean that the useable deck space has to be further aft and not really where it is required at the foremost point for transfer and crane lifting onto the turbine.

Welfare

Passenger seating is necessary to protect crew from injury in the case of an accident plus reduce whole body vibrations. The effect of visibility of the horizon has not typically been considered but would be valuable. The consideration of welfare on board is also key with a need to provide food and refreshments along with toilets and showers and entertainment to maintain morale.

3.2.5 Market Conditions

The current market place is going through a period of consolidation. Smaller vessels that where introduced many years ago are slowly falling out of the market as larger more capable vessels are constructed. Typically vessels less than 15m are coming up for sale. Vessels less than 18m are beginning to find long term contracts harder to secure. The current trend is for vessels 20 up to 24m. Some manufacturers have moved into constructing the larger vessels and some have fallen away. The companies that have built so far are:

Table 3: Maintenance vessels manufacturers list

Manufacturer list	
South Boats	Mercurio Shipyard
Alnmaritec	Aluminium boat company - Hayling Island - formerly Pepe now dissolved
Buckie Shipyard - dissolved	Windcat workboats
Blyth	Lyme boats - dissolved
Damen	Alicat - Arklow

Austal - Trimaran for Turbine transfers	Safehaven Marine
Danish Yachts - swaths	Strategic Marine
Fjellstrand shipyard	Technicraft
C truk	Fintry - Carbocats

3.3 Class and Statutory Requirements

The risks associated with vessel design, construction, maintenance and operation are managed through a combination of statutory regulation and classification. These are complex due to the multiple stakeholders including national governments, vessel owners and operators and the multinational nature of transport.

The IMO has established a correspondence group to tackle areas of uncertainty with respect to vessels serving the offshore wind industry. They apply two definitions to vessels applicable in this industry as:

Offshore Construction Vessels (OCV) - a mechanically self-propelled or towed vessel, which is primarily engaged in offshore wind farm construction, assembly, maintenance, disassembly, demolition or similar activities and carrying crew and industrial personnel qualified to man the vessel and undertake the construction works.

Offshore Service Craft (OSC) refers to a conventional relatively slow vessel or a high-speed craft that is used to transport industrial personnel who may not be working on board.

3.3.1 Statutory Regulations and Classification of Offshore Construction Vessel (OCV)

OCVs will be engaged in the installation of foundation, tower and turbine installation and maintenance work. This definition is obsolete for the installation of floating wind turbines by towing to site.
In general OCVs should meet the following broad regulatory factors:

- Vessels above convention size (>500 GT) require classification and flag state certification
- Vessels below convention size may not require class certificates, dependent on the flag state requirements. In this case they should be built to national standards such as the MCA's Codes of Practice for Small Commercial Vessels. However few offshore wind farms OCV's are likely to be under 500GT.
- Vessels registered under one state but operating in water of another shall be considered as international voyages and shall therefore meet the requirements of both Coastal state and Flag state. A Memorandum of Understanding could be arranged between the two, if the vessel is for dedicated trade.

The application of the various IMO Statutory Regulations (e.g. SOLAS, MARPOL etc.) will be entirely dependent on the flag state and operating location of the vessel. However the following list indicates the generic list of conventions and codes that may be applicable to an OCV:

- International Load Line Convention, 1966 (ILLC) and Protocol of 1988 as amended
- Anti-Fouling Convention
- Regulation of International Tonnage Measurement of Ships, 1969
- SOLAS 1974 and Protocol of 1978 as amended
- Mobile Offshore Drilling Unit Code (MODU Code) 2009

- Convention on the International Regulations for Preventing Collisions at Sea (COLREGS) 1972
- MARPOL 1973/78 as amended
- Intact Stability Code 2008
- Code for the Safety of Special Purpose Ships (SPS Code) 2008
- MLC 2006

The particular selection of the relevant codes will be entirely dependent on the flag state and they must be contacted on a case by case basis. In general a vessel engaged in international voyages must comply with SOLAS, unless the flag state has agreed that the Special Purpose Ships (SPS) code or the Mobile Offshore Drilling Unit (MODU) can be used as an alternative. The IMO has established a working group to resolve the issue of possible flag state refusal of SOLAS alternatives as some states did not ratify SPS and expect MODU, and others require SPS.

A framework of the IMO flow diagram on construction standards applicable to ships can be seen in Figure 20.

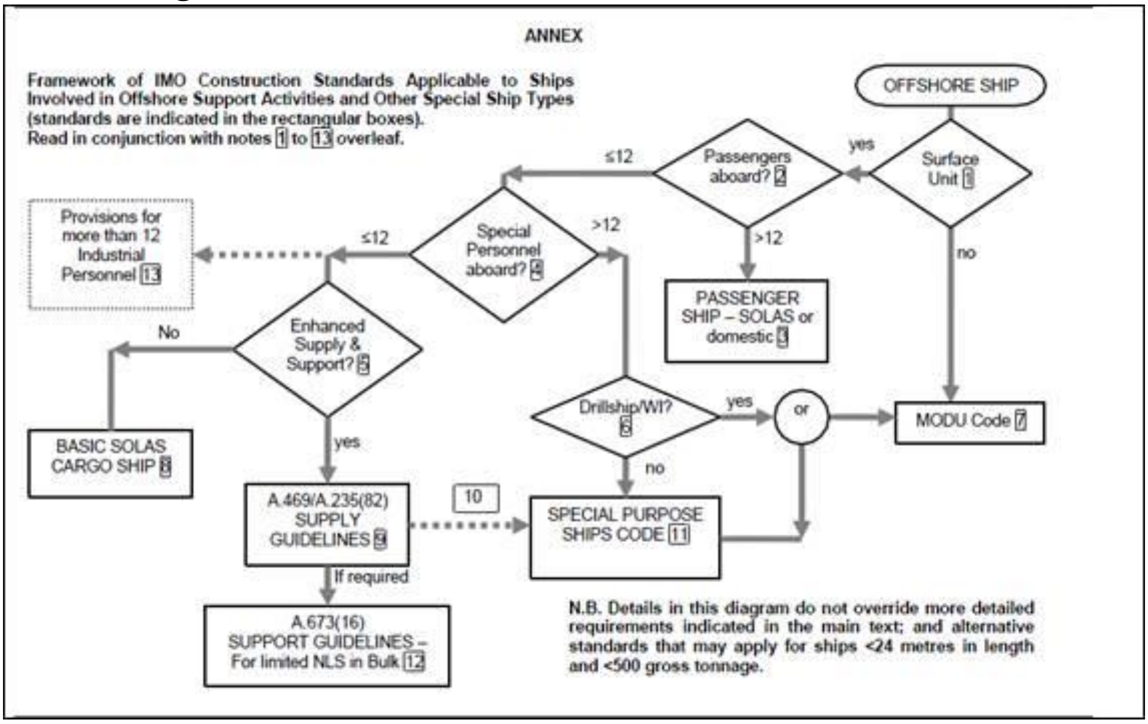


Figure 20: Flow diagram about framework of IMO Construction Standards Applicable to Ships Involved in Offshore Support Activities Source: [21]

There are a lot of regulations out of the scope of the IMO which could affect strongly to the design of Offshore Wind Farm Construction Vessels. Mainly those regulations related to the environmental impact including:

- Noise radiated to the harbor.
- Underwater noise from piling and marine operations – this is a large concern in German waters
- NOx, SOx and other emissions which may extend beyond MARPOL via national legislation.

- Increased turbidity in the waters potentially incurred due to disturbed sediment during construction.

There are only two classification societies that currently produce guidance for Wind Installation Vessel Class. Both LR and DNV specify a set of rules and regulations that are to be adhered during the classification process with the predominate focus being on that of offshore features (e.g. Column stabilised and self-elevating units). Currently the flag state decides whether a vessel below 500 GT requires classification; the flag state will decide the appropriate construction standard if this is the case.

The LR *Guidance Notes for the Classification of Wind Turbine Vessels* gives guidance for different unit types as differing rules sets will be applicable. From a structural perspective the emphasis is on the analysis of the various forces that will be experience in transit and during installation with a variety of loading conditions being analysed. The machinery element focuses more on the specific jacking up gear and dynamic positioning systems that are required for a vessel of this type.

DNV *Rules for Classification of Wind Turbine Installation Units* focuses predominately on the structural properties and material selection used for Self-elevating/Column stabilised units. A comprehensive list of the various DNV rules and regulations required is also given.

For “standard” type vessels (e.g. vessels other than self-elevating units, i.e. Tugs, Barges etc.) then the normal rules for the classification of those vessels would apply from a number of class societies. Most IACS Class Societies will have a set of rules for both “Ships” and “Special Service Craft”. Additional features, such as cranes etc. would require their own rule set (e.g. LR *Code for Lifting Appliances in a Marine Environment*)

3.3.2 Statutory Regulations and Classification Applied to Service Vessels

There are a number of constraints placed upon the industry by the various codes and regulations that are affecting the design of OSV for offshore wind. The main issue is that imposed by SOLAS and the ILLC on the definition of a “Passenger” (Defined by SOLAS as being anybody other than the master or the crew or other persons employed or engaged in any capacity on board a ship on the business of that ship). The current requirement is that a vessel carrying more than 12 passengers should be in possession of a Passenger Ship Safety Certificate and since July 2010 any vessel built over a 120m must comply with SOLAS “Safe Return to Port” (SRPR). Compliance with the Passenger Ship Safety Certificate requires additional features such as extra lift rafts, lifeboats and safety drills that may well be impractical for a vessel of this type.

The main purpose of the SRPR regulation is to ensure that the vessel can return to port under its own propulsion following the complete loss of one compartment due to fire or flood. The potential consequences include the total redundancy of the essential systems of the vessel (e.g. propulsion, steering, bilge and ballast etc.) representing significant additional cost to both the ship owner/operator and designer. The increased redundancy could also be viewed positively by the wind farm operator. This regulation will be relevant for the potential new designs of large accommodation/maintenance vessels.

The alternate route, which does not require compliance with SRPR, involves the implementation of the Special Purpose Ships (SPS) Code which allows certain personnel on board to be designated as "Special Personnel". The SPS Code defines such personnel as "persons who are not passengers or member of the crew or children of under one year of age and who are carried on board in connection with the special purpose of that ship or because special work being carried out aboard that ship". The code can be used as a suitable alternative to SOLAS and has been applied to Survey and similar vessels for a number of years. A point of contention at the IMO relates to whether the special personnel are actually working on board, given that they disembark at the wind turbine and re-join the vessel at the end of their maintenance tasks. Currently the decision is made by the flag states and it is at their discretion.

Access equipment, which also provides a statutory issue, is included in the MODU code but not in SOLAS. It is the owner's choice whether to include the access equipment in certification or classification activities, the only statutory conditions come from the ILO. As such there are no mandatory regulations for access equipment.

Many vessels currently used for maintenance on offshore wind farms are below 24m and carry less than 12 passengers (and if cargo vessels under 500GT), the requirement of a class certificate is dependent on the flag state and owners may only need to comply with the relevant statutory regulations. Classification is sometimes seen as a demonstration of the quality of the vessel so is sought even if not mandated. Due to the much smaller size of current service vessels, and the scope of their work, many flag administrations place not only personnel and length restrictions but also range to a port of refuge. The UK Maritime and coastguard agency apply MCA *Small Commercial Vessel and Pilot Boat Code of Practice Code- MGN 280* to < 24m vessels; this stipulates area categories ranging from 0 to 6, with distance restrictions dependent on the carriage of safety equipment.

Recently builders have instead developed >24m vessels carrying >12 personnel under the High Speed Craft Code and certified as passenger vessels. Vessels built to these larger Statutory Instruments cause the implementation of Rules and Regulations aimed at upholding the safety of passengers of cruise ships and ferries with no seafarer training. This may not truly reflect the risk associated with the maintenance personnel who are able-bodied and with appropriate training.

Current small vessel codes generally only cover domestic voyages however in the future the nearest port of refuge may well be in a foreign flag state. Memos of Understanding (MOU) can currently deal with this problem, providing that the two flag states recognise each other's standards.

3.3.3 Regulatory Work Underway

The IMO correspondence group is discussing a possible new category of person on board: that of Industrial Personnel. It is expected that these people will be fit and able and have training which will reduce their risk at sea (See IMO *Classification of Offshore Industry Vessels and Consideration of the need for a Non-Mandatory Code for Offshore Construction Support Vessels SDC1/INF11)*. Current regulations means that since personnel on board have an awareness and training on the vessel, the requirements will be less than a passenger ship. The challenge for the flag states is how to fit the application of the term "industrial personnel" into the current international regulations. Currently, if a high speed service craft is below 500GT and the industrial personnel are not considered as passengers, the vessel will be non-convention.

The IMO group has published guidelines for wind farm construction with respect to Jack-up and DP, and maintenance vessels which are defined to stay on station and those which are for the high speed transfer of personnel. Guidelines are also being produced with respect to the statutory regulations, of which 20 flag states are involved.

The guidelines are non-mandatory but it remains possible for all flag states to accept them. The national bodies can apply regulations over and above those imposed internationally to vessels operating in their waters to maintain their acceptable working conditions. This causes some difficulty in creating a unified set of guidelines. By having a uniform set of safety standards, the market will be clearer and will provide confidence for vessels owners in making investments in build or conversion, and in the installation of new technology on board.

4. Industry Challenges

The state of the art, described in Section 3 outlines the functional requirements for installation and maintenance and alludes to some of the challenges in optimising designs for the industry. These are outlined in more detail in this section.

To appropriately consider the implications of rising costs attributed to different environmental parameters for planned wind farm sites, the project has identified four generic cases to consider based on characteristics of existing and future wind farms. For more information on the derivation of these cases see Section 5.

Table 4: Site scenarios

Case	Water depth (m)	Distance to port (km)
0	20	30
1	40	30
2	60	100
3	100	30

4.1 Installation Vessels

The development of new installation vessels is closely linked to the development of new types of foundations and the development of new installation methods and all three developments should be seen as one integrated optimization problem. Innovations in installation are facilitated by the introduction of new vessels and the design of these vessels is driven by the likely market they will be able to serve and the potential to be economic over the lifetime of the vessel. This reciprocity has created uncertainty in the market.

4.1.1 Outline of Industry Challenges

The increase in water depth and distance from shore poses two significant challenges both for installation operations and heavy maintenance operations. The leg lengths for jack up vessels will be a limiting factor in the deepest waters. Also the increasing water depth and exposure of sites may increase the severity of the average metocean conditions. The operations required for the transit and installation of farm components is highly dependent on the environmental conditions, with favourable conditions creating weather windows for operations to occur. More severe environmental conditions will challenge the operating limits for the component lifts and jack-up, for vessels using this procedure. The parameters which define whether an operation can be performed can be based on significant wave height Hs, Tp, wave direction, persistence, wind speed and direction and tidal flow, but depending on the operation, vessel acceleration could be the limiting parameter. The percentage of non-workable days drops rapidly with increasing maximum wave height. This is site specific and data for the baseline sites will be used in the later parts of this project to determine vessel design requirements.

The increasing size of turbine nacelles and rotors require a more structurally capable and so heavier tower. Tower height has increased from approximately 40-55m in the 1990's to 60-65m in the 2000's to 80-90m in the last few years. In line with this, tower weights have increased from between 25-75 metric tonnes in the 1990s, to 100-160 metric tonnes in the 2000s, to around 210-450 metric tonnes recently. Limited information is available due to the intellectual property issues associated with turbine designs. The turbine designer will be cognisant of the range of available lifting cranes but the trend towards heavier lifts is shifting the installation market towards larger vessels [9].

To provide some clarity on what the technical challenges are for future wind turbine and substructure installation, a series of scenarios have been considered reflecting typical existing and proposed wind farm conditions. The derivation of these is outlined in further detail in Section 5.

The future spread of foundations best suited for these scenarios will most likely comprise:

- Monopiles (primarily for case " 0")
- Jackets and tripods (piled or suction based) primarily for cases "1" and "2"
- Gravity based foundations primarily for cases "0" and "1"
- Floating concepts (e.g. spar or semi-submersible platform) primarily for case " 3"

The most cost effective installation vessel designs will be the ones tailor made for the actual combination of foundation design, turbine design, soil conditions, environmental conditions and water depth. To maintain the economic viability of the vessel however, the owner will attempt to maintain flexibility towards alternative cases (foundation types/ water depths) with higher market volumes.

The following four tables list the main industrial challenges for each of the four cases:

Table 5: Industry challenges for CASE 0, 1, 2 and 3

Case	Water depth (m)	Dist. To Port (km)	Foundation Type	Installation Vessel Type Foundation	Installation Vessel Type Topside	Main Challenges	Possible Solutions	Cost reduction potential impact
0	**20**	**30**	Monopile	Jack-Up	Jack-Up	No industrial standard for sea fastenings	Standardised and flexible sea fastenings	Medium
						Time for positioning	Improved DP / manoeuvring performance	Medium
						Quality of weather forecasts	Improved decision support	Medium
						Weather windows for Jacking	Improved Jack-Up design	High
						Time for Jacking	Increased jacking speed	Low
						Weather windows for crane lifts (tower and blades)	Improved damping of relative motions	High
							Consider whole turbine installation “All-in-one”	High
			Gravity based	Tug	Jack-Up	Time for positioning for foundation installation	Improved tug coordination (3 tugs)	Medium
							Relaxed positioning accuracy	Medium
						Reduce time for tow	Increase transit speed by reducing structure drag	
1	**40**	**30**	Jacket or tripod	Jack-Up	Jack-Up	Limited space for foundations on installation vessel	Consider feeder arrangement	High
						Time for positioning	Improved DP / manoeuvring performance	Medium
						Quality of weather forecasts	Improved decision support	Medium
						Weather windows for Jacking	Improved Jack-Up design	High

Case	Water depth (m)	Dist. To Port (km)	Foundation Type	Installation Vessel Type Foundation	Installation Vessel Type Topside	Main Challenges	Possible Solutions	Cost reduction potential impact
						Time for Jacking	Increased jacking speed	Low
						Weather windows for crane lifts (foundations, tower and wings)	Improved damping of relative motions	High
							Consider whole turbine installation "All-in-one"	High
						Lifting jacket through splash zone	Jacket design	-
							Crane heave control/ compensation	-
				DP Float/ Sheer-leg	Jack-Up	Weather windows for positioning (incl. DP)	Improved holding capability	-
						Weather windows for sheerleg crane lifts	Crane heave control/ compensation	-
			Gravity base structure	Tug	Jack-Up	Time for positioning for foundation installation	Improved tug coordination (3 tugs)	Medium
							Relaxed positioning accuracy	Medium
						Reduce time per tow	Improve GBS design for reducing drag during tow	-
2	60	100	Jacket or tripod	Jack-Up	Jack-Up	Limited space for foundations on installation vessel	Consider feeder arrangement	High
						Time for positioning	Improved DP / manoeuvring performance	Medium
						Quality of weather forecasts	Improved decision support	Medium
						Weather windows for Jacking	Improved Jack-Up design	High
						Time for Jacking	Increased jacking speed	Medium
						Leg length	Increased leg length	Low

Case	Water depth (m)	Dist. To Port (km)	Foundation Type	Installation Vessel Type Foundation	Installation Vessel Type Topside	Main Challenges	Possible Solutions	Cost reduction potential impact
						Weather windows for crane lifts (foundations, tower and wings)	Improved damping of relative motions	High
							Consider whole turbine installation "All-in-one"	High
						Splash zone challenges, (foundation design dependent)	Jacket design	-
							Crane heave control/ compensation	-
				DP Float/ Sheer-leg	Jack-Up	Weather windows for positioning (incl. DP)	Improved holding capability	-
						Weather windows for sheerleg crane lifts	Crane heave control/ compensation	-
			Floating	Tug + DP floater	Jack-Up	Relative motion between crane and topside during installation	Whole turbine tow-out	-
							Reduction of relative motion : SPAR gripper	-
3	100	30	Floating	DP Floater	DP Floater	Relative motion between crane and topside during installation	Whole turbine tow-out	-
							Reduction of relative motion : SPAR gripper	-
				Tug	DP Floater	Increase in sea state for towing operations	Improved prediction of hydrodynamic response	-
						Handling of mooring		-

Weather Windows for Jack-Up

A considerable industry challenge is the limitation regarding the sea state in which a vessel is able to jack-up. This is restricted by the capabilities of DP systems to remain on station but also the jack up system's capability to withstand the transferred wave loads and bending moments. During the lift of the hull from the sea surface, the loading imposed on the jack-up system plus guides as transferred from the wave loading on the hull must also be accommodated.

Time for Jack-Up

The jack up process includes the jack down of the legs to the seabed on predetermined sites, followed by preloading to embed into the soil. When complete, the hull is jacked up above the water. The time to complete this process both depends upon the ability of the DP system to establish the vessel on station and the jack up speed. Jack-up systems include pin and hole systems and rack and pinion systems. Current maximum jack up speeds are around 1m/min and the challenge of increasing this will need to be further explored.

Weather Windows for Crane Lifts

The wind speed becomes the limiting factor for the scheduling of crane lifts. Given that the installation sites are selected for their optimum resource, this is a challenge for any lifting activity although certain components are more sensitive to accelerations and more susceptible to inducing wind load than others. The technical challenge remains to balance the crane's capability to withstand dynamic loading against the component's capability of withstanding increased load.

Jacket through Splash Zone

Lifting any structure through the splash zone induces wave loading. Depending on the design of the jacket, the dynamic loading due to waves and current during the deployment could potentially cause enough force to create slack in the slings and cause large snap loads in the slings and crane structure.

Sea Fastenings

Sea fastening is required to secure monopiles from movement when the ship is in transit to prevent damage to cargo and ship. There is no industry recognised standard for sea fastening on monopiles. Normal practice is that all cargo should be restrained in the three directions of movement, e.g. forward to aft, port to starboard and against upward movement. Using the vessels eye plates or rings typically sunk into the deck, various types of lashing equipment can be applied. This is typically bespoke in design and includes feedback of loading information to the vessel crew. Due to the sheer weight of monopiles in excess of 250 tonnes more innovative methods are required and a standardised approach is considered essential to reduce costs.

Time for Positioning Jack-Ups

Site survey work is carried out for each turbine installation location to determine the optimal location for the jack up legs to be embedded in the sea bed. The time taken to establish the position at these sites is dependent on the positioning capability of the vessels and typically employs a DP system. DP systems may include additional thrusters, which may need to be engaged when on station.

Also additional time can be incurred as leg punch-through may occur during jack-up at the predetermined sites. This may incur the need to relocate. A way to mitigate is by increased knowledge of the soil conditions. At present geophysical data is acquired during pre-installation via cone penetration tests, and acoustic sensing, although to determine conditions to greatest accuracy core sampling is required.

Limited Space for Foundations on Installation Vessels

With increasing water depth the sizes of the jacket foundations is increasing posing a challenge regarding optimisation of available deck space. Maximisation of deck space and optimal arrangement of jackets on deck therefore remains a challenge to be solved. Alternative options include the repeated return to port to reload the installation vessel or feeder vessels to resupply the installation vessel.

Jack Up Vessel Leg Length

Moving to deeper waters means that leg lengths must increase to accommodate the embedment depth, water depth plus air gap. The challenge remains that the vessel must have adequate stability when jacked up and, either be of a size which still enables port access or be supplied with turbines and substructures by a feeder vessel. The challenge with feeder vessels includes the lifting of components from the deck using the installation vessel crane.

Relative Motion between Crane and Topside

Attempting to use floating vessels for offshore lifting and installation has led to extremely difficult operations, since even small wave-induced motions at the sea level are amplified into large oscillations at the top crane level.

GBS foundations

As with the locating of the jack up legs onto predetermined sites, GBS also need to be installed in predetermined locations. If these are float-out GBS the challenge is in coordinating the towing vessels. For GBS installed by heavy lift vessels, anchors or DP systems are used to maintain station; with anchors incurring a time penalty for deployment.

Additional challenges:

- Increase weather windows to enable deployment in more serve environmental conditions.
- Seek solutions to operate in harsh conditions thus increasing the ability to withstand higher wind speeds and higher wave heights without detriment to the operation of the vessel.
- Transport all parts of the wind turbine structure in a single voyage thus avoiding the use of heavy lift vessels.
- Reduce transit time.
- Reduce time for the positioning of tugs in star configuration
- Reduce time for sinking the foundation.

Technical Solutions which could solve the challenges include:

- Improvement the geometry of GBS foundation for example reducing the drag coefficient, and therefore to reduce the bollard pull required for the operations.

- Development of novel barges (non-propelled) for transportation and installation GBS, increasing the buoyancy. Even, the transportation of all turbines components together (foundation + tower + wind turbine) in a single voyage.

Challenges Arising From the Installation of Floating Foundations

The experience from Windfloat has outlined the following challenges:

- Handling the length of mooring required for floating turbines in larger water depths e.g. 100m
- Configuration of mooring for deployment and detachment for maintenance
- Ability to install platform in higher sea states, Windfloat had significant challenges at Hs = 1.5 to 2m
- Adequate accommodation on installation vessels such that ROV and operating crews can be accommodated

4.1.2 Key Design Aspects for Future Installation Vessels

From the main challenges identified above, the following parameters become critical for specification of the vessel requirements:

Crane Specifications

- Today's nacelle weight is about 200 tonnes but is expected to reach 440 tonnes for the future 6-7 MW turbines
- Hub height will increase as well from 90m to 105m+ in the next decade
- Future foundations will weigh around 500-900 tonnes (monopiles will remain the most common type of foundation and will be used in around half of turbines forecast in 2013-2030, followed by jacket and tripods who are expected to become increasingly popular with 42%)
- Vessel installing both future turbines and foundations will require crane capacity of 1500t at 30m and sufficient boom length to allow installation at 105m+
- Due to splash zone and offshore lifts challenges passive or active heave control/compensation may be needed

Payload and Deck Space

If a feeder strategy is not applied the following should be considered:

- Existing installation vessels have deck capacity from 4 to 20 tonnes per square meter approximately
- Future 400 tonnes nacelles or around 800 tonnes jacket will require deck capacity of 5-6 t/m^2
- Deck space for future vessel should require a minimum deck space of $3500m^2$

DP and Engine Performances

- DP2 Class vessel should become the standard for the installation vessel as it provides more efficiency and safety especially for all vessel positioning operations. Such DP2 vessel shall be equipped with bow tunnel thrusters.

Jacking System

- 4 or 6 legs Jack-ups to be preferred to 3-legs units in order to save time during pre-loading
- Jack-up duration is approximately 4 to 7 hours
- Jacking system : rack and pinion and hydraulic jacks should remain the main system jacking system

Operating Water Depth

- In the 2 next decades 44% of the turbines will be in 30 m+ water depth and 30 % will be in 20-29m
- New built jack-ups are designed to operate in water depths up to 45m
- Only a small number of jack-ups are able to operate beyond 50m
- Legs length to be appropriate

Operational Weather Limitations

- Maximum significant wave height (for jack-ups Hs max between 1,5 and 2m)
- Tidal current limitations (for jack-ups typically of the order of 3-4 knots on the beam)
- Maximum wind speed(typically between 15-18 m/s)
- Operational air gap is project specific

Transit Speed and Fuel Consumption

- Only self-propelled vessels are foreseen for future installation vessels
- Higher transit speed increase fuels costs so the cost difference has to be taken into account

Accommodation Capacity

- Marine crew represents around 25 to 35 people
- Construction crew represents 20-40 people and more than 50 people in monopile configuration (now it is often normal to have one man cabins for the construction crew)
- Offshore management team adds 5-6 people
- Wind farm owner adds 3 to 5 representatives
- New jack-ups have accommodations for 60-100 persons (some on development will have accommodations for up to 200 people)

Helideck Requirements

- CAP-437 specifications

Remark: a market shall remain for smaller wind turbines which are field proven.

Turbine Assembly Strategies

- Onshore offshore assembly, etc.
  - Wind turbines typically consist of 6/7 individual components (3 blades, 2 or 3 tower sections, the nacelle with the hub)
  - Some degree of onshore assembly is performed to reduce number of offshore lifts (which are risky and susceptible to cause delay)

  - Different assembly scenarios

- “Stick-build” configuration (tower sections installed separately, nacelle installed with the rotor pre-attached, all 3 blades lifted separately)
- Tower assembled onshore (tower installed in a single lift, nacelle and hub lifted together, blades installed separately)
- “Rotor Star” method (tower transported in 2 or 3 pieces and lifted, nacelle lifted separately, rotor and all 3 blades lifted together)
- “Bunny-Ear” configuration (tower transported in 1, 2 or 3 pieces, nacelle, rotor and 2 of the blades lifted together, third blade lifted independently)

“All-in-one” configuration (tower, nacelle, rotor and all three blades assembled onshore and installed in a single lift, non-mature method)

Parameters Specific for Floaters

- Decrease operating constrains due to meteorological conditions
  - Improve vessel design for less restrictive weather limitations
    - Increase maximum operation sea state;
  - Improve weather prediction
    - Improve weather monitoring system
- Decrease transit time
  - Increase deck payload
  - Increase useable deck area
  - Increase transit speed
- Decrease offshore operation durations
  - Increase vessel speed
  - Consider a vessel for accommodation

4.1.3 Possible Solutions for Future Installation Vessels

Innovative concepts have been already proposed for producing vessels meeting the above-mentioned requirements.

A preliminary literature and industry review of future installation vessel concepts being considered currently has revealed the following candidate concepts for future installation vessels. These should all be regarded as complements to a continued evolution of the market dominated by jack-up vessels seen today.

A2SEA have modified ships to a hybrid of jack-up and self-sustained container careers. The vessels are capable of erecting one wind turbine per day, and have been employed for the Horn Rev Wind farm installation. These custom vessels also provide accommodation for the technical crew. The novel concept aims to complete whole turbine installations to reduce construction at sea.

Figure 21: Sea Installer, an example of the state of the art installation vessel [21]

Aeolus

Aeolus (Figure 22) is an innovative vessel for offshore wind farm transportation and installation, developed by Van Oord. The sailing speed is set at 12 knots, and the crane capacity is approximately 900 tonnes at 30 m radius. Aeolus can accommodate 74 people including ship crew and the installation technicians. Aeolus is planned to be commissioned in spring 2014 [22].

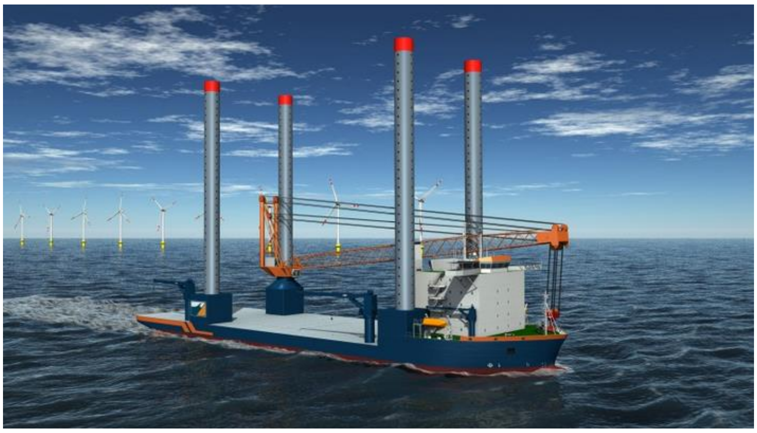


Figure 22 'Aeolus': specialised Van Oord vessel for offshore wind farm installation [23]

Semi-Submersible Mid-Sized Dynamically Positioned Concepts

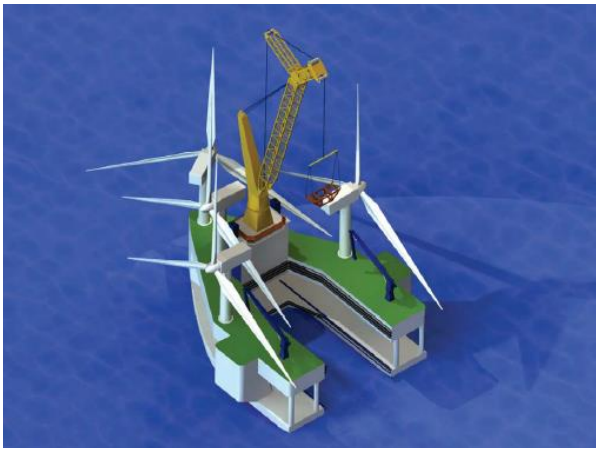


Figure 23: Leenaars Semi-submersible Wind Turbine Installation Vessel [24]

Figure 24: Luisman's Wind Turbine Shuttle [25]

Mid-Sized Barge Concepts

Figure 25: (From left to right) Wind farm installation barge, Ballast Nedam TWG installation vessel proposal, Float – over concept – DSIV Technip.

Ship Shaped Mono-Hull Alternative

Figure 26: Windlifter – Idea Heavy Equipment BV [26]

Figure 27: Vuyk Engineering Rotterdam [27]

Figure 28: Versatile DP Vessel NorWind [28]

The OWTIS W3G Marine and IHC Merwede, pictured below, is a floating DP monohull concept designed to install jacket structures with its fit for purpose crane.

Figure 29: OWTIS W3G Marine and HIS Merwede Source: [30]

SWATH Hull Forms

Wind Turbine Shuttle is an emerging concept with dynamic positioning and relatively fast sailing capabilities (14 knots). It is a SWATH-type vessel, with a compensation system for maintaining the vessel motions at a very low level, which makes it suitable for transporting and installing two fully-assembled wind turbines [29]. Alternatively, the vessel can be used for transporting the support structures, e.g. large jackets or monopiles [25].

Figure 30: Wind Turbine Shuttle [29]

Transport of Floating Wind Turbine Concepts

Windflip is another innovative specialised barge for transportation of fully assembled wind turbine and tower to the wind farm site. Windflip can carry one turbine at a time, in a nearly horizontal position, while being towed to the site using conventional tugs, at a maximum speed of 8 knots. Once arrived at the wind farm location, the barge starts filling its ballast tanks, which makes it flip 90 degrees to a vertical position. At this stage the barge is detached from the wind turbine, returns back to its horizontal position by emptying the ballast tanks, and towed back to the port using the tugs, where it is ready to carry another wind turbine [30].

Figure 31: Windflip Concept: SPAR based [30]

Specific Concepts for GBS Foundations

Strabag has developed a conceptual design of a naval platform for the transportation and installation of a type of foundation. It is able of carrying structures up to 8000 tons; the operation is based on the principle of semi-submersible platforms, allowing transport of all parts of the structure from the dock to the final location in an only one operation. In this way it seeks to minimize the work done in offshore and reduce risk, while also increasing the window of opportunity for wind turbine installation.

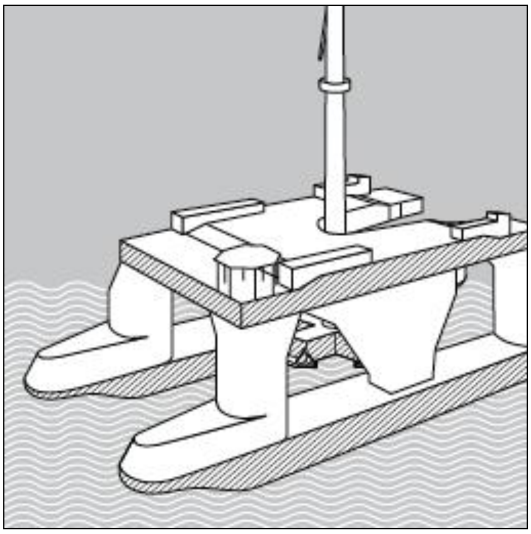


Figure 32: Strabag solution for transportation wind turbines. [31]

Figure 33: GBF solution [32]

The BMT Nigel Gee solution involves the transport of the pre-assembled GBS and turbine to the final location, avoiding the use of heavy lift vessels for the installation the upper part (tower, nacelle and blades), reducing drastically the cost of installation. This method has not been used yet, although it is presented as one of the future solutions for the installation and transport of GBS foundations under the Carbon Trust Offshore Wind Accelerator project.

4.1.4 Installation Vessel Summary

As indicated in the Table 5 the potential cost reductions are closely linked to:

- reduction of the needed time for the various installation operations and
- extension of the weather windows in which the operations are feasible

From these strategies the main optimization trends can be derived:

- Decreasing use of offshore lifts which requires Increased amount of onshore pre-assembly or increased loading capability for components being lifted to increase number of available weather windows
- Decrease operating constraints due to meteorological conditions
  - Improve vessel design for less restrictive weather limitations
    - Increase maximum jacking sea state
    - Increase max crane operating wind speed
  - Improve weather prediction
    - Improve weather monitoring and decision support system
- Decrease transit time
  - Increase number of turbines loaded per trip
    - Increase deck payload
    - Increase useable deck area
  - Increase transit speed
- Decrease offshore operation durations
  - Increase jacking speed

4.2 Maintenance Vessels

4.2.1 Outline of Industry Challenges

As outlined in Section 3.2.1, maintenance operations will require up to three different activities:

- Transportation of maintenance personnel and tools

- Shipment of larger spare parts and equipment
- Lifting activities

Each activity may require a specific vessel type. Offshore Service Vessels or Personnel Transfer Vessels are used to transport maintenance team from O&M Port to the offshore wind farms. Heavy maintenance operations, e.g. for the replacement of large or heavy components such as the blades or gearbox, require wind service vessels or jack-up vessels; such vessels are currently the same as the vessels used for installation. With the increased number of operating turbines and the increased demand for installation of more, the demand for wind service vessels or jack-up vessels for heavy maintenance is likely to compete with the demand for the installation of turbines and foundations. This, coupled with the increasing intention for modular wind turbine design, will stimulate the development of specific wind turbine construction vessels for maintenance activities.

There are two major factors that influence this transfer when utilizing an O&M Vessel (Crew Transfer Vessel – CTV or Personnel Transfer Vessel - PTV):

- Transit time – the time needed to transfer a maintenance crew from the O&M base to the wind farm. Due to limited shift hours available, the time taken to transport crews to and from a maintenance job reduces the amount of time actually allocated to the maintenance of the turbines and other equipment. The further the wind farm is from the O&M base, the less time can be spent by crews on active work, given the longer transit time and risk of fatigue. The distance from the O&M base impacts not only the transit time (vessel cruise speed) but also the effective working time on site.
- Accessibility – the proportion of the time a turbine can be safely accessed from a particular vessel. It is highly dependent on the weather conditions (wave height, wind speed and water currents): influence on the operability of a vessel, personnel safety and accessibility to offshore structures. For example if, at a particular wind farm, the significant wave height is greater than 2m during 40% of the time, a vessel that can transfer crew and equipment only in wave heights less than 2m might have a 60% accessibility. Accessibility is especially critical for unscheduled maintenance since the wind farm operator will often have no opportunity to plan any production outages for times of calmer sea conditions.

Therefore at present, when planning O&M activity for a wind farm, the operator will endeavour to reduce the total cost (direct cost and lost production) by finding ways to optimise transit time and increase accessibility to the turbines. O&M cost would also be negated by preventative maintenance schedules allowing the developer to capitalize on weather windows with lower sea states. This is the concern of WP4, and this WP will concentrate on decreasing cost incurred through vessel design.

The Carbon Trust has presented information suggesting current turbines require six maintenance visits per year; the Carbon Trust Offshore Wind Accelerator project aims to achieve three visits per year for UK Round 3 sites, as shown in Figure 34.

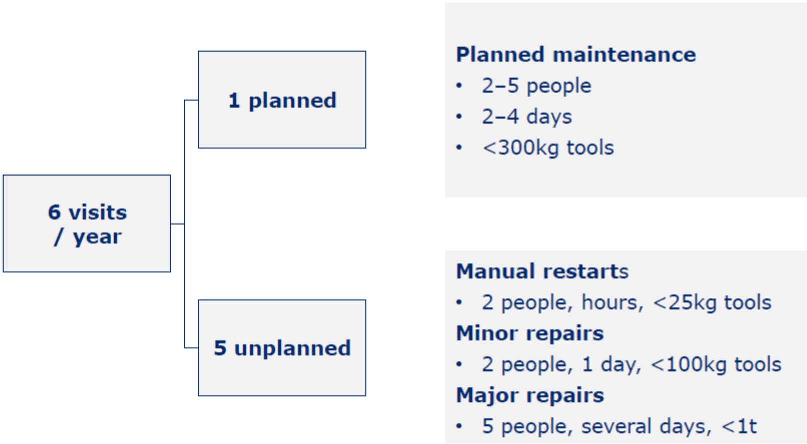


Figure 34: Annual wind turbine visits [33]

In the North Sea, accessibility can be improved to around 90% if access is made possible and safe in significant wave heights between 2.0 and 2.5m. According to the sailing directions no.2006 of the BSH (Federal Maritime Administration) for the North Sea, wave heights of 1.5 m occurred approximately 54% per year. This is equivalent to 54% accessibility. During winter time, the lower values are between 35-40% and the highest values could be found during the summer with 75-80%. In winter, when accessibility is typically worst, there also is the greatest likelihood of turbine failure and, at these times, there are higher winds and hence potentially higher levels of production loss.

By allowing the operation of maintenance vessels safely in up to 3.0m significant wave height in the North Sea, the annual average accessibility increases to approximately 88%. Even in winter time this value is not below 75%. In reality, while H_s is used as measure of to determine limits on operation, other environmental conditions determine the vessel response, which is of more importance for personnel transfer.

While H_s is used a measure of sea state to determine limits on operation, other environmental conditions determine the vessel response which is of more importance for personnel transfer.

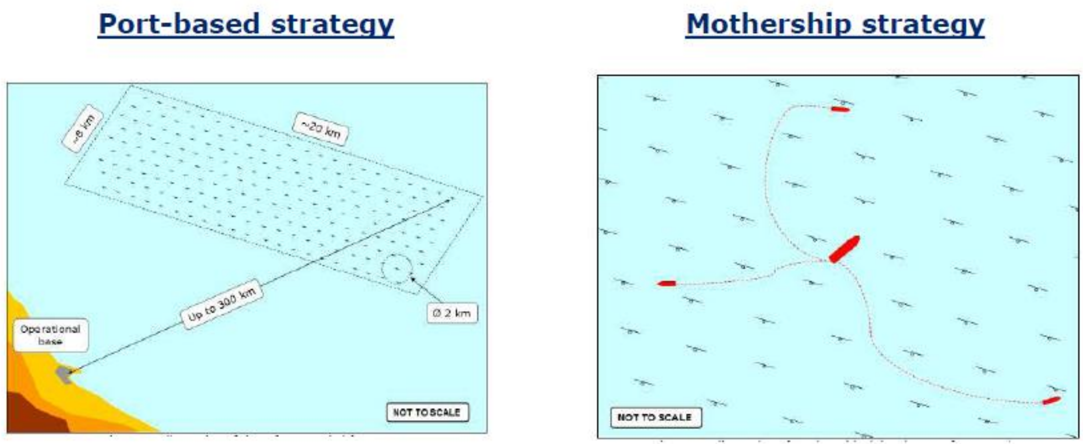


Figure 35: O&M Strategies Source: [35]

For a 1GW offshore wind farm equipped with 200 turbines rated 5MW and located 300km from the nearest O&M port, assuming each turbine has one fault per month and requires 2 planned visits per year, then 2400 unplanned and 400 planned maintenance operations per year are needed. If we consider that for the 2400 unplanned maintenance, 70% require only one access and a couple of hours to fix the problem, 27% require one access during the whole day and 3% require 4 accesses due to significant failure and if planned maintenance requires 2 accesses (2 days work) twice a year, the total number of access per year is 3416. These assumptions come from the Carbon Trust specifications for the funding call for innovative vessel designs.

Assuming that the maintenance team will work only during day and will be recovered from the turbine each day, this offshore wind farm will require an average 11 accesses per day, provided the significant wave height is less than 3.0m (average 310 day per year in the North Sea). Considering a maximum 2 to 3h time transfer per day (assuming a Vessel speed from 20 to 30 knots; distance to the O&M port of 100km or 60 nautical miles), the effective on site working time should be from 4 to 6h (respectively in winter or in summer according to daylight duration). This duration may be not suitable for maintenance tasks.

As the vessel speed cannot be significantly increased, an offshore based maintenance concept can be envisaged incorporating accommodation and spares storage.

For both nearshore and offshore farms, based upon these currently expected numbers of turbine visits, future maintenance vessels need to have the ability to navigate in more severe sea states with safer transfer systems and with optimised fuel consumption - currently around 30% of a vessel budget is spent on fuel.

4.2.2 Key Design Aspects for Service Vessels

Developers always want to ensure the welfare of the passenger and increase their comfort where possible. Noise and vibration contribute to sea sickness and any effort to reduce fatigue is well received. The MCA built vessels don't generally consider noise and vibration but, class such as DNV have stringent requirements. Reductions in noise and vibration can be achieved through appropriate selection of hull form, ride control systems and vibration damping seats. These features do increase the cost of the vessel which is ultimately passed on to the developers. Seating, welfare facilities, entertainment and overall comfort is a great focus to current generation vessels.

Vessel hull design varies, it is a difficult compromise between fine entry hull forms giving good speed and economy and broader hull designs that are able to carry weight. Therefore the consideration of the fine line between speed and economy and weight carrying capability is a critical design task.

4.2.3 Possible Solutions for Future Service Vessel Designs

A range of designs have been proposed to tackle these challenges; this has been stimulated by the recent OWA Access Competition [34].

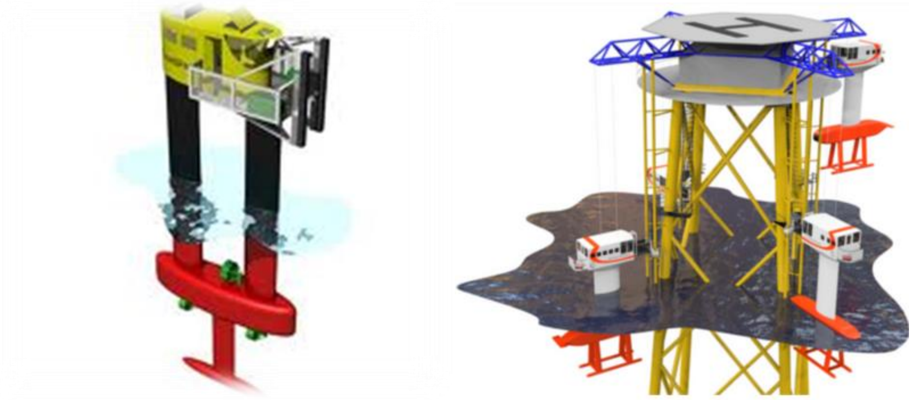


Figure 36: TranSPAR Concept [35]

The TranSPAR Craft aims to mitigate wave action through a small water plane area and fin keel arrangement, which, it is claimed, results in a stable transfer vessel. The concept is retrieved to a central platform to enable transfer back to port via helicopter or offshore accommodation base.

Figure 37: Windserver maintenance vessel Source [37]

The WindServer, built by Fjellstrand, uses a SWATH and hydrofoil hull form to minimise motion in transit and reduce fuel consumption. The hull has been designed to also be stable when stationary for more dependable transfer of crew to turbine when on station. To achieve this, ballast tanks are filled when in crew transfer mode creating the lower draft condition (SWATH mode) to reduce hull motion. Active fins and the bow hydrofoil also damp motion when on station.

Four WindServer 24 are already owned and operated by World Maritime Offshore under Danish flag. [36]

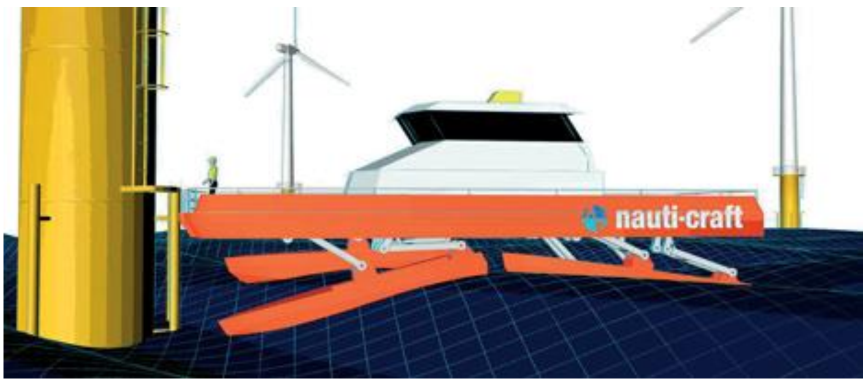


Figure 38: Rendering of Nauti-Craft Vessel [37]

The Nauti-Craft has articulated hulls which are separated from the deck and superstructure via a ‘passive reactive’ hydraulic suspension system. This system reduces the motion of the deck so increasing passenger comfort and permitting greater speed to the work location [38].

Figure 39: Pivoting Deck Rendering [42]

The North Sea Logistics Pivoting Deck Vessel concept incorporates a deck into the vessel, which links with the turbine foundation and reduces motion significantly during transfers. It also allows heavier equipment to be transferred, compared to many competing systems meaning that the vessel can be used for more O&M operations [39].

Figure 40: Surface Effect Vessel [40], [41]

The Wavecraft surface effect vessel uses an air cushion, like a hovercraft, to reduce contact with the water while in transit and so increasing transit speed. The air-cushion can be used to stabilise the motions of the vessel when on station.

Figure 41: BMT Nigel Gee XSS [42]

BMT Nigel Gee's XSS (Extreme SemiSWATH) is aiming to balance construction cost against improved ride [43]. Some of the key design features include

- Active interceptors and T-foils enabling a high level of motion control

- Active fender system, aimed at minimising impact loads experienced by the turbine foundations. Nigel Gee BMT claim a reduction vessel impact loads of up to 3 times those found with conventional fender systems.
- Optional use of Houlder's Turbine Access System™ which is a compensated gangway systems allowing transfers in higher wave conditions.

To tackle the issues associated with farms located further from shore, Damen shipyards have introduced a new Wind Farm Service vessel: the Walk-2-Work vessel. It provides on-site work facilities and accommodation for 45 maintenance personnel including 15 crew members for duration of up to one month at sea.

Figure 42: Damen's Walk to Work Vessel [44]

The vessel is DP2 with a telescopic and a motion-compensated gangway to allow three man maintenance teams to effectively carry out transfers between vessels and turbines. The vessel was designed with a target of 80% availability in wave heights of up to 3m whist providing a high standard of comfort for turbine engineers. The vessel has a length of 90m overall and a beam of 20m with a deck area of 500m^2 including a helideck and a heave compensating crane [45].

4.2.4 Possible Solutions for Access Systems

In the past, transfer baskets have been used for personnel transfer in offshore applications, such as the Billy Pugh, Esvagt and the personnel transfer capsule such as the Reflex Marine example, as shown in Figure 43.

Figure 43: Personnel Transfer Basket FROG-XT from Reflex Marine

This system is designed for the most demanding conditions and fulfils the duty of care to transfer personnel safely, to and from, offshore work places. The unit has a small footprint, making it easy to store, and cost effective to ship. It is also capable of being deployed quickly in Medical Evacuation situations (MedEvac), a crucial feature in emergency scenarios.

A number of designs of vessel mounted access system have been developed. The Autobrow, which is being developed by Otso Ltd and designed by Ad Hoc Marine Designs Ltd, works by having a gangway, or brow, automatically controlled up and down to compensate for the heave and pitch of the vessel. The tower end of the brow automatically extends to ensure firm contact at all times. The low cost system provides a significant improvement in transfer safety and operating window.

Figure 44: Illustration of Autobrow system Source: [50]

An alternative design is the Wind Bridge, which is pneumatic-based featuring an impact absorbing boarding system and dynamic heave compensation. Once contact is made, an automated retention clamp system is activated forming safe access. The Wind Bridge is clamped to the boat landing of the wind turbines foundation resulting in a rigidly connected embarkation point which greatly improves operability in higher sea states.

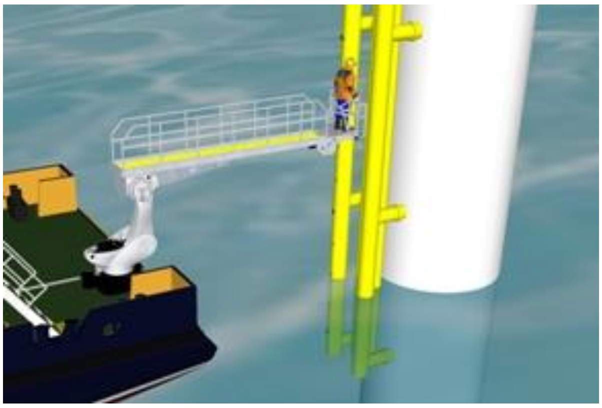


Figure 45: Wind Bridge illustration Source: [51]

4.2.5 Offshore O&M Bases

Offshore accommodation bases can significantly reduce the time to access the wind farm for light repairs or inspection. Moreover, because of the reduced travel times, the required weather windows are smaller, thus allowing for more weather window opportunities that also reduce wind farm downtime. There are also drawbacks however: cost of platform or mother-ship and worker wages are higher.

Fixed O&M Accommodation platforms have been used previously. The first one for the offshore wind industry was Poseidon, which was built for Hornsea 2. It is connected by a walkway to the substation platform and is 750 square meters large with 3 decks and weighs 422 tons. Having on-site accommodation is more efficient than transporting service personnel by boat (which is 2 hours from Esbjerg harbour, 60 kilometres away). Flying people by helicopter to turbines like on Horns Rev 1 is not possible on Horns Rev 2 as the turbines there are not built for it, although the substation platform has a helipad. Poseidon has 24 rooms of 12 square meters each fitted with TV and internet. It is also equipped with a gym, kitchen, dining room, laundry room, and a study room. The second O&M Accommodation platform (2500 tons) is currently been built by Vattenfall for the 288MW DanTysk wind farm in the German North Sea. The 20-metre high structure will sit 20 meters above the sea and will be situated 70 meters from site.

Figure 46: Artistic impression of DanTysk high seas home **[46]**

Mother-ship concepts are already in operation for the installation phase including converted Roll-on Roll-off vessels, ferries or barges. For example, C-Bed Floating Hotels [47] currently owns and operates three accommodation vessels with respectively 80, 150 and 500 cabins. The concept of a mother-ship solution, accommodation vessel or floating hotel that can stay on-site, providing accommodation for the wind turbine maintenance and service personnel has been proposed.

Figure 47: C-Bed Wind Perfection floating Hotel [47]

Tailor-made accommodation vessels could also be designed and constructed for the offshore wind sector, including functionality such as personnel access equipment, DP systems and on-board crane for maintenance lifting activities. Small parts (up to several tons) can be kept in stock at the mother vessel instead of the harbour.

Two concepts are currently being developed: the Sea Wind maintenance vessel proposed by Offshore Ship Designers and Ulstein's X-bow concept designed for Sea Energy PLC. These vessels also support helicopter operations including transport of personnel to and from shore.

Figure 48: Sea Wind -Offshore Ship Designers [48]

Figure 49: Ulstein X-Bow Source: [55]

Based on the expected number of personnel transfers, a large O&M accommodation and crane vessel would not be able to transfer all technicians to the turbines to complete maintenance work each day. This is applicable for a fixed platform or mother-ships. Therefore Personnel Transfer Vessels can be used to ferry personnel out to the individual wind turbines. The transfer of personnel from the service vessels to the mother-ship or platform becomes critical.

Another concept emerging is the Dutch harbour at sea, an artificial island with the purpose to reduce sailing times for installation and maintenance of the offshore wind turbines. The island would serve as a station for transporting, assembling and maintaining turbines, with hotel for personnel, storage of spare parts and a heliport among other things. Although the required investments in civil infrastructure are estimated to €1000m, the harbour is intended to serve several offshore wind farms [49].

Figure 50: Concept of "Dutch harbour at sea" [49].

4.2.6 Summary of Industry Challenges

Vessels need to be fast during transit and stable for the transfer of personnel to wind turbines. However O&M ports may be shallow and subject to tidal restrictions, which limits some of the geometrical design parameters for the vessel that may otherwise improve its performance towards these goals.

Any improvements to current vessels that will have a positive impact on accessibility and / or transit time will in turn reduce vessels operational costs. The main task is to be able to effectively balance the cost of making vessels more sea worthy against the benefit of increased accessibility.

Novel vessel designs or access system technologies need to be able to support maintenance vessels in increasing transfer capabilities beyond the 1.5m significant wave height limitation whilst reducing the levels of risk to acceptable levels.

As demand for larger maintenance vessels has grown, almost all vessels entering the market currently are above 20m, with better sea keeping traits. Health and safety regulations in place are slow to adapt to improving vessel capabilities and hence, 1.5m Hs is still a cut-off point regardless of vessel size and capability. A new form of determining the safe operating conditions, on a per vessel basis, would have an improvement on these limitations and is being tackled by the Carbon Trust OWA project.

Maintenance crews must be able to perform their work when at the turbine, and time in transit is not only useless but can be physically fatiguing. It is common for technicians during transit to experience sea sickness, reducing their capability and efficiency whilst carrying out maintenance activities. As a result, a certain amount of staff overlap is required. Increasing passenger comfort to a level where sea sickness can be largely avoided may mean that cost savings can be made by reducing the number of staff overlap required.

Communication between wind farm operator and builder needs to improve. End users and wind farm operators are subject to the impacts of design decisions, while the builder will understand how such impacts come about. Therefore wind farm operators need to be consulted in the vessel design process. Ultimately the cost-benefit analysis for the wind farm should be used to drive the functional design; this will ensure that the vessels are sufficiently fit for purpose but not over specified which would make the vessel unattractive in the market place.

While some vessels will be owned by the farm operators, a significant number will still be operated by independent companies. From a vessel operator's perspective, the vessels need to be multi-functional and adaptable to a number of tasks as it is more likely that a multi-functional vessel will be employable in other markets. The offshore wind market is still seen as unstable as it is dependent on political will and therefore more highly specialised vessels with better specifications requiring more investment will need to be able to work across industries. A balance of industry specific design against flexibility is therefore sought.

Overall the small vessel industry is familiar with iterating based on existing designs which can make the innovation process slow. This is reflected in the Carbon Trust Offshore Wind Accelerator call to fund innovative designs.

Access to offshore marine structures is considered a high risk activity, which requires the preparation of appropriate procedures to ensure safe personnel transfer. Accordingly, the following challenges should be addressed:

- Increased metocean limits for safe access, including access during the hours of darkness or in poor visibility
- Personnel Protective Equipment (PPE) required during personnel transfers
- Maximum loads for personnel accessing the structure
- Personnel training
- Reduced likelihood of personnel arriving on-site with sea-sickness
- Increased response time to a site remote from shore
- Contingency arrangements for emergency egress or extraction of a casualty

5. Baseline Scenario

The overall design of the wind farm is very site specific; design decisions are based on a multitude of physical and economic factors. This chapter provides a brief introduction to these physical parameters, and summarises the proposed design scenarios that will be used in the vessel design process in Work Package 3.

5.1 Site conditions

5.1.1 Water depth

Water depth influences the choice of foundation design and so then the choice of installation vessel. The effect on the use of jack-up vessels relates to the leg length. Current jack-up vessels available for use for turbine installation are limited to an average maximum water depth of 45 m; there are outliers such as Swire Blue Ocean's Pacific Orca which has a maximum leg protrusion of 80m below the hull. For water depths that are deeper, floating DP vessels or HLV barges must be used.

5.1.2 Distance from port

The distance from port impacts several aspects of the transportation, and maintenance planning, e.g. the choice of feeder vessel or not during installation and the need for an offshore O&M base or service vessels deployed from shore. Distance from port is an important parameter to be considered if a precise evaluation of the cost effectiveness of the wind farm is to be made, since it leaves a great impact on LCOE.

5.1.3 Soil profile

The soil properties not only influence the geotechnical design of foundations but also affect the jack up of installation vessels. Interaction between spudcans and the sea bed is critical in establishing a firm footing for the vessel while carrying out installation. The soil condition also affects the water depth that a particular jack-up can operate in.

5.1.4 Met-Ocean condition

The environmental loads resulting from the wind and wave actions on both installation and O&M vessels play an important role in restricting the operational weather window. Met-ocean conditions will therefore drive decisions on O&M strategies and vessel selection. These are, by their nature, site specific and will be determined for each site by the wind farm developer as part of their investment and planning decisions.

5.2 Wind farm characteristics

5.2.1 Wind turbine capacity

The wind farm size and the turbine capacity are the parameters that determine the overall wind farm capacity. Increasing the turbine capacity can increase the amount of energy produced for a unit of foundation and support structure, and hence can improve the energy production, although this lead to higher support structure and turbine weights.

5.2.2 Wind turbine design and assembly configuration

The specific wind turbine and substructure design determines the lifting requirements for installation and limits on component accelerations during the transport and installation process. The drivetrain design will also have a large impact on the nacelle weight.
The assembly strategy affects the lifting requirements and number of turbines capable of being transported for a given vessel deck-space. The design requirements driving installation vessel design are based on an economic balance including market share and available and anticipated turbine designs. The envelope of the vessel design requirements

may include a number of different turbine designs, but vessels have also been adapted to suit particular wind farm developments if economically justified.

5.2.3 Wind farm layout

The wind farm layout can influence the overall energy production. Optimal positioning of turbines can minimise the wake effects and hence maximise the efficiency of the wind farm. Another important aspect of wind farm is the number of wind turbines deployed in the site. The wind farm size can impact the transportation and maintenance costs and strategies, and hence the LCOE.

5.3 Suggested scenarios

The physical factors which fundamentally drive the design have been used to develop baseline scenarios for the project. These are determined by giving consideration to the state of the art of the offshore wind industry and the expertise of LEANWIND partners in their field.

The final design scenarios in terms of water depth, distance to port, and wind farm size are presented and summarised in Table 6. The proposed scenarios aim to cover the various ranges of parameters as should be investigated by the different LEANWIND work packages.

Table 6: Design Cases

	Site conditions		
Design Cases	Water Depth (m)	Distance to Port (km)	Wind Farm Size (Number of Turbines)
0	20	30	100
1	40	30	250
2a	60	100	250
2b	20	100	250
3	100	30	20

6. WP Framework development

This report fulfils the deliverable for Task 3.1 and outlines the industry challenges from which the rest of the work package will follow.

6.1 Task 3.2

Task 3.2 “Novel installation vessel concept design” is intended to identify a maximum of three installation vessel design concepts with the overall goal of increased economic savings over current installation vessels. Task 3.2 will use the vessels identified in this document in conjunction to industry stakeholder workshops to gain ideas from developers in order to proceed with new design and existing vessel optimization.

The design process which will be undertaken in Task 3.2 is outlined in Figure 51 below:

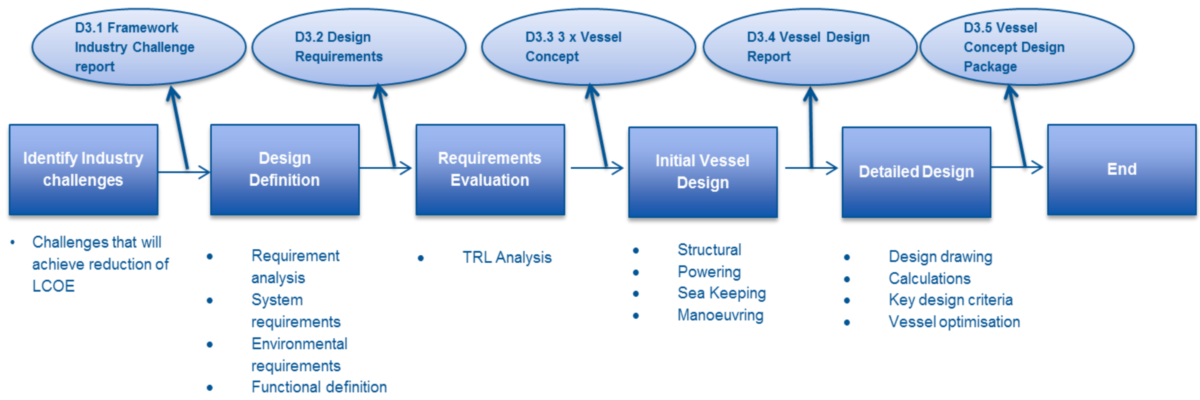


Figure 51: Task 3.2 design process

This process the tasks will follow is:

1. Review of industry challenges report and outline challenges that will achieve reduction of LCOE.

2. Design Definition - The design requirements will be drawn from the challenges identified in this document together with the experience of the industry. The parameters essential for the design of installation vessels will be listed and their relationship with the design requirements will be developed.

3. Requirements Evaluation - Using a scoring system taking weightings of key parameters, such as sea state, lifting capacity and achievable LCOE per vessel, a maximum of three installation vessel concepts will be identified, these may be novel or adaptations of existing vessels.

4. Initial Vessel Design -The identified vessels will enter the initial design phase; including global structural analysis with a limited number of loading conditions and this will confirm the suitability of the key hull structural plans

5. Detailed Vessel Design - The identified vessels will enter the detailed design phase, where evaluation will include powering assessment and supporting seakeeping and manoeuvring calculations will also be undertaken. The vessels key design criteria

will be evaluated and optimized to increase vessel operability i.e. materials, hull forms.

This process will identify areas where cost savings can be made and provide supporting information to WP5 and WP8.

6.2 Task 3.3

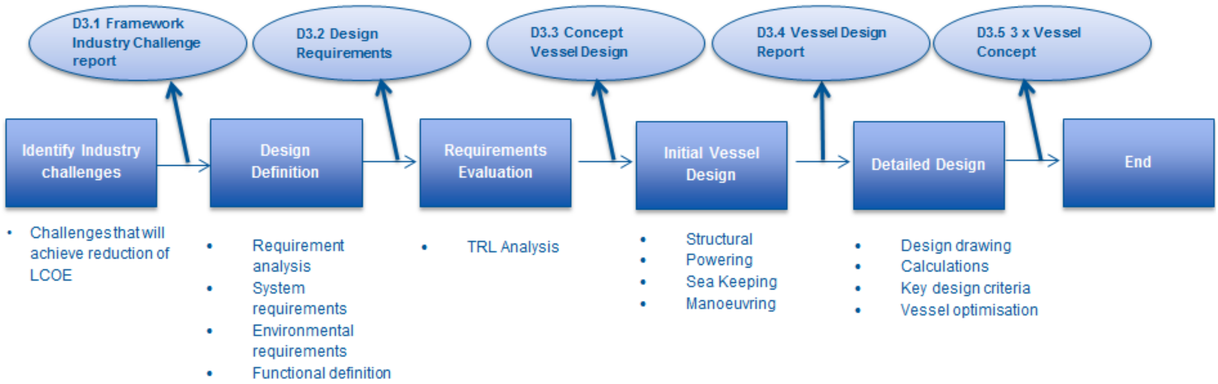


Figure 52: Task 3.3 design process

As in Task 3.2, Task 3.3 “Novel service vessel concept design and access equipment” is intended to identify novel vessel design concepts with the overall goal of increasing economic savings over currently available vessels. This task will develop designs for service vessels and access systems. The task will follow the same process as Task 3.2 as outlined in Figure 51, however the focus will differ from T3.2 in respect of the separate challenges identified in this report for service vessels from installation vessels.

6.3 Task 3.4

This task will identify key requirements with regards the deck layout for current and future installation and maintenance vessels with regards primary lifting equipment and transportation of wind turbines. Installation and maintenance vessel layouts will be optimized for cargo capacity in conjunction with the position of the primary lifting equipment, various wind turbine sizes and weights and other required selection criteria as applicable.

Key requirements for typical crane operations and methodologies will be developed. By using a simplified TRL approach a review will be undertaken on novel wind turbine installation and lifting concepts and which will focus upon the types of technologies and evaluate the potential economic savings over current wind turbine installation and lifting concepts. Further work will be required to identify the key design criteria to be evaluated for lifting operations. These criteria will then be optimized to increase vessel operability in conjunction with assessing the impact this optimization has upon the design and cost of the vessel.

This task requires input from T3.2 and T3.3 and refers back to T3.1 when elaborating the predefined scenario. Also, a strong interaction with WP2, mainly subtask 2.6 (Turbines – deployment and assembly strategy) will be required and compatibility with WP6 will be evaluated.

Further, this task will provide supporting information to WP5 and WP8 on the areas where cost saving can be made and provide improved efficiencies when installing and maintaining wind turbines in an offshore wind farm taking into account improved installation and construction methodologies.

6.4 Task 3.5

Task 3.5 "Concept design tools and validation" is intended to identify and develop a number of tools, testing protocols, procedures and processes which can be used to assess the design of installation and maintenance vessel covering a number of key areas. The tools provide key input information for the logistics and economics models such that the impacts of the innovations (like e.g. faster transit times, higher storage capacity, lower fuel consumption, extended weather windows etc.) can be determined.

The novel conceptual designs for installation vessels, O&M vessels and access systems developed in Task 3.2 and Task 3.3 will constitute the baseline for the Task 3.5 in which three candidate vessel designs will be evaluated with respect to performance and gains achieved through adopting the new designs.

The tools and test procedures developed in Task 3.5 will be applied in Task 6.4 "Training of installation and service operations by simulators" and in Task 7.2 "Simulation Activities" in which the design concepts and procedures developed in LEANWIND will be demonstrated to IAG and selected stakeholders in a show case event.

And finally – as indicated above – Task 3.5 will provide key input information to the WP8 economic models.

7. Conclusion

Electricity generated from offshore wind remains at an uneconomic level in comparison with that from conventional fuel sources in most parts of the world. Significantly increased costs have been incurred by the wind industry in the move from onshore development, with the associated ease of access and installation, to offshore sites. Now these are being further increased by the progression from inshore into deeper waters in search of greater resource and by the pressures of coastal development. This is driving a need for cost reduction.

Due to the relatively early state of the sector, there remain significant cost savings to be made through learning and technological innovation. “LEANWIND” (Logistic Efficiencies and Naval architecture for Wind Installations with Novel Developments) is an EU project under funded FP7 which aims to provide cost reductions across the offshore wind farm lifecycle and supply chain. The Lean aspect of the project aims to characterise the processes involved in the industry, identify value creating steps and reduce waste, thereby maximising value to the client. Technological improvements will be used to reduce the waste in the process.

One significant area of cost is in the installation and commissioning phase. The industry has predominantly been reliant on jack-up vessels (or liftboats) for installation and large maintenance actions, such as gearbox replacement. These barges and vessels have been increasingly adapted to become specific for the market and are now seeing investment by wind farm developers and wind turbine OEM. However, the number of capable jack-up installation vessels required for the hundreds of 5-6MW turbines in the next generation of offshore wind farm developments is estimated to outstrip supply by 2020. Also substructure design is moving away from monopiles to jacket, gravity base structures and floating turbines and so alternative installation strategies may be required in these cases.

Installation has been identified as an area that would benefit from technological innovation where potential cost reductions are closely linked to

- reduction of the time needed for the various installation operations
- extension of the weather windows in which the operations are feasible

The cost reductions could be achieved by

- Decreasing use of offshore lifts requiring Increase amount of onshore pre-assembly or increased loading capability for components being lifted to increase number of available weather windows
- Decrease operating constraints due to meteorological conditions
    - Improved vessel design for less restrictive weather limitations
        - Increased maximum jacking sea state
        - Increased max crane operating wind speed
    - Improved weather prediction
        - Improved weather monitoring and decision support system
- Decreased transit time
    - Increased number of turbine loaded per trip
        - Increased deck payload
        - Increased useable deck area
    - Increased transit speed
- Decreased offshore operation duration

    - Increased jacking speed
    - Decreased leg-preload duration (by using 4- or 6-legs vessels)
- The use of component feeder vessels
- The use floating installation vessels

O&M activity accounts for approximately one quarter of the life-time cost of an offshore wind farm. As part of this, service vessels are required to transfer wind turbine maintenance crew to perform duties on the turbines with significant regularity. Delays in carrying out unplanned maintenance incurs lost revenue and access in sea states higher than the current typical limit of 1.5m significant wave height and 12m/s wind speed is considered necessary to reduce costs in the industry. Vessels and access systems capable of transferring personnel in 3m significant wave height are desired.

The transfer of technicians from vessel to turbine is easier and safer when there is little vessel motion when station keeping. Technological innovations in the transfer of personnel from vessel to turbine have sought to improve accessibility. The bump and jump method, based upon a bow fender design creating a high friction force between bow and boat landing, remains the preferred access method but is limited to a 1.5m Hs. Active and passive crew transfer access systems have been developed to compensate for motion in more severe sea states but have yet to become commonly implemented.

Service vessel designs may also have recently been limited by the regulations resulting from SOLAS and the International Load Line Convention definition of a “Passenger"; vessels carrying more than 12 passengers must be in possession of a Passenger Ship Safety Certificate which incurs additional safety equipment and operational activities such as safety drills. Vessels with a load line length below 24m and fewer than 12 passengers are able to avoid the more stringent regulations under the Load Line Convention and most of SOLAS, therefore incurring less cost in the fit-out and operation of the vessel. The IMO has established a working group to discuss a new category of person: that of Industrial personnel, which will be required to hold appropriate qualifications.

The main challenges for service vessels remain:

- Reducing motion to increase accessibility in larger sea states
- Increasing fuel efficiency
- Reducing sea sickness and its detrimental effect on maintenance crew operational efficiency
- Establishing optimum vessel size and hull form type for varying distances from shore

The challenges for both installation and service vessels will form the basis for the remaining activities in the work package 3. These will be addressed through vessel and equipment design, analysis, simulation and physical test. For example, the need to increase the maximum sea state for the jack-up of installation vessels or increase the deck payload will require structural consideration.

This report has highlighted the challenges in the industry regarding installation and maintenance which will form the basis for the remaining activities in work package 3. Solutions to tackle the most critical of these challenges will be sought through vessel and equipment design, analysis, simulation and physical test. The next stage of this project will refine the design requirements, such as maximum metocean conditions for operations, which will be used to create the designs. These will be considered in light of economic and technical factors and the lean principles on which the project is based. Design stages will follow and activities will include

- Global structural analysis for a number of loading conditions to verify the structural integrity of the vessel hulls
- Performance assessment of DP systems in terms of the increased functionality of vessels in being able to maintain station when undertaking installation and maintenance tasks
- Vessel motion will be assessed via sea-keeping and manoeuvring calculations; essential in the assessment of comfort and wind turbine access on service vessels

Marine operations and equipment functionality also require consideration to verify the design. This workpackage will also therefore consider the modelling of

- Seabed/spudcan interaction
- Motions minimization/compensation equipment
- Floating offload/loadout
- Jacking equipment
- Advanced personal transfer equipment

Vessels perform a transportation function for the industry and can be optimised appropriately but the industry must be capable of sustaining their use to justify investment in their bespoke design. Identifying cost reduction through reduced operational time also requires a collaborative approach on farm design and operation: the cheapest foundation to design and construct may not be the cheapest to install due to sensitivity to precision in the installation, the weight or volume of the structure. This is accommodated in this project through the consideration of foundation design in WP2, O&M procedures in WP4 and the economic and market assessment in WP8, all of which this work package feeds in to.

8. References

[1] Crown Estate, "Offshore Wind Cost Reduction Pathways," 2012.

[2] Navigan Consulting, Inc., "Global Offshore Wind Shipping Opportunity," Danish Shipowners' Association, London, 2010.

[3] T. Ohno, Toyota Production System: Beyond Large-Scale Production, Productivity Press, 1998.

[4] Strategos Inc, "Toyota Production System (TPS) & Lean," September 2007. [Online]. Available: http://www.strategosinc.com/toyota_production.htm. [Accessed 17 March 2014].

[5] EWEA, "The European offshore wind industry - key trends and statistics 2013," EWEA, 2014.

[6] EWEA, "The European offshore wind industry key trends and statistics 2010," EWEA, 2011.

[7] RenewableUK, "Offshore wind Project Timelines," www.RenewableUK.com, 2013.

[8] European Environment Agency, "Europe's onshore and offshore wind energy potential," Copenhagen, 2009.

[9] M. J. Kaiser and B. Snyder, "Offshore Wind Energy Installation and Decommissioning Cost Estimation in the U.S. Outer Continental Shelf," BOEMRE, Louisiana, 2010.

[10] I. Lazakis, *Vessel charter rate estimation for offshore wind O&M activities*, Istanbul: Paper presented at 13th International Congress of the International Maritime Association of the Mediterranean (IMAM 2009), 2009.

[11] Briggsmarine, "Briggs," 2014. [Online]. Available: Briggsmarine.com. [Accessed 24 March 2014].

[12] I. R. d. T. Alonso, "Gravity Base Foundations for Ofshore Wind Farms - Marine Operations and Installation Process," 2013.

[13] Riviera, "Marine Propulsion & auxilary machinery," 2010. [Online]. Available: http://www.rivieramm.com/article/voith-propulsion-for-egyptian-tugs-7183. [Accessed 24 March 2014].

[14] H.-S. MARINE, "Well-in type Azimuth Thruster," [Online]. Available: http://www.hiseamarine.com/well-in-type-azimuth-thruster-1918.html. [Accessed 24 March 2014].

[15] A. Wassink, “NEXT GENERATION CRANE VESSEL,” 2013. [Online]. Available: http://www.gustomsc.com/index.php/zoo/brochures/doc_download/154-next-generation-crane-vessel. [Accessed 28 March 2014].

[16] Scottish Enterprise and The Crown Estate, “GL Garrad Hassan, 2013 'A Guide to UK Offshore Wind Operations and Maintenance',” Scottish Enterprise and The Crown Estate, 2013.

[17] C. Gundegjerde and I. B. Halvorsen, “Vessel fleet size and mix for maintenance: A stochastic approach,” Trondheim, 2012.

[18] 4C Offshore, “Wind Farm Service Vessels - An Overview,” 2014. [Online]. Available: http://www.4coffshore.com/windfarms/wind-farm-service-vessels-an-overview-aid246.html. [Accessed February 2014].

[19] OSBIT Power Ltd, “MaXccess T12 T18,” Northumberland, 2014.

[20] Momac, “MOTS 500,” [Online]. Available: http://www.offshore-access-system.com/MOTS-500-momac-Offshore-Acccess-System-for-crew-vessel-boat-landing.html. [Accessed 17 02 2014].

[21] MOBIMAR, “Mobimar 18 Wind,” Turku, Finland.

[22] International Maritime Organisation, “DE 57/12 SUB-COMMITTEE ON SHIP DESIGN AND EQUIPMENT, 57th session, Agenda item 12,” 2012.

[23] News, World Maritime, “SEA INSTALLER Completes Installation of Two Siemens Turbines at Gunfleet Sands (UK),” 2013. [Online]. Available: http://worldmaritimenews.com/archives/74647/sea-installer-completes-installation-of-two-siemens-turbines-at-gunfleet-sands-uk/. [Accessed 24 March 2014].

[24] Van Oord Marine Ingenuity, “Home,” 2014. [Online]. Available: http://www.vanoord.com/contact. [Accessed 27 March 2014].

[25] 4C Offshore, “Aeolus,” 2014. [Online]. Available: http://www.4coffshore.com/windfarms/vessel-aeolus-vid225.html. [Accessed 24 March 2014].

[26] Leenaars BV: Marine & Offshore Design, “SWIV,” 2011. [Online]. Available: http://www.leenaars-bv.nl/index.php/swiv.html. [Accessed 24 March 2014].

[27] Huisman, “Wind Turbine Shuttle,” 2011. [Online]. Available: http://www.huismanequipment.com/en/products/new_concepts/wind_turbine_shuttle. [Accessed 24 March 2014].

[28] Maritime Executive, "Ulstein Establishing New Company," 2011. [Online]. Available: http://www.maritime-executive.com/article/ulstein-establishing-new-company/. [Accessed 24 March 2014].

[29] Yellow & Finch Publishers, "Vuyk Engineering Rotterdam B.V," 2013. [Online]. Available: http://www.ynfpublishers.com/2009/10/vuyk-engineering-rotterdam-bv. [Accessed 24 March 2014].

[30] NorWind Installer, 29 November 2011. [Online]. Available: http://www.arenanow.no/download.php?file=NWI_EWEA_Amsterdam.pdf. [Accessed 24 March 2014].

[31] IHC, "Offshore Wind Turbine Installation Ship," 2014. [Online]. Available: http://www.ihcmerwede.com/home/.

[32] Gaoh Offshore - Offshore wind energy services, "Home," 2014. [Online]. Available: http://www.gaoh-offshore.com/. [Accessed 27 March 2014].

[33] B. Liggett, "The WindFlip Barge Concept Installs Offshore Wind Turbines Inexpensively and With Ease," 2011. [Online]. Available: http://inhabitat.com/the-windflip-barge-concept-installs-offshore-wind-turbines-inexpensively-and-with-ease/. [Accessed 28 March 2014].

[34] I. Alonso, "Strabag solution for transportation wind turbines Strabag solution for transportation wind turbines," University of Applied Sciences Giessen-Friedberg, Giessen, 2013.

[35] GBF - Gravity Base Foundations, "Home," 2014. [Online]. Available: http://gbf.eu.com/. [Accessed 28 March 2014].

[36] Carbon Trust Offshore Wind Accelerator, "New systems to access offshore wind turbines," 2012. [Online]. Available: http://www.norcowe.no/doc//konferanser/2012/NORCOWE%20Days%20sept%2019/S2%20de Villiers%20NORCOWE%20-%20Carbon%20Trust%20OWA%20Access%20systems%20v0.3-17Sep12-PdV.pdf. [Accessed 26 March 2014].

[37] Carbon Trust, *O&M strategies,* Carbon Trust.

[38] Carbon Trust, "OWA Access Competition," [Online]. Available: http://www.carbontrust.com/media/105306/owa-access-innovators.pdf. [Accessed 2 3 2014].

[39] Carbon Trust, “Offshore Wind Accelerator Access Competition - shortlisted,” [Online]. Available: http://www.carbontrust.com/media/105306/owa-access-innovators.pdf. [Accessed February 2014].

[40] Fjellstrand, “Windserver,” 2014. [Online]. Available: www.fjellstrand.no.

[41] World Marine Offshore, “WINDSERVER 25 datasheet,” [Online]. Available: http://www.wm-offshore.com/files/4413/8078/5826/Short_spec_WS25.pdf. [Accessed February 2014].

[42] A. Czyzewski, “The Engineer,” 2011. [Online]. Available: http://www.theengineer.co.uk/in-depth/analysis/ride-the-wave-vessels-for-wind-turbine-maintenance/1011039.article. [Accessed 25 March 2014].

[43] Nauti-craft, 2014. [Online]. Available: www.nauti-craft.com. [Accessed 25 March 2014].

[44] North Sea Logistics, “Pivoting Deck Vessel,” 2014. [Online]. Available: www.northsealogistics.co.uk.

[45] NorthSea Logistics, “NorthSea Logistics,” 2014. [Online]. Available: http://www.northsealogistics.co.uk/. [Accessed 25 March 2014].

[46] W. Moy, “My UM Job: What do I do?,” 2011. [Online]. Available: http://www.winstonmoy.com/2011/12/my-um-job-what-do-i-do. [Accessed 25 March 2014].

[47] Umoe Mandal, “Umoe Mandal,” 2014. [Online]. Available: www.um.no. [Accessed 27 March 2014].

[48] World Maritime News, “BMT Nigel Gee to Present XSS Cymyran Bay at Seawork (UK),” 2013. [Online]. Available: http://worldmaritimenews.com/archives/86721/bmt-nigel-gee-to-present-xss-cymyran-bay-at-seawork-uk/. [Accessed 25 March 2014].

[49] BMT Nigel Gee, UK, “XSS - A next generation windfarm support vessel,” London, 2014.

[50] Damen, “Damen sets the pace with Walk-to-Work vessel,” 2011. [Online]. Available: http://www.damen.com/en/news/2013/11/damen-sets-the-pace-with-walk-to-work-vessel. [Accessed 25 March 2014].

[51] DAMEN, “Damen sets the pace with Walk-to-Work vessel,” 2013. [Online]. Available: http://www.damen.com/en/news/2013/11/damen-sets-the-pace-with-walk-to-work-vessel. [Accessed 4 March 2014].

[52] Autobrow, “Autobrow,” 2014. [Online]. Available: http://www.autobrow.com/.

[53] KNUD E HANSEN A/S, "Wind-Bridge," [Online]. Available: http://www.knudehansen.com/.

[54] reNews, "DanTysk high seas home," 2014. [Online]. Available: http://renews.biz/62277/dantysk-high-seas-home/. [Accessed 25 March 2014].

[55] C-bed Floating Hotels, "c-bed," 2013. [Online]. Available: www.c-bed.nl. [Accessed 25 March 2014].

[56] gCaptain, "Offshore Wind-Farm Maintenance Vessel (WMV) concept cuts costs and carbon," 2011. [Online]. Available: http://gcaptain.com/offshore-wind-farm-maintenance/. [Accessed 25 March 2014].

[57] SeaEnergy, "SeaEnergy construction wind farm support," 2014. [Online]. Available: http://www.seaenergy-plc.com/services/downloads/ULSTEIN%20general%20SeaEnergy%20inputs.pdf.

[58] Startnotitie Milieueffectenrapportage, "Haveneilandopzee," 18 September 2009. [Online]. Available: http://www.haveneilandopzee.nl/docs/StartnotitieIJmuiden.pdf. [Accessed 25 March 2014].

[59] BVG Associates, "Offshore Wind: A 2013 supply chain health check- A report prepared by BVG for The Crown Estate," Nov. 2013.

[60] VSL Communicating Safety, "The International Crane Operations & Cargo Handling Pocketbook," 2002. [Online]. Available: http://www.nsl-america.com/downloads/handbooks/Cranes%20and%20Cargo%20Book.pdf. [Accessed 27 March 2014].

[61] J. Olsen, "Challenges with cranes on ships and floating installations," 4 December 2012. [Online]. Available: http://www.ktf.no/fileadmin/Dokumenter/Kursdokumenter/2012/2-Subsea-Lifting-Operations/6_-_NOV-Presentation_for_Subsea_Conference_STV_Dec_12_-_Challenges_with_Cranes_on_Ships_and_Floating_Installations.pdf. [Accessed 28 March 2014].

9. Appendices

9.1 Wind Turbine Design Parameters

Table 7 Wind Turbine Design Parameters

Manufacturer	Model	Blade Length (m)	Blade weight (metric tonnes)	Rotor Diameter (m)	Rotor weight (hub+blades) (metric tonnes)	Nacelle Weight (metric tonnes)	Tower height (m)	Tower weight (metric tonnes)
Alstom	*Haliade 150 - 6MW*	*73.5m*	33	*150m*	*105*	*244-400*	*100*	
Siemens	SWT3.6-107	52m	16	107m	95	125	80	180t
Siemens	SWT3.6-120	52m	18	120	100	125	90	180-200
Siemens	*SWT4.0-130*	*63*		*130*	*100*	*140*		
Siemens	SWT6.0-120	58	18	120	-	190-360		180
Siemens	*SWT6.0-120*	*75m*	?	*154m*	-	200-360		
Vestas	V90-3.0 MW	44m	7 6.6	90m	41	70	80 -105	108,160,285
Vestas	V90-3.0 MW						70m	108 tonne

Wind Turbine Design Parameters cont.

Manufacturer	Model	Blade Length (m)	Blade weight (metric tonnes)	Rotor Diameter (m)	Rotor weight (hub+blades) (metric tonnes)	Nacelle Weight (metric tonnes)	Tower height (m)	Tower weight (metric tonnes)
Vestas	V112-3.0 MW	54.65	11.9	112		120	84-119	
Vestas	V112-3.3 MW	54.65	11.9	112		-		
Vestas	*V164-8.0 MW*	80	35	*164*		390		
Senvion (REpower)	5M	61.5m	19.5	126	130	325	85 - 95	210-225
Senvion (REpower)	6M-126	61.5	23	126	135	325		
Senvion (REpower)	*6M-152*	*74.4*		*152*		350		
BARD	5	*60*	28.5	122	156	280	90 63	450
Areva	M5000-116	56	16.5	116	112	233	90	350
Areva	*M5000-135*	66	23.5	*135*		235		
Samsung	*S7.0-171*	83.5	-	*171.2*				
Mitsubishi	*Sea Angel 7MW*	*81.6*	-	*167*				
Gamesa	*G128-5MW*	*62.5*	?	*128*			*80-94*	

9.2 Regulatory and Statutory Guidance

As a guide for statutory regulations, below is a summary of the vessels and the most likely Codes and Regulations applicable by vessel type:

	ILLC	Tonnage	SOLAS	MODU Code	MARPOL	SPS Code	HSC Code
Self Elevating	Yes*	Yes*	Yes*	Flag Dependent	Yes	Flag Dependent	No
Column Stabilized	Yes*	Yes*	Yes*	Flag Dependent	Yes	Flag Dependent	No
Heavy Lift Vessels	Yes*	Yes*	Yes*	No	Yes	Flag Dependent	No
Platform Supply Vessel	Yes*	Yes*	No if < 500 GT	No	Yes	Flag Dependent	No - In most situations
Towing Tugs	Yes*	Yes*	No if < 500 GT	No	Yes	Flag Dependent	No
Barge and Tug	Yes*	Yes*	Only applicable to the TUG not the BARGE	No	Yes	Flag Dependent	No
Crew boats	No if <24m	No if <24m	No if < 500 GT	No	Yes	Flag Dependent	Yes (see note 1)
Multicats	No if <24m	No if <24m	No if < 500 GT	No	Yes	Flag Dependent	Yes (see note 1)
Dredger	No if <24m	No if <24m	No if < 500 GT	No	Yes	Flag Dependent	Yes (see note 1)
Tugs	No if <24m	No if <24m	No if < 500 GT	No	Yes	Flag Dependent	Yes (see note 1)
Dive Support Vessel	No if <24m	No if <24m	No if < 500 GT	No	Yes	Flag Dependent	Yes (see note 1)

Note 1: providing:
a) > 500 tonnes, cargo craft no more than 8 hrs. @ 90% max speed from place of refuge when fully laden
b) passenger vessel no more than 4 hours from place of refuge

*In almost all situations, however this may be replaced by the MODU code at the flags discretion.

As an example of applicable rules, Lloyds Register would use the following rule set for the generic vessels outlined above:

	Rules and Regulation for the Classification of Ships	Rules and Regulations for the Classification of Special Service Craft	Code for Lifting Appliance in the Marine Environment	Rules and Regulations for the Classification of Mobile Offshore Units (soon to be termed Offshore Units July 2014)
Liftboat	No	No	Yes	Yes
Column Stabilized	No	No	Yes if fitted with Lifting Appliance	Yes
Heavy Lift Vessels	Yes	No	Yes if fitted with Lifting Appliance	No
Platform Supply Vessel	Yes	No	Yes if fitted with Lifting Appliance	No
Towing Tugs	Yes	No	Yes if fitted with Lifting Appliance	No
Barge and Tug	Yes	No	No	No
Crew boats	No	Yes	Yes if fitted with Lifting Appliance	No
Multicats	No	Yes	Yes if fitted with Lifting Appliance	No
Dredger	No	Yes	Yes if fitted with Lifting Appliance	No
Tugs	Yes	No	No	No
Dive Support Vessel	No	Yes	Yes	No