Norsk Industri

LEVERANSEMODELLER FOR HAVVIND

Delrapport – Marine operasjoner

Cover photo: Ulstein

Innhold

Abbreviations used

Norsk begrep	Engelsk begrep
OW	Offshore Wind
OWF	Offshore Wind Farm
BFOW	Bottom Fixed Offshore Wind
FOW	Floating Offshore Wind
GW	Gigawatt
WTG	Wind Turbine Generator (tower, nacelle and blade for bottom-fixed foundation
FWT	Floating Wind Turbine (complete assembly of turbine and foundation)
LCC	Life Cycle Cost
BoP	Balance of Plant
TP	Transition Piece
OMS	Operation Maintenance and Service
MP	Monopile
AHTS	Anchor Handling Tug Support vessel
CLV	Cable Lay Vessel
OCV	Offshore Construction Vessel
WTIV	Wind Turbine Installation Vessel
FIV	Foundation Installation Vessel
HLV	Heavy Lift Vessel
SOV	Service Operation Vessel
CTV	Crew Transfer Vessel
ROV	Remote Operating Vessel
AUV	Autonomous Underwater Vehicle
PSV	Platform Supply Vessel
MPV	Multipurpose Vessel
I&R	Inspection and Repair
DP	Dynamic Positioning
NDT	Non Destructive Testing
HVDC	High Voltage Direct Current
HVAC	High Voltage Alternating Current
POB	Persons on Board (accommodation) capacity

1 Summary

The marine operations required in the lifetime of a fixed or floating offshore wind farm, are described in this report. Criteria for the vessels to perform the operations are detailed. On this basis the Norwegian fleet has been examined with respect to capabilities and capacities for offshore wind.

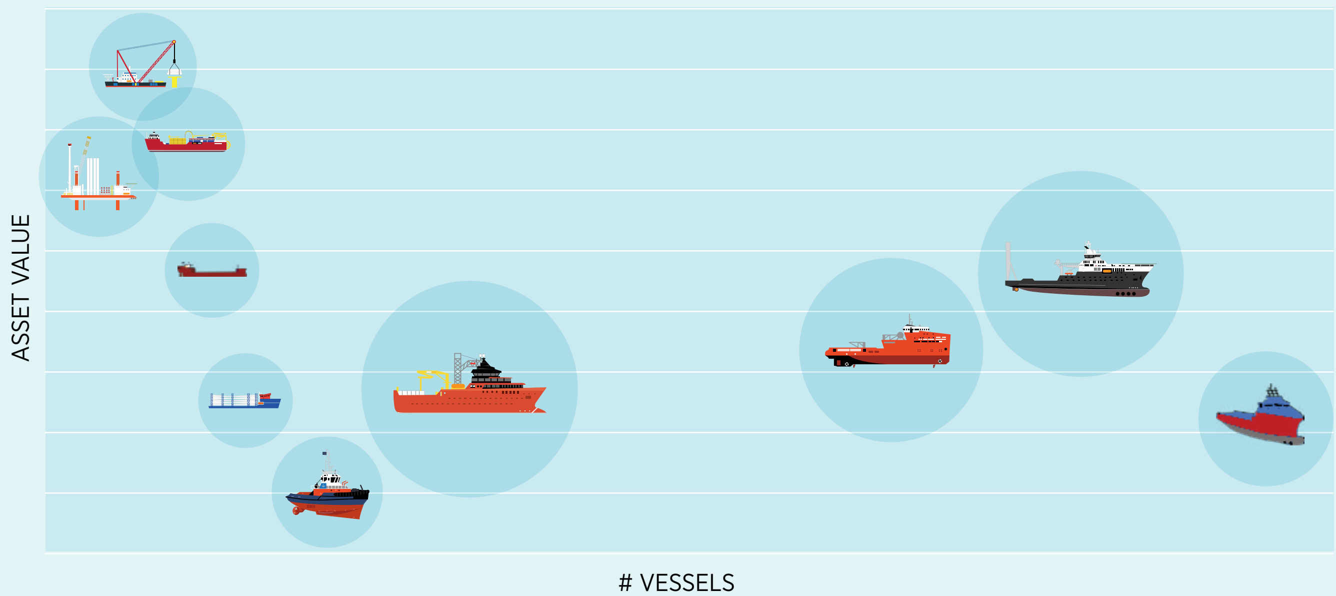
Further, the durations of the operations have been estimated, and the total value of the operation established by applying the market day-rate for the applicable ship type. The estimates are qualitative and may serve to give an understanding of magnitude. Considering the immature state of the floating sector (lack of best practices for the construction, installation and maintenance) and the continuing cost reduction for bottom fixed wind farms, this estimate is a snapshot of the current situation.

It is estimated that the marine operations in offshore wind represent 15–20 % and 10–15 % of the total life cycle cost for the bottom fixed and floating offshore wind sectors respectively. The difference is attributed primarily to the fundamental change in installation methods. Bottom fixed turbines are installed in sequence at sea (at the farm site), while floating foundations and turbines are assembled at shore, and towed to site where it is installed (hooked-up to moorings). Activities performed at sea will always be challenging to plan and perform due to weather sensitivity and shore-based operations have a higher potential for process optimalisation.

In the bottom fixed offshore wind the most cost driving segments are cable lay, installation and operation, maintenance and service. These are segments with good Norwegian presence and hence the segments offering the best opportunities for Norwegian vessel owners.

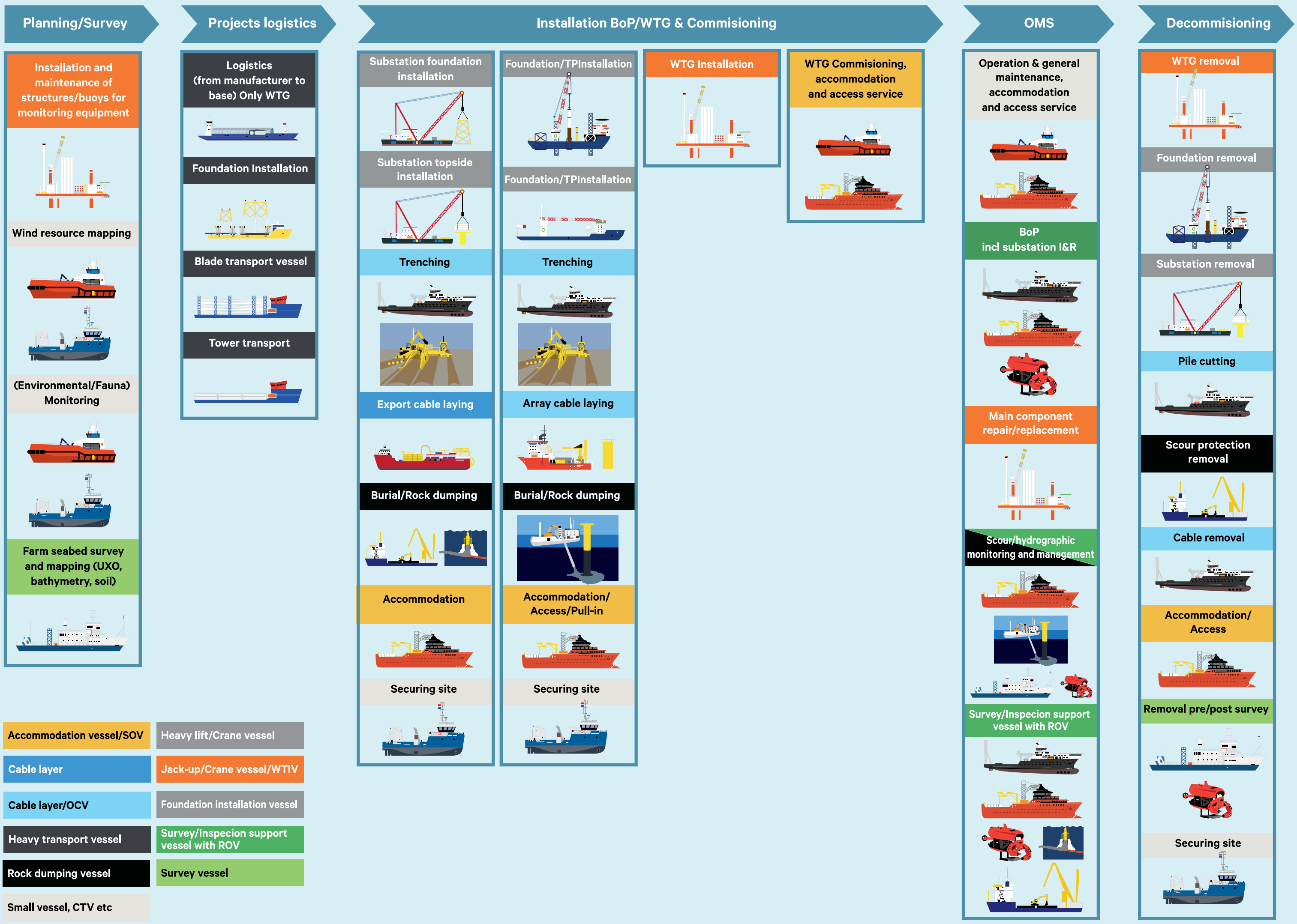
In the floating offshore wind, the corresponding segments are cable lay, operation maintenance & service.

The diagram below illustrates the vessel segments for which the Norwegian shipping cluster have the best opportunities (circles indicating size of opportunity), derived as the product of operation specific fleet size times value opportunity.

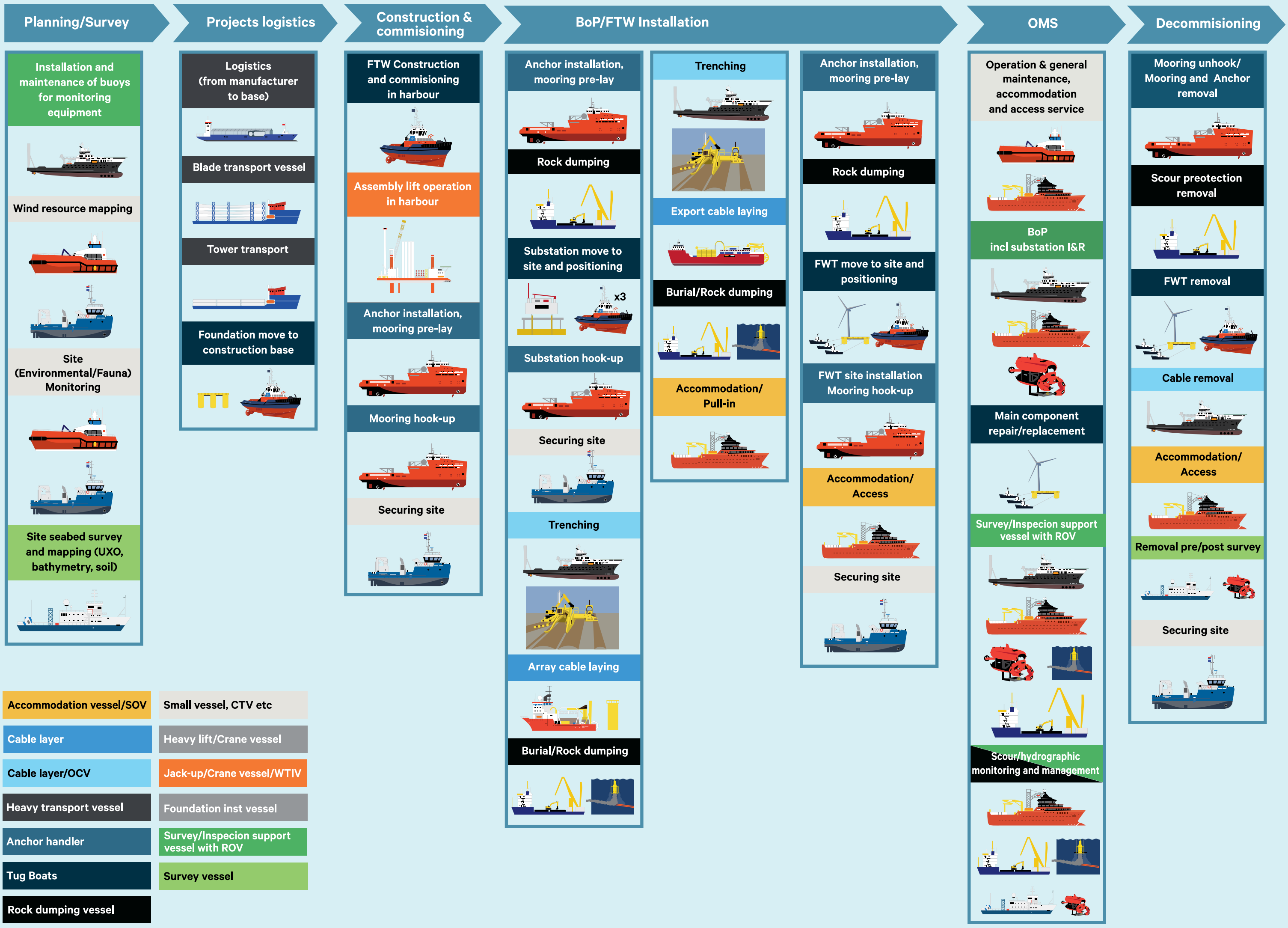


Norwegian fleet in offshore wind (bottom fixed and floating) – circle size illustrates opportunity

Marine operations spread – Fixed installations



Marine operations spread – Floating installations



2 Background and introduction

This is part of the Federation of Norwegian Industries (Norsk Industri) project to assess the value chains within offshore wind to identify the Norwegian opportunities in the industry.

Recent projections indicate a large growth potential initially for the bottom-fixed offshore wind power, and later for the floating offshore wind. The marine operations are represented in the entire value chain, from planning phase to decommissioning. The Norwegian market share in the industry today is small and specialised into particular segments. With the advent of floating offshore wind farm globally and in the North Sea in particular, this share is set to grow on the virtue of competence, experience and assets operating the oil and gas industry.

Photo: CSV Siem

3 Objective

This report makes a brief introduction of the various marine operations involved in the Bottom-Fixed Offshore Wind (BFOW) and the Floating Offshore Wind (FOW) sectors.

Further the report sets out to describe the Norwegian presence in each of the operation segments, from planning to decommissioning, in terms of vessel types and their merits, size of fleet and number of owners/operators engaged. An effort is made to estimate a qualitative level of the significance of each segment in terms of contribution to lifecycle cost per gigawatt (GW) installed. Combined with projections of future growth, this may provide an understanding of the potential value opportunity in OW marine operations.

Photo: Ørsted

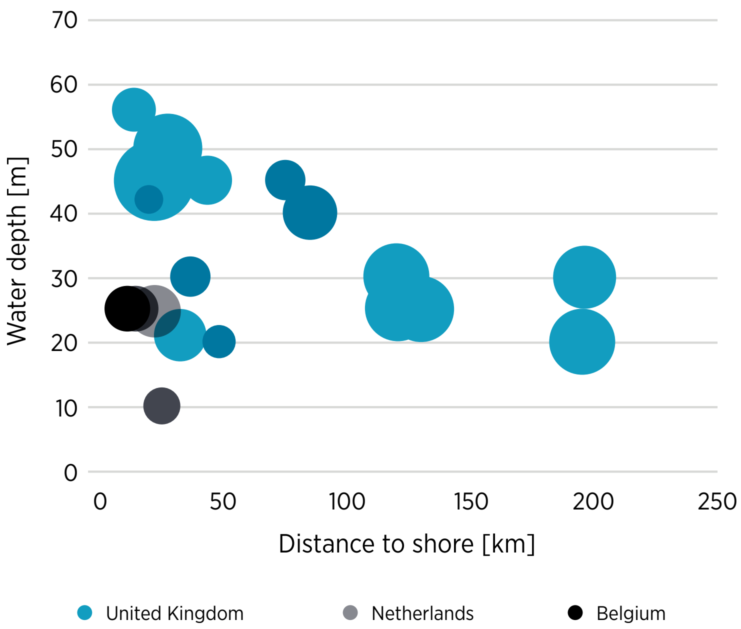
4 Offshore Wind Farm development – typical traits

Future OW farms will consist of larger and possibly more WTG units, installed further from shore and at deeper water depths.

Increased distance and depth will necessarily be true for FOW, but also for many BFOW. Components to balance of plant and turbine will be more complex and costly due to size, length (of cables, mooring systems etc.) and environmental exposure. From the marine operations perspective, transit times will increase and hence weather forecasting/operations planning will be more complex. This will increase the risk for weather waiting. Improvements in weather forecasting increase the efficient use of staff and vessels, and reduces the lost energy production by maximising activity during weather windows. This requires advances in the accuracy and the granularity of forecasts. Currently, accuracy drops significantly for forecasts beyond five days ahead for an area of approximately 100 km^2.[1]

Nevertheless, harsher environment will most likely anyway call for larger and more robust vessels to ensure operability.

As to foundation/turbine installation, however time has been disruptively reduced since the early days of offshore wind, disregarding the influence of weather waiting. Technological and organisational skills have allowed an average reduction in installation time per MW of more than 70 % for OW farms built between 2000–2017. It should be noted that a reduction in installation times has occurred despite the (general) increase in distances to shore, and without correlation with water depth. Neither was the effect of economies of scale, measured based on wind farm size, significant in reducing the installation time.[2]



Source: Thema 2020

1. IRENA, «Innovation Outlook_ Offshore Wind IRENA 2016».
2. R. L. A. e. al, «Offshore wind installation: Analysing the evidence behind improvements in installation time,» 2018.

For other operations such as export cable lay, distance to shore and water depth is a major driver for duration and cost due to cable length and weather operability limitations. While the oil and gas industry have required expensive pipelay equipment for operation in harsh conditions and deep waters, the OW (cable lay) operations have been characterized and governed by limitations from shallow waters, cost and environmental impact. With FOW this may change and synergies to the oil and gas fleet may increase, although cost will always remain in focus.

Survey and towing operations are also likely to require larger vessels for longer missions.

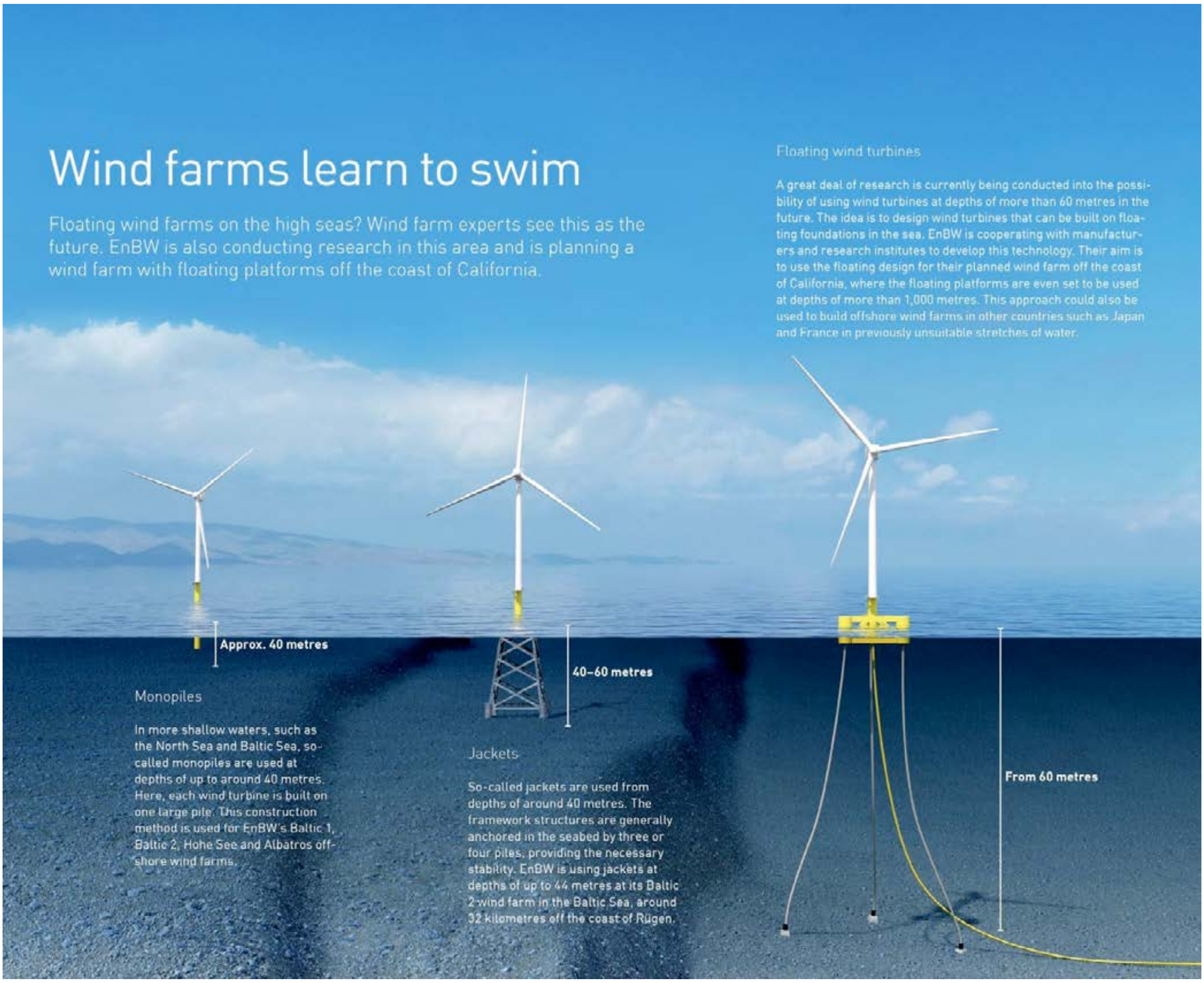


Illustration: EnBW AG

The development goes very fast and marine operators needs to adapt quickly

5 Value chain for marine operations

Marine logistics is a key element in development of an offshore wind farm. Marine operations value chain is key for a successful execution of the project.

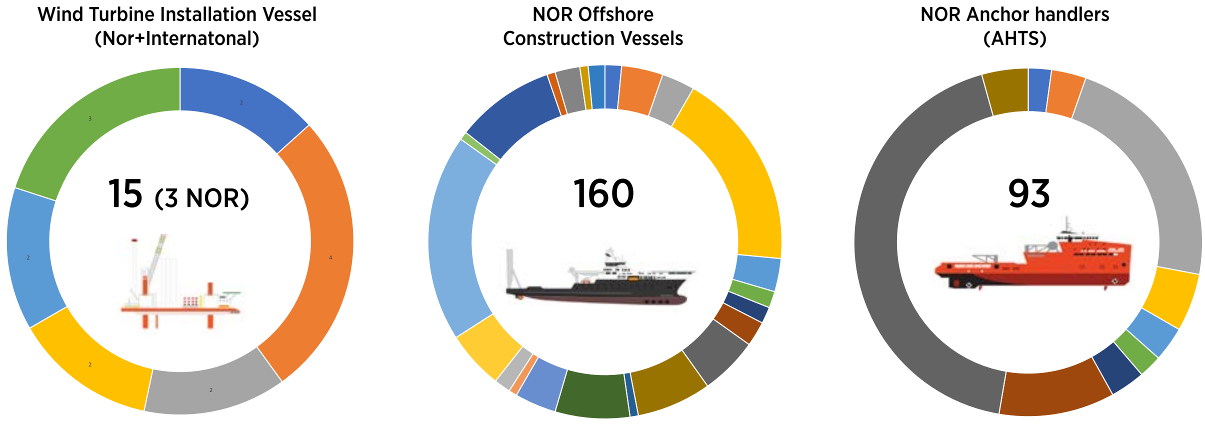
5.1 SHIPPING STRUCTURE AND MECHANISMS IN OFFSHORE WIND

The trade in all shipping and marine operations is flexible and liquid in nature. Opportunities will be pursued in any legitimate business in any part of the world, as found viable in commercial, strategic/tactical and perhaps political terms. Today the OW marine operations mainly connote operations for BFOW but this is about to change.

While some operations/ship types (such as cable layers, survey vessels, service operation vessels) are common and independent of OW installation methodology, BFOW operations are largely dependent upon specialized ship types. Jack-ups and heavy lift (crane) vessels are indeed used in many offshore construction and operation activities and today these are also the backbone of the BFOW transport and installation activities. These use of these vessels reflect the main differentiating factors between OW and Oil and gas: repetitive work at height at many (turbine) locations for foundation and turbine installation vessels versus large subsea/seabed work scope at a single/few location(s) for Oil and gas vessels.

The expected growth in the FOW, however, implies the increased utilization of a more generic fleet such as tugboats, Anchor Handlers (AHTS) and Offshore Construction Vessels (OCV, MPV etc.). More than 200 ships of these types are found in the fleet controlled by Norwegian interests and have so far been heavily engaged in the Oil & Gas industry. In addition, come equally many Platform Supply Vessels (PSV), a generic ship type serving various logistic, support and survey/inspection operations.

The oil and gas fleet is larger in number and the trade in these assets and their operations is more liquid compared to e.g. jack-up and heavy lift vessels. Hence such vessels and their operations are more susceptible to competition between industries and geographical areas.

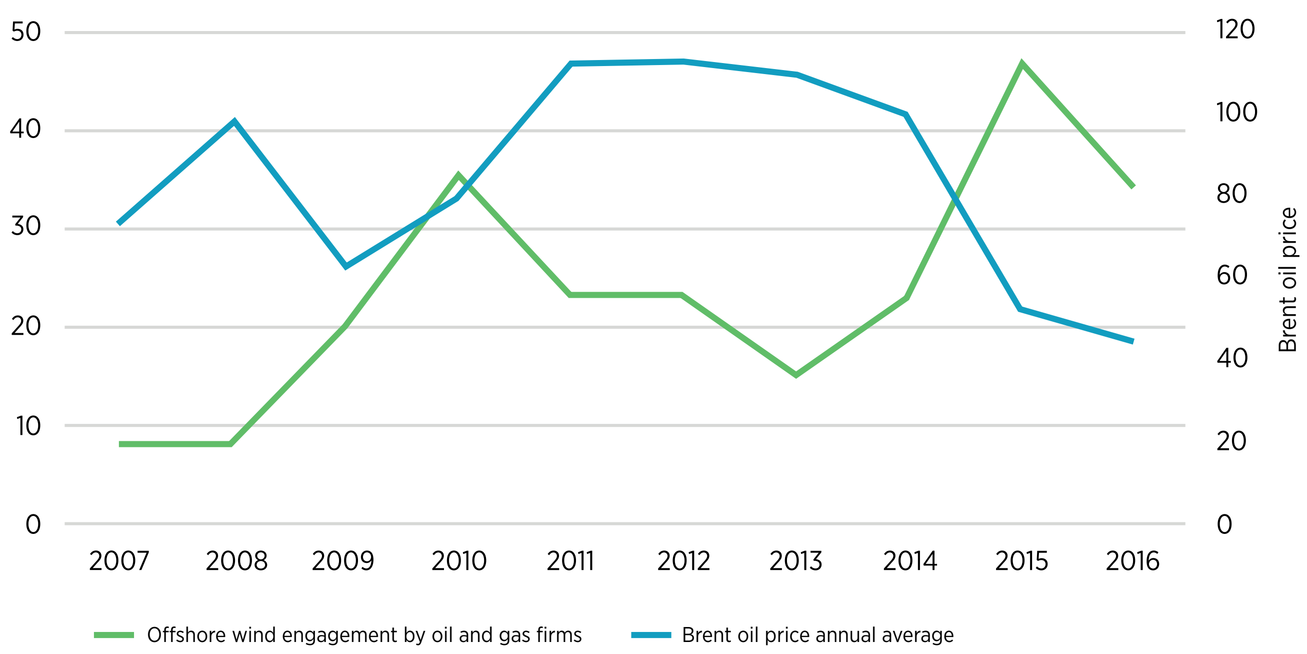


Numbers of vessels. Color scale indicates ownership distribution

Examples of fleet size and ownership distribution – Bottom fixed installation vessels (WTIV) vs Floating installation and operation /Oil and gas vessels

Specific marine operations are generally priced through the usage of a particular ship type at a specified day rate. The day rate will vary with asset value, risk-assignment (responsibilities in operation and risk) and according to supply vs demand, i.e. utilisation level. While the availability of special assets such as heavy lift vessels (HLV/FIV) and wind turbine installation (WTIV) vessels is limited and may represent a bottleneck to the construction of fixed foundation wind farms, these may also be of limited demand at certain periods of time or geographical locations.

On the other side of the spectre, anchor handlers come in abundance (in particular since the 2014 oil price downturn). Given their versatility and usefulness in any towing and anchor handling operation, we may still expect a high utilisation of these vessels should the floating OW industry growth predictions come true[3]. Another aspect of this interchangeability to oil and gas is the threat to availability imposed by any future demand from the Norwegian continental shelf. In general the willingness to pay in the OW is significantly lower than in Oil and gas and the below Figure illustrates how the interest and commitment to OW was higher when the oil price was low – and conversely[4].



Source: Tuukka Mäkitie, Håkon E. Normann, Taran M. Thune, Jakoba Sraml Gonzalez (2019). The green flings: Norwegian oil and gas industry's engagement in offshore wind power. Energy Policy, Volume 127

Jens Hanson, Håkon Endresen Normann, Samson Afewerki, Arild Aspelund, Øyvind Bjørgum, Stuart Dawley, Asbjørn Karlsen, Assiya Kenzhegaliyeva, Adriaan van der Loos, Danny Mackinnon, Markus Steen, Erik-Andreas Sæther (2019). Conditions for growth in the Norwegian offshore wind industry. International market developments, Norwegian firm characteristics and strategies, and policies for industry development. Centre for Sustainable Energy Studies (CENSES)

3. «Will floating wind farms be the saviour of the AHTS market?,» Riviera, Oct 2020.
4. Censes, «Conditions for growth in the Norwegian offshore wind industry,» 2019.

Marine operations – Sheringham Shoal

5.2 MARINE OPERATION SEGMENTS IN BOTTOM-FIXED OW FARMS (BFOW)

1 Planning and survey

Environmental survey

To determine the environmental impacts, a full suite of environmental surveys of the wind farm location and its surroundings is undertaken. These surveys establish the baseline for the assessment and allow impact modelling to be undertaken. The surveys include bird, fish, marine mammal and habitat surveys as well as marine navigation studies, socio-economic surveys, commercial fishing, archaeology, noise analysis, landscape and visual assessment as well, as aviation and military defence training impact assessments. Environmental surveys are typically undertaken by companies from the home market, partly because there is sufficient local resource and partly because some of the wildlife impacts are site specific and require detailed local knowledge and expertise. [5]

Results from environmental survey basis for Environmental Impact Assessement (EIA) in the concent application.

5. O. Catapult, «A guide to,» Crown Estate, April 2019.

Site Investigations

Site surveys are executed to provide information about the subsea terrain, topography, soil properties and provide basis for project risk assessment. Site surveys are geophysical, geotechnical surveys and hydrographic surveys. The survey missions may take a month into account and the vessels engaged must have sufficient fuel, potable water and storage capacity etc. for the period (endurance).

Geophysical survey	Geophysical surveys are performed to establish sea floor bathymetry, sea bed features, water depth and soil stratigraphy, as well as identifying hazardous areas on the sea floor including unexploded ordnance (UXO). All considering the seabed positioning of the foundations and cables. Geophysical surveys are non-intrusive and include remote sensing techniques such as seismic methods, echo sounding and magnetometry.
Geotechnical survey	The scope of the geotechnical survey includes soil sampling through intrusive methods such as borehole and cone penetration tests (CPT). The samples/tests are taken in way of a representative area for the entire balance of plant to determine the soil properties and seabed penetration resistance properties. The samples are investigated in laboratory on board.
Hydrographic surveys	Hydrographic surveys examine the impact of the wind farm development on local sedimentation and coastal processes such as erosion.

Results from site survey will effect layout of the wind farm and effect design of foundations

2 Project logistics

Transport of balance of plant (substations, foundations) and WTG components.

The marine operations covered here as part of the project logistics are limited to the transport of substations, foundations, tower, nacelles and blades.

Substation

The substation foundation (jacket or monopile) and topside of about 1.500 tonnes (for a HVAC installation and five times that for HVDC)[6] are transported from the manufacturer directly to the OWF site by barges or heavy lift vessels for installation by a large heavy lift/crane vessel (ref. Installation below)

Foundations and transition pieces (TP) for BFOW can be transported from the manufacturer directly to site by the Foundation Installation Vessel (FIV), but also by various (large) transport ships to an assembly point where the FIV vessel load on the units and go out to site.

A Foundation Installation Vessel (FIV) vessel can be a heavy lift vessel (floater), a jack-up or a barge with a heavy crane. The

6. «https://connect.ihsmarkit.com/upstream-insight/article/phoenix/2705738/offshore-wind-substation-topsides--issue-1,» [Internett].

choice of vessel will be determined, among other parameters, on the scope of work and sequence for the installation work (ref. Installation below).

WTG components

The typical, specialised vessels transporting towers, nacelles and blades from manufacturer to the marshalling port are heavy transport vessels with long and flat, unobstructed deck for transport of towers in sections and/or blades in racks. The nacelle transport may be on the same vessel, but would preferably carry the load in protected space. A covered Ro-Ro vessel with deck strength and height designed for heavy transport may serve this purpose. The transport from marshalling port to site is performed by the Wind Turbine Installation Vessel (WTIV), as included in the scope of a typical Transport & Installation contract.

3 Cable lay

Cable lay operation is divided into Export cable lay from shore to wind farm/substation and (inter) Array cable lay, between the WTGs.

Cables lay operation follows a seabed preparation campaign. This may include pre-sweeping and pre-trenching to level the seabed and prepare for the cable routing by trenching and seabed rock berm for stable and safe cable/pipeline crossings or lay on bedrock[7].

The cable may be laid and buried in a single process or in two stages: pre-lay and burial. A modern specialised Cable Lay Vessel (CLV) have power, space and equipment capacity for a simultaneous lay and burial operation. Trenching/burial is performed either with a plough, by jetting or cutting. Method and vessel or remotely operated vehicle (ROV) will depend on water depth, soil and proximity to structure.

Cable lay vessels may be specialised Cable Lay Vessels (CLV) or Offshore Construction Vessels (OCV) with sufficient deck space for one or two carousels. Shall the vessel perform a more comprehensive part of the scope (e.g. trenching and burial in addition to laying) it also must have sufficient pulling capacity (bollard pull), be equipped with large deck crane, an A-frame to handle the plough and a ROV with associated launching and control/maintenance equipment. Installation over long distances/many cables will require additional carousels/cargo carrying

Bildetekst. Photo: Equinor/Jan Arne Wold

7. Facts about sea bed intervention, IADC.

capacity and bundled lay (simultaneous lay of different cables) will require split carousels. For work in deep waters, the vessel must be prepared to accommodate a vertical lay tower to enable sufficient hold-back tension capabilities and avoid excessively small cable bending radius. Cable jointing and equipment repair work require covered workshop facilities.

The different laying strategies and hence vessel spread will depend on OWF size, geology (soil and bathymetry) and weather conditions. Cable lay is a particularly wave sensitive operation, while trenching and burial may be performed in higher sea states. Hence leaving such operations to separate and expectedly less expensive vessels may prove beneficial for progress and cost.

Although it is possible to use a cable barge for the purpose, export cables are most likely to be installed by self-propelled vessels with dynamic positioning. They have shallow drafts so they can operate in shallow water for the near-shore installation. Until now export cables are typically installed in a single length but with increasing distance to shore there will be need for jointing capabilities/facilities on board and multiple cable carousels. Specialised vessels use large carousels with capacities of up to 10 000 tons[8]. With such requirements to capacities and associated endurance cable laying vessels become more specialized. The large cable manufacturers have their own vessels and their recent vessel contracting (e.g. by Prysmian, NKT and Nexans) underscores the trend of increased specialisation and complexity. Cable laying ships also work in the oil and gas and telecommunications markets. A key feature for OW export cable vessels has been their ability to operate in shallow waters to support the pull-in to the beach landing or conversely, pull-in from land-fall. The vessel then is positioned close to shore and onshore equipment pull-in the cable from the vessel or the vessel pulls the cable from land fall. The shallow water access is not particularly critical for Norwegian conditions.

The array cables may be carried as long lengths and cut to size at each location or pre-cut onshore. At each location the cable is laid before being pulled into the base of the turbine tower through the "J-tube" mounted on the foundation. Vessels with dynamic positioning are used for rapid installation, to minimise the risk of cable damage and to support the pull-in of the cable. Each cable takes about 24 hours to be laid, buried and pulled-in to the tower base. [1]. The pull-in operation is performed from the WTG and may be supported by a SOV for safe and convenient access and transfer of personnel, tools and material.

The CLV mobilisation period is governed by the time needed for the loading of the cable, depending on cable length and type. The demobilisation is governed by the offloading and sale of any residual cable.

4 Installation

Substation

Substation foundation and topside are installed by very large crane barge/vessels, often supported by a barge due to limited deck space and carrying capacity on the crane vessel. The lift operation is sensitive to weather and sea state, but since this is a "one-off" installation the time period planned is usually for good weather seasons.

One option for substation installation is a self-installing platform, a design employed by ABB and Alstom. The platform was placed on a pre-installed jacket and brought out to the installation site The buoyant and self-erecting platform design waived the need for crane ships for the transport and installation of the substation[9]. There are also future innovations contemplating substations on the seabed (much like X-trees or other installations in the oil & gas). However, operation and maintenance of such innovations requires further research.

Foundation installation

Foundation transport and installation is undertaken either by the jack-up vessels that also are used later for turbine installation or by floating heavy-lift vessels with mooring and/or dynamic positioning systems. Monopiles (the predominant foundation type) are transported in horizontal position, upended by an upending tool and lowered/piled into the seabed while secured by a pile-gripper. To allow floating installation on dynamic positioning, upcoming technology integrates the vessel DP system with the pile guide and positioning frame, which is ensuring vertical installation.

Jackets, the foundation type which may become more applicable for larger depths, are transported in vertical position. For pre-piled jackets a reusable piling template is lowered to the seabed and the pin piles hammered into the seabed using the same process as for Monopiles.

Monopile installation is a two-stage process with the monopile driven into the seabed with a transition piece then bolted or grouted (with concrete) afterwards when the monopile is in place. . Usually the two stages are undertaken sequentially using the same vessel. Vessels installing monopiles typically up to now have had a need for a crane capacity of at least 900 tonnes. Foundation weight is increasing and total lift capacity (including tools and rigging) approaches 2000 tonnes. So-called XL Monopiles are generally considered to be the most effective solution for the foundation for larger WTGs in deeper waters. Monopiles with diameters of up to 12 m weights of up to 2500 tonnes.

8. Leonardo da Vinci Technical specification, Prysmian.
9. Alstom, [Internett]. Available: https://www.alstom.com/press-releases-news/2015/10/alstom-completes-commissioning-of-offshore-substation-for-windpark-enbw-baltic-2-in-germany.

Fred Olsen Windcarrier.

Jacket foundations are installed using the same type of vessels. Jackets may be post-piled or pre-piled. With post-piling, a single vessel carries the piles and the main structure. The main structure is lowered into place, and the piles are driven through holes in its base. With pre-piling, the piles are driven into place using a re-usable template. The structure is lowered onto the piles and grouted in position. This may be performed by a second vessel, operating in a separate campaign. Large vessels of today have deck space for about 4 jackets, but upcoming vessel delivery to the Norwegian OHT (in 2022) is about to more than double that number.[10] Rock dumping follows to secure the foundation's position.

A third option, Gravity base foundations made from steel or concrete require significant seabed preparations, prompting concerns about their impacts on benthic ecology.
All foundations, but particularly monopiles installed in sandy conditions, may suffer from scour. Rock dumping mitigates the risk, but new solutions are still being sought. [1]

Turbine installation

BFOW turbines are transported from marshalling port and installed at site by a WTIV. The installation vessel is a jack-up type designed for repeated/daily jacking operations at water depths up 40-60m and with a crane capacity (total mark) of at least 800 tonnes and growing. The WTG lifts are performed in elevated mode to mitigate movements, ensure stability and to have sufficient lift height. Most commonly the installation is completed in five lift operations: the tower (all sections in one lift), the nacelle including hub and finally the blades in three separate lifts. Larger towers may require to be installed in sections, hence increasing the number of lift operations. The jacking operation is restricted with respect to waves and the lifting operation is sensitive with respect to wind speed. Wind limits are determined by the size/height of the component in the hook, the lifting height and the crane itself.

Jacking operations at any location (in port, at site) require updated bathymetry surveys (normally not older than 6 months).

WTG size and weight increase and tower weight approaches 1000 tonnes, requiring total lift capacity of 1200 tonnes as a minimum. Larger towers may be transported in sections and assembled at offshore site but this will increase time for installation, mechanical/electrical completion and commissioning and should therefore be avoided.

The lifting and jacking capacity govern the efficacy and the vessel and crane sensitivity to wind and waves will govern the efficiency (operability). Deck loading (space and weight) capacity will determine the number of transits and port calls and will be important factors for efficiency.

Out of 23 purpose-built vessels, only 15 are currently operating in the market. Of these 15, 2-3 can handle the upcoming «stretched» WTG size without significant upgrade. Half of the fleet is judged to be incapable of accommodating the necessary upgrade. None of the existing vessels can handle the

10. Alfa Lift Specification, OHT.

future size (120 m blade). Two European owners have currently (one each) new build contracts signed for future generation WTIVs, while several potential contracts remain uncertain. Japanese (two) and US (one) owners seem to be entering the market but will stay in respective local market.[11]

WTIV mobilisation involves the installation of large prefabricated seafastening structures for the WTG components as well as supporting/securing structures for loading frames, tools and working/storage containers. Further, the crane may have to be provided with WTG specific equipment for controlling the lift and the deck arrangement completed with WTG specific power supply to the components during transit and installation. This is a 1-2 weeks' process to complete, involving welding works and lifting operations hence this will be largely weather sensitive. The demobilisation involves the removal of the equipment and structures, which to an increasing degree may be reused.

A step change in turbine installation could be achieved through the use of floating vessels for turbine component installation, which could shorten installation times further. The movements of the lifting hook at hub heights greater than 110m on a floating vessel have the potential to be substantial, however. Progress on floating installation methodologies will depend on collaboration between turbine suppliers and installation contractors as well as vessel design and technology.

5 Operation, Maintenance and Service (OMS)

Operation, maintenance and service includes scheduled and unscheduled activities and requires the regular transfer of personnel and equipment to the wind turbines and offshore substation.

WTG OMS

Inspection and regular maintenance of the WTG require continuous and dependable safe transfer of personnel and tools. The access vessel, whether a small unit (CTV or daughter craft) or larger unit (SOV) will leave the technicians on the turbine for the next mission on a pre-determined schedule. There must however be an available vessel for fast escape of the personnel, with typical response time to be less than an hour. The size of the OWF and the maintenance schedule will determine the necessary number of vessels to be operating in the field. To enhance efficiency, several adjacent OWFs may share the transfer and watch task. CTV operation may be a fast and cost-effective alternative for near-shore locations and relatively calm seas. Carrying personnel in long distances in heavy sea states is not only time consuming and inconvenient, but seasickness will often lead to sub-optimal utilisation of personnel. In addition, the transfer from CTV to the turbine (TP) boatlanding may be dangerous in high waves. Service Operation Vessel with a vessel motion compensated (Walk-to-Work) gangway will ensure the access in sea states up to about 2.5 m significant wave height and the requirement to operability is continuously growing. 3D (high precision motion compensated) cranes are being used for the transfer of material and tools that may not be trans-

Walney, UK. Photo: Ørsted

11. K. Arvessen, Interview, FOWIC, 2020.

ferred safely or effectively across the gangway. Safe access to the turbines is a critical area for further focused innovation. Ørsted recently unveiled the first CTV equipped with Bring-to-Work (B2W) transfer system, voiding the need for climbing the boatlanding.[12]

Another important area of innovation is the electrification of the CTV and service operation fleet. With batteries installed the vessels can be recharged using generators onboard or via a recharging buoy system at the OWF, currently under testing.[12]

Main component refurbishment, replacement and repair involves the replacement of large components such as gearboxes, blades, transformers and generators. The same jack-ups as used for installation (or smaller) are employed for these operations. Replacement/refurbishment operations are irregular, and exchange is carried out in one visit followed by off-site refurbishment. Blade repair may be performed at site with repair workshop onboard the jack-up, subsequently replacing worn blades by repaired units.

Balance-of-plant maintenance and service, including substation

Foundations are regularly monitored with respect to material (corrosion) protection and seabed scouring around their base by sensors for remote monitoring and through surveys. Increasingly such survey work is carried out by aerial drones, sonar and unmanned vehicles (AUV/ROV) through which repairs may also be performed where needed. [1].

Monopiles with grouted connection between monopiles and TP require monitoring and sometimes remedial action. Jacket foundations are particularly vulnerable with respect to the welded tubular joints.

The marine operations involved is to support visual inspections, NDT and subsea/seabed survey work and require vessels equipped for ROV operations and dynamic positioning.

Substation maintenance are mainly inspections of electrical switchgear and transformers, their foundations and topside structural inspection. It includes cleaning, paint repairs and secondary steelwork repairs (for example to railings, gratings, gates, stairs and ladders). These operations require means of access, which is normally a helicopter but may also be a vessel. Large repair operations, such as replacing transformers, require heavy lift vessels.

Substation foundation require the same attention and marine operations for maintenance and service as turbine foundations.

Cable maintenance, repair and service record management. Hydrographical impact from tides and currents or physical impact from anchors or jack-up vessel legs may scour the cables, remove cable protection or damage the cables. Portable, unmanned, underwater vehicles are becoming essential to examining subsea cable locations and diagnosing problems.[13] Cable reburial can be done through a ROV but repair will however normally require a full cable laying spread. For array cables, shorter cable lengths and challenges in joining shorter cables mean that replacement of the cable may be more cost effective than repair. If so, the cable will be cut at the bases of the foundations, the internal section of cable removed, and a new cable laid using the same process as installation. [5]

6 Decom

The first OWF to be decommissioned was Yttre Stengrund (5 off 2 MW turbines) in 2016.[14] Since then only a handful have followed suit and a sustainable, best practice method is yet to be established. Before considering decommissioning, the alternatives of lifetime extension or repowering (upgrading to more powerful turbines) are likely to be evaluated. Learning from the Oil and gas industry, the decommissioning strategy needs to be integrated into the project plans to mitigate cost and budget overruns.[15]

Turbine decommissioning will require complete removal of the structure. The process will be the reverse of the installation and jack-ups will serve these operations, supported by CTVs/SOVs. For nacelle and tower mechanical/structural components, the potential for recycling is considerable. There is currently no process for recycling composite materials such as those used in the blades and nacelle cover but is likely that methods will emerge by the time a large volume of offshore wind turbine commissioning is required.

The foundations will have to be removed and shipped to shore by heavy lift vessels. Monopiles and jacket piles will have to be cut-off below seabed level in the same manner as for the decommissioning of Oil and gas installations. These operations are familiar to OCVs.

Substation decommissioning will also follow the reverse of the installation process, while it may prove cheaper to cut the substation into sections for removal to enable a series of smaller lifts that can be undertaken by a lower cost vessel.

Cable material represent large values. Nevertheless, today's practice is often to leave the cables buried in the seabed since their removal is not only costly but also cause damages to the seabed. With number of installations increasing in the future there may be raised requirements for removal. Such operations would be performed by an OCV, disconnecting the cable and winding it to drums or chopped into short sections for storage on the vessel.

12. Riviera, [Internett]. Available: https://www.rivieramm.com/news-content-hub/unique-bring-to-work-system-selected-for-oslashrstedrsquos-hybrid-ctvs-62984.
13. A. Durakovic, https://www.offshorewind.biz/2020/09/28/orsted-and-maersk-to-test-offshore-vessel-charger/, OffshoreWind.biz, Sept 2020.
14. «The future of cable maintenance and repair in offshore wind farms».
15. EvaTopham, «Sustainable decommissioning of an offshore wind farm,» 2016.

5.3 MARINE OPERATION SEGMENTS FLOATING OW FARMS (FLOW)

1 Planning and survey

Although a FOW will be installed in deeper waters and generally farther from shore the planning and survey operations will be similar, performed by similar vessel types with the same kind of equipment. The geographical and environmental conditions are expected to increase requirements to seakeeping capabilities and duration.

2 Project logistics

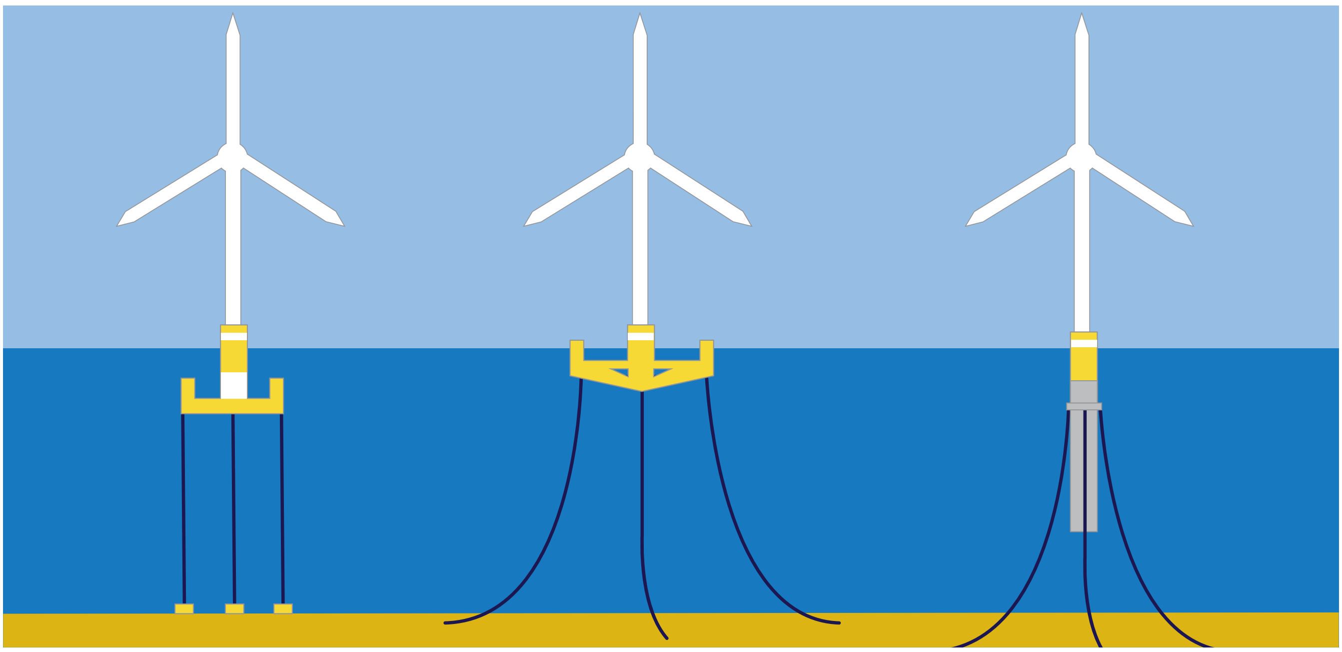
The project logistics will differ significantly due to the different technologies and assembly methods applied. While the BFOW WTG is assembled at farm site to where foundation/TP arrives direct from manufacturer, the floating foundation is constructed at or transported to the marshalling port by heavy lift vessel or towing boats. The turbine components (towers, nacelles and blades) arrive to the marshalling port as for BFOW.

3 Construction

The construction and assembly will depend on the concept but involves lifting operations either by land based or crane barges /crane vessels supported by barges, towing boats and possibly anchor handlers for mooring operations. The option for a land-based crane will require deep water quays, long reach cranes and heavily reinforced quays.

4 Cable lay

Cable lay operations for FOW are different from BFOW in terms of the general increase in water depth and the termination towards the floating substation (export cable) or the FWT. The same vessels are used in the FOW cable lay operations as for BFOW but operation in deep waters must take into account the larger vertical forces and avoid too small bending radius of the cable across the vessel stern or side. The cable laying must also



FWT. Illustration: Norsk Industri

Cable lay. Photo: Nexans

take into account the FWT anchor and mooring line arrangement and be planned accordingly.

The cable consists of a static part on the seabed and a dynamic part, connected to the FWT.

The dynamic cable conFigureation will depend many variables such as cable cross section, FWT motions and environmental conditions (e.g. current and marine growth).

The static cables are pre-laid, while the dynamic part may either be pre-laid and connected upon arrival of the FWT or installed and connected in after the FWT is in place.

The installation of dynamic cables can be separated into two parts which occur one before the other but not in a specific order. Recommended for units with many array cables nearby is a "first-end pull-in"-operation. While the rest of the cable is still (dry) stored on the CLV its first end is pulled in and temporarily attached to the FWT. The CLV lays the cable towards the pre-laid static cable, pull-up and connects on the ship or underwater by using a ROV. The pre-laid cable is wet stored on the seabed or attached with buoyancy modules to guarantee an easy pick-up process at a later date for the pull-in operation into the FWT. Depending on logistical and/or technical parameters, the cable may be laid in one piece including the transition joint.[17]

The pull-in operation and electrical connection is performed from the FWT and the vessel required for this is merely for access of technicians, tools and materials.

Dynamic cables and installation of such is technology commonly used within the Oil and gas industry. The particular challenges regarding the FWT cable installation pertains to the multiple operations and obstacles under the constrained time schedule and limited operational weather (wave) window.

17. CoreWind, «Review of the state of the art of dynamic cable system design,» Feb 2020.

Larger turbines imply larger distances between the turbines which again leads to larger quantities of inter-array cabling and more associated cable laying work. Hence increased need of capacity is expected. The increased turbine sizes also imply larger (thicker/heavier) cabling which also drives the capacity requirement.
Future OWF, fixed or floating, are set to supply power to several areas by interconnection lines across borders and hence the export cable volumes are expected to grow.[18]

5 Installation

The installation of FOW park/FWT is a towing and mooring operation with more similarities to Oil and gas operations than BFOW/WTG installation. The anchors (3-4 per FWT, all depending on concept) is pre- installed and mooring lines pre-laid on the seabed by an AHTS for a drag anchor or OCV with ROV in case of suction anchor.

The assembled FWT is towed to site by a team of boats to control the tow. Depending on the concept, the floating foundation may be ballasted and the towing configuration may be designed so to mitigate weather sensitivity for the operation. The larger the distance to shore, however, the higher the uncertainty of meeting the projected weather conditions for next step upon arrival in the farm. At site, an anchor handling vessel (AHTS) with high particularly high pulling capacity keeps the FWT in place for hook-up the to the mooring lines.

Instead of concerns for scouring around foundations as for fixed installations, the focus for protection is here on anchors.

Norwegian marine installation operators are important contributors to Norwegian content in offshore wind farm developments

6 Operation, Maintenance and Service (OMS)

FWT OPERATION, MAINTENCE AND SERVICE (OMS)

Inspection and regular maintenance of the turbine, excluding the foundation, involves the same items as for BFOW (ref. above). The important difference from a marine operations perspective, however, is the access and transfer of personnel and tools, between two floating units. Neither a CTV nor a SOV (with W2W) arrangement will be a dependable solution under the current technological limitations. The water depth at the FOW farm will inevitably exceed that feasible for jack-up operation which otherwise could have provided a steady, however expensive, platform. It appears that the industry remains concerned about the unresolved situation[19].

Considering the increasing distance to shore and the size of the OWF, it may prove worthwhile to establish stationary bases for OMS personnel at the farm. The challenges regarding transfer of personnel remains or is even exacerbated, but efficiency may be improved by mitigating transit time and seasickness.

The challenge appears even larger with respect to main component refurbishment, replacement and repair. The process for this appears unresolved in the FOW sector. The option of disconnecting the cables, unhooking the mooring to tow the entire FWT to shore for replacement of heavy items or blades is generally rejected. Not only time consuming and resource demanding for the single FWT but for the entire string of FWTs interconnected by cabling and perhaps mooring. The alternative, however, to do high precision lift operations (e.g for blade repair) at site seems infeasible due to the uncontrolled relative motions. It is expected to see solutions of cranes attached to turbine tower etc. supported by DP vessels such as SOV, PSV or OCV with motion compensated cranes and capable of carrying an unloading material and tools for such operations.

Balance-of-plant maintenance, repair and service including substation

Foundations, anchors and moorings are regularly inspected with respect to material (corrosion) protection with interval of 3-5 years depending on component. Anchors are subject to scouring around their base and mooring subject to corrosion and marine growth.

The systems and components are increasingly kept under continuous surveillance through sensors for remote monitoring (e.g. tension control for mooring system). Inspection and repair work is increasingly carried out by unmanned vehicles (AUV/ROV) operated from a vessel at site or even remotely from shore.

18. GWEC, «Global offshore wind report 2020,» 2020.
19. SOV Webiner, Riviera, 2020.

The marine operations involved is to support visual inspections, NDT and subsea/seabed survey work and require vessels equipped for ROV operations, dynamic positioning and W2W arrangement as for bottom fixed installations.

Scour and hydrographic survey work applies also for the BoP of floating installations but here for the subject items are the anchors and static cables instead of the foundations. The same equipment as for bottom fixed installation is applied for this work.

Substation monitoring, inspection and repair involves the same items as for the foundation and their anchors/mooring system. The substation topside OMS involve the same as for the BFOW, with the same challenges in terms of access, although the relative motions would be expected to be smaller.

Cable inspection, maintenance, repair and service record management

Static cable inspection and repair involves the same items as for the BFOW.

The dynamic cable parts are subject to fatigue and marine growth in addition to corrosion and the motions, catenary tension and position is subject to continuous monitoring. Inspection by AUV/ROV is carried out regularly (5 years schedule). A ROV may also perform minor repairs, while larger repairs may call for a full cable lay spread.

7 Decom

Decommissioning

Due to the immature state of the industry, there is little information on decommissioning of FOW. The marine operations will to some extent be the reverse of the installation, excluding however the hook-up and as such less weather dependant. Once detached the FWT will be towed to shore for disposal/recycling. The recycling of materials will be to the same extent as for the BFOW components. Nacelle and tower mechanical/electrical and steel construction parts as well as steel or concrete from foundations may be recycled. Mooring lines and anchors may be recycled while for blades and nacelles cover composites the industry has yet to find a sustainable method for the volumes in question.

Dynamic cables will have to be removed while it is unclear whether the static parts will be allowed to be left buried in the seabed.

The marine operations will primarily include tugboats, access vessels and OCVs for the subsea (mooring, anchor and cable works).

A pre-decom seabed survey will be performed and the decommissioning is accomplished when the post-decom survey is completed.

The marine operations will primarily include tugboats, access.

6 Norwegian fleet presence in offshore wind

Norwegian marine operators are offering their services globally. Ability to adapt and innovation of new technologies has created opportunities and given a competitive advantage.

6.1 BACKGROUND

The Norwegian commercial fleet has a long history in offering services worldwide and to a broad set of industries. Responsiveness, adaptability and innovation in technology (products) and processes have been key elements in the Norwegian maritime industry evolution and its resistance to low wage and low regulation competition. Diversification of products and services has provided synergies for innovation and cluster development. Small scale (personal and family-owned) businesses, networks and clusters have shared and combined existing knowledge. Institutions and incremental innovation in policies have created opportunities for growth in the industry[20].

The development of the oil and gas fleet provides evidence of this ability to respond to challenges. This fleet has in many respects set the standard for harsh weather offshore vessels. The knowledge and experience gained from designing, building and operating these ships and associated equipment have not only benefited the shipping and oil companies but any industry operating in the offshore environment. Today ship design, equipment, services and competence employed in the offshore wind industry have evolved on the backbone of the past and recent fleet and technology development: lifting operations, personnel transfer, systems for in positioning and station keeping, subsea technology and operations, propulsion and power generation systems for fuel efficiency and alternative fuels.

6.2 PRESENCE AND OPPORTUNITIES

With the number of ships and their merits pertaining to offshore operations, it is an a priori assumption that the Norwegian shipping cluster would be able to offer services within most operation segments, both for fixed and floating installations. For BFOW, the Norwegian cluster already have a small part (3-5 %) primarily of the turbine installation (through WTIVs), OMS/service operation (through SOVs) but also through project logistics and cable lay. The latter used to have a significant share (almost 20 %) market share (in export cable lay) but seems to be decreasing in the recent years.
Given the maturity of the BFOW industry it is expected that the current Norwegian market share will not grow but be maintained. Still, the growth in volumes will offer opportunities for the Norwegian suppliers[21].

Looking ahead, the FOW would be well served by the existing OW fleet combined with the oil and gas fleet offering the necessary capabilities and capacities for mooring, towing, cable laying, lifting operations as well as subsea inspection and works.

6.3 NORWEGIAN MARKET SHARE FLOATING OFFSHORE WIND

Floating OW is currently in its cradle. The Equinor Hywind demo, the Scotland pilot (for which 30-40 % of the contracts were won by Norwegian suppliers [4]) and now the "full scale" development of Hywind Tampen, serves to demonstrate the Norwegian industry competence in the field. When commissioned in 2022 Hywind Tampen will be the world's largest FOW. With this the Norwegian industry has a flying start with a large market share, although there are several development projects ongoing worldwide.

Quoting Thema (2020): The Norwegian Supply Chain has a significantly stronger position in floating offshore wind compared to bottom fixed offshore wind, mainly as a result of early in-

20. M. Gunther, The Dynamics of the Norwegian Maritime, Lund University, School of Econmics and Management, 2014.
21. «MAKE Norwegian Opportunities in Offshore Wind,» 2016.

volvement in the Hywind Scotland and Hywind Tampen projects. Due to the immaturity of the floating wind industry, Norwegian companies have a unique chance of taking leading positions in this market. [22]

Further to the above, due to the nature of the construction methods (land/harbour based operations and installation offshore/subsea operations), local contents in general and Norwegian service supply in particular may be well positioned for a significantly increased market share (5-30 % as a base case).[22]

6.4 INDUSTRY AND SECTOR INTER-APPLICABILITY

Marine operations in the construction, installation and service/operation of a floating OW farm are in many respects similar in nature to those of Oil and gas operations. While the ships and equipment involved may be the same, however, the complexity, risks, logistics and volume of the operations may differ. In a heuristic approach, a DNVGL panel of experts has systematically ranged the level of applicable experience on floating OW systems/operations as found from the floating OW, bottom fixed OW and oil and gas industries per 2021. The results are found in the below table[23]. The "relevant experience" level compounds volume of projects and the operation applicability/similarity compared to the other sectors. "Low" does not necessarily imply dissimilarities in the operations, neither that few related operations have been performed. Rather it reflects the fact that many operations in floating OW are tailor-made for a particular concept and that the sheer logistical challenges may result in lack of experience.

In particular the mooring and anchoring operations in Oil and gas are highly transferable to floating OW. Other floating installation operations pertaining to towing/hook-up and installation of dynamic cables and export cable lay may also benefit from the Oil and gas experience.

Subsystems/operations		**Relevant experience for Floating offshore wind (considering volume and degree of similarities)**			**Overall**
		Floating wind	**Bottom-fixed wind**	**Oil and gas**	
Design and fabrication	WTG (RNA)	Medium	Medium	NA	Medium
	Tower	Medium	Medium	NA	Medium
	Substructure	Medium	Low	Medium	Medium
	Mooring and anchoring	Medium	NA	Medium	Medium
	Dynamic cable (array cable	Medium	NA	Medium	Medium
	Floating offshore substation	Low	Low	Low	Low
	Dynamic high voltage cable	NA	NA	Low	Low
	Export cable	Low	Hight	Medium	Hight
Installation	Mooring and anchoring	Medium	NA	High	High
	Turbine installation/mating	Medium	Low	NA	Medium
	Towing and hook-up	Medium	NA	Medium	Medium
	Floating offshore substation	Low	NA	Medium	Medium
	Dynamic cables	Medium	Low	Medium	High
	Export cables	Low	High	Medium	High
Operation	Normal WTG maintenance	Low	High	Low	High
	Heavy WTG maintenance	Low	Low	NA	Low
	Substructure maintenance	Medium	Medium	Medium	Medium

Table 1 - Relevant experience from Floating OW, Bottom-fixed OW and Oil and gas that is applicable to future Floating OW development, Source: DNV 2021

22. Thema, «Offshore Wind – Opportunities for the Norwegian Industry,» 2020.
23. BVG Associates, «Opportunities in offshore wind for the Norwegian supply chain,» 2019.

The Norwegian offshore fleet generally complies with the mentioned requirements regarding stability, deck load capacity (size and strength), propulsion and positioning and accommodation capacity. The Ocean Construction Vessels (OCV) already play a central role in serving the offshore installation campaigns, working in cable laying and mooring operations. Some vessels may require extensive modifications to comply with the offshore wind standards in terms of layout/workflow, fuel efficiency, accommodation or storage capacity. The standard Platform Supply Vessel (PSV) serve in various roles – in installation, inspection & repair and accommodation service - in their original outfit or after being modified and retrofitted with the adequate equipment or updated systems. The extent to which modified and/or older vessels will have access to the wind industry also in the future will depend on the availability of vessels (market conditions/day rates) and the bargaining position of the parties. While OW developers or EPCI contractors may solemnly declare their clear requirements to charter candidates, the choice will eventually be determined by the supply and demand.

6.5 GENERAL DESIGN AND EQUIPMENT ISSUES

Cable laying and BFOW installation work are examples of segments that involve and require specifically designed ship types of high asset value and high entry barriers, both financially and competence wise. With the objective of this assessment to identify the potential for the entire fleet, the basic assumption is, however, that most operations may be performed by a variety of ship types. The choice will depend on project specific circumstances such as installation technology/methodology/strategy, OWF and turbine size, geography/geology and external conditions such as market/availability and regulatory/environmental requirements.

Below are listed select technical parameters and technology items applicable to the OW fleet. Some are relevant to all segments, while others are segment specific. The listed items are critical in the sense that they are difficult or costly to retrofit. While vessel navigation and position data logging equipment may be critical to most of the operations it is relatively easy to supplement.

- Ship technology:
  – hull design for manoeuvrability and seakeeping abilities
  – hull design for stability for load capacity, lifting, load-out operations
  – hull and propulsion design for efficacy/efficiency for speed and station keeping
  – machinery for propulsion and power generation
- Endurance
- Deck layout and dimensions to fit infrastructure and operational/operability needs incl. technicians workflow efficiency, workshops
- Adaptability (for conversion into other segments or increased capacity)
- Load carrying capacities
- Crane lifting capacities (height, min. reach, maximum reach)
- Jacking system capacity – max. elevated weight, height, soil conditions, speed, operational and survival conditions at site
- Fuel economy
- Emissions and abatement measures (hydrogen-based fuel, cold-ironing in port/in-situ)
- POB capacity, recreation facilities. Single cabins in certain markets
- Condition (using age as a proxy)
- Equipment, systems and accessories:
  - Station keeping/Dynamic Positioning (accuracy and redundancy) for all installation/decom operations
  - W2W (B2W) for service operation
  - 3D crane, daughter craft for installation and service operation
  - A-frame for cable lay operations
  - Anti-roll and anti-heel system for lifting operations during construction and service
  - Cable tensioners/carousel for cable lay
  - AUV/ ROV facilities (hangar, launching equipment) for all operations incl. survey, I&R, cable lay and installation/decom
  - Bollard pull (for towing, anchor handling and trenching/plough operations)

6.6 TECHNICAL CRITERIA FOR FLEET APPLICABILITY (BFOW/FOW)

The vessel applicability may be instant or require modifications which are feasible as long as the criteria are fulfilled. The criteria pertain to “inherent” features such as hull design, dimensions and essential equipment that is costly or difficult to retrofit.

The Norwegian offshore fleet is generally strong technologically and capacity wise and we may find vessels with the requested capacities and capabilities to perform most operations. The criteria are based on operational and commercial experience as well as features being officially requested by the owner/ operators for future operations.

The technical criteria of the offshore wind fleet per segment and ship type are tabled in Appendix 1.

6.7 SUMMARY OF FLEET APPLICABILITY

The Norwegian fleet identified as currently operating, or being candidates for operation, in OW is divided in the following commonly designated categories (see table underneath).

Among the approximately 650 vessels identified as feasible for OW operation, about 100 has a proven track record within the industry.

6.8 VESSEL/OWNERS SEGMENT DISTRIBUTION

The assessment of potential for the fleet in the various segments is based on specifications, dimensions and capacities. It is not limited to the designated ship type but instead based on the criteria listed in table Appendix 1. In fact, inter-applicability is the essence of the assessment outlined in this report. Many vessels of low specification/equipment level may do rock-dumping jobs by the using a crane to dump stones in bags. PSV provide inexpensive deck space with good station keeping capabilities and may be instrumental in cable laying and mooring hook-up operations. These ships may also be converted to SOVs under the right market conditions. Properly equipped, OCVs may operate as cable layers and anchor handlers may serve as survey vessels. As pointed out in section 1 above, eventually the market will decide the limits, and certain transactions will never occur due to the low willingness to pay in OW compared to Oil and gas.

VESSEL TYPE	#VESSELS	#OWNERS	BFOW	FOW
Survey/Seismic	67	24	X	X
Cargo transport	9	2	X	X
Submersible Heavy Lift	5	2	X	X
Barge	20	2	X	X
Lift barge	5	2	X	X
SOV/W2W	18	7	X	X
CTV	12	2	X	X
Cable Lay Vessel	7 (11)	6	X	X
Pipe Lay Vessel	16	2	-	-
Rock dumping	1	1	X	X
Heavy lift (crane)	3	2	X	X (construction phase)
FIV	5	1	X	
WTIV	3	1	X	X (construction phase)
AHTS	46 (93)	6 (10)		X
OCV	160	24	X	X
TUG	13 (BP>60 tons) 3 (BP>100 tons)	3 1		X
PSV	199 (211)	30	X	X

Norwegian vessels with OW potential. Numbers in brackets are sub-specification vessels. Pipe layers are considered N/A assuming too high modification cost for cable lay operation.

The distribution of vessels feasible for the different segments is found in the table below with details in Appendix 2.

Bottom Fixed Offshore Wind fleet

	Planning and Survey	Project logistics	Cable lay	Installation	OMS	Decom
#Vessels (incl. on order)	67 survey vsl (375 feasible)	8 Heavy Cargo 10 submsble HL incl. UWL	45 OCV (array) 11 CLV (export, 70 feasible OCV)	5 Foundation 2 Substation 3 WTIV 18 SOV (300 feasible)	5 Lift barge 18 SOV (300 feasible) 12 CTV 3 WTIV 121 OCV	As for cable lay, Installation and Survey
	1 Rock dumper (many feasible) Most vessels will serve as guard vessels but only the less expensive (less than 300) will be feasible					
#Owners	24	2 (Heavy cargo) 1 (submsble HL)	10 (OCV) 6 (CLV)	3 (Foundation) 2 (WTIV)	2 (Lift barge) 7 (SOV) 2 (CTV) 2 (WTIV) 24 (OCV)	

Table 2 Vessels with OW potential per segment, BFOW

Floating Offshore Wind fleet

	Planning and Survey	Project logis-tics	Construction	Cable lay	Installation	OMS	Decom
#Vessels (incl. on order)	67 survey vsl (375 feasible incl. AHTS, OCV)	8 Heavy cargo 10 submsble HL incl. UWL 20 Barge 46 Tug	3 WTIV 5 Lift barge 46 Tug 76 AHTS	45 OCV (array) 7 CLV (export, 70 feasible OCV) 199 PSV	13 + 89 AHTS (tow) Tug 46 AHTS (hook-up) 199 PSV	46 Tug 46 AHTS 18 SOV (300 feasible) 12 CTV 121 OCV 199 PSV for modification 121 OCV	46 Tug 46 AHTS 121 OCV 67 Survey
	1 Rock dumper (many feasible) Most vessels will serve as guard vessels but only the less expensive (less than 300) will be feasible						
#Owners	24	2 (Heavy cargo) 1 (submsble HL) 2 (Barge) 4 (Tug)	2 (WTIV) 2 (Lift barge) 4 (Tug) 10 (AHTS)	10 (OCV) 6 (CLV)	5 (Tug) 10 (AHTS)	4 (Tug) 10 (AHTS) 7 (SOV) 2 (CTV) 70 (PSV) 24 (OCV)	4 (Tug) 22 (OCV) 24 (Survey)

Table 3 Vessels with OW potential per segment, FOW

7 Norwegian opportunity in OW marine operations – a qualitative assessment

Norwegian marine operators can offer their services in the complete life cycle of an offshore wind farm.

7.1 METHODOLOGY

The operation segments are based on BVG associates value chain model for the development and operation of OWF. This model estimates the contribution of the various segments of the value chain to the total Life Cycle Cost (LCC) of a 1GW OW farm for an assumed lifetime of 25 years. The total LCC for a 1 GW BFOW farm as estimated by BVG is around fifty thousand MNOK[24]. The corresponding value for a FOW farm of same output is for the purpose of this report, estimated to sixty-seven thousand MNOK. This is based on CAPEX estimate from[23] and assuming OPEX remains the same. These LCC values are associated with large uncertainties due to variations in projects, the few and different concepts in reference floating projects and the fast development in both sectors. The purpose of introducing the LCC is to offer a reference for the order of magnitude of the value of the marine operations.

	LCC (MNOK)	Turbine (MW)
BFOW	50 000	10 x 100 off
FLOW	67 000	15 x 67 off

Distance to shore 200 km (both above)

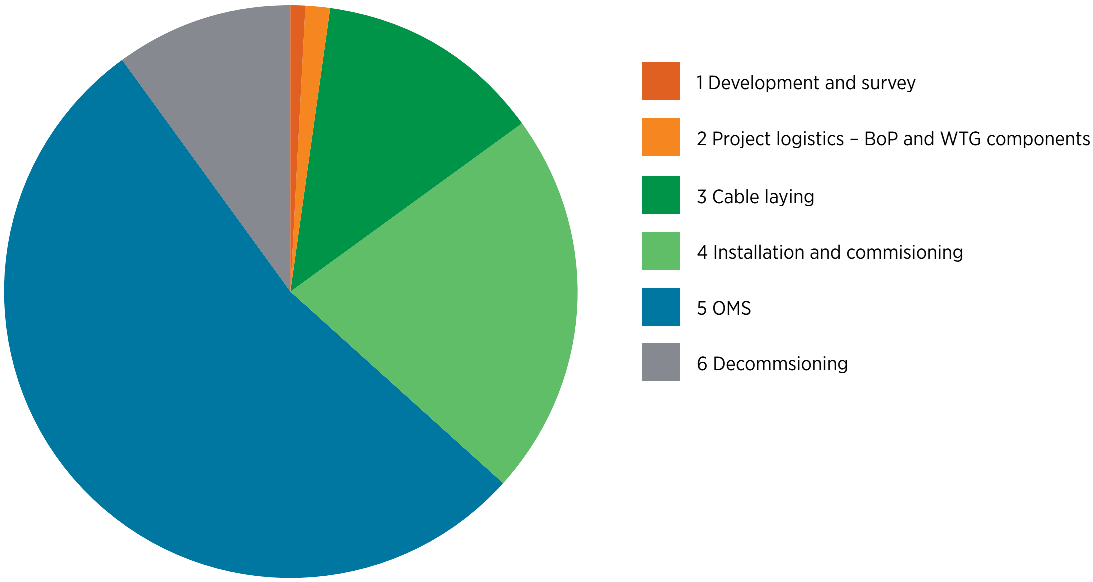


Figure 7.1: Ref: BVG: Opportunities in offshore wind for the Norwegian supply chain

23. M. D. Ebbesen, «Risks and opportunities as seen from the advisors,» i High Wind, 2020.
24. BVG Associates, «Opportunities in offshore wind for the Norwegian supply chain,» 2019.

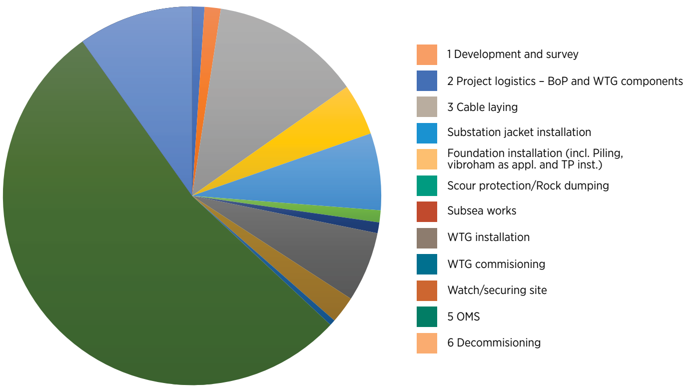
The model has been adjusted to focus on the marine operations value chain by identifying and extracting these operations embedded in the seven segments. In the process it was found that marine operations represent about 15-20% (BFOW) and 10-15% (FOW) of the total value chain respectively. From the BVG pie chart it should come as no surprise that only in OMS, Installation (incl. cable lay) and decom segments the marine operations are significant contributors. 1/3 of the total LCC pertains to turbine and balance of plant product supply (i.e. value chain items which represent few marine operations).

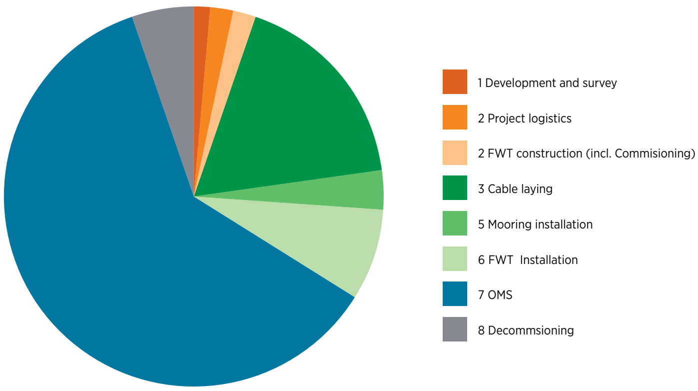
The marine operations value chain was broken down into the segments and segments broken down into tasks, each associated with capabilities and capacities and often specific ship types. The applicable vessel types are determined according to criteria defined in section 6.6 above, by breaking down the operations into duration, typical mobilisation, demobilisation and weather waiting time, marine spread (ship types) involved and applying the current day-rates.

For the purpose of this assessment the day-rate and duration applied are those of the normally preferred ship type, setting the standard and willingness to pay in the market.

The value chain "Opportunity value" is the total cost of the operation established on a qualitative level as (operation days x day rate). Operation days (duration) includes the actual operation, transit, mobilisation/demobilisation time and weather waiting.

The "Opportunity value" times applicable vessels (based on criteria as per Sec.7.6 above) determines the vessel potential in the specific segment.





Pie chart 1: BFOW 100 % Marine ops marine ops cost per segment (total abt 15–20 % of LCC)
Pie chart 2: FOW 100 % marine ops cost per segment (total abt 10–15 % of LCC)

Any track record in the OW industry (BFOW or FOW specific) may exacerbate the potential but is not a prerequisite as it would be disqualify most vessels and owners. Instead the assessment tries to identify opportunities into segments that apply similar vessel technical capabilities and capacities.

It must be noted that there are large uncertainties in the estimates, both with respect to duration and day-rates.
Project specific parameters are mentioned above as determinants for the ship type selection and these parameters will also impact the operations duration. In addition, weather and sea state (i.e weather down time) and technological /methodological development distort every effort to find a representative duration. It is true that the operations' commencement date will be a proxy for expected delay due to weather but commencement date may also be delayed, if it was ever optimized for weather.

The variations and uncertainties pertaining to vessel cost (day rates) are explained in

Shipping structure and mechanisms in 5.1 above.

For the above reasons the opportunity value estimates can only serve to provide an understanding of the magnitude of the opportunity and its comparative size.

8 Shipbuilding in offshore wind

Norwegian ship designers have a strong position. Norwegian ship yards are facing tough competition internationally

This report aims at outlining the variety of marine operations involved in bottom fixed and floating offshore wind. Shipbuilding is not part of the operations and fleet assessment but since it represents an important part of the value chain, a survey of Norwegian shipyard's capability and focus on offshore wind ship types is included here for completeness.
Ref. Appendix 4.

In this yard survey, a total of 42 yards have been covered. The survey scope include technical and resource capability, strategic focus and track record.

Out of the 42 yards, 12 are currently have the capability of building vessels towards the offshore wind industry (It should be noted that the three Vard yards are here counted as one).

4 of the 12 are only capable of delivering smaller vessels such as CTVs.

Of the 12, only 6 have the offshore wind industry as a main focus area.

Further, vessels which have been designed by Norwegian yards, but have been or currently are being built abroad do not count in the overview. An example is the Alfa Lift vessel to OHT which is an Ulstein design being built in China.

The overall demand experienced by Norwegian yards towards the renewable energy sector varies significantly between the yards. The reason is that some yards have strong focus towards the sector with active marketing while others are more passive, i.e. "We can do it if asked, but it is not our core focus".

However, overall the demand is not great due to the fact that Norwegian yards are experiencing tough competition internationally. The one single challenge mentioned by most yards is financing. Financing and guarantee services are perceived to favour shipowners' option to build abroad instead of promoting activity at Norwegian yards.

8.1 CONCLUSION

The assessment sets out to identify the marine operations in OW and map the existing Norwegian fleet with respect applicability in the identified operation segments. Further to identify the opportunity for the ship type in the OW.

Through an heuristic and experience based approach the individual duration of segment tasks and subtasks has been estimated. By multiplying with the typical (current) day rates, the total cost (operation days x day rate) has been obtained. Ref. Appendix 2 A (Bottom fixed) and 2B (Floating). The opportunity for a specific ship type is judged from the number of vessels applicable times the value of its operations (total cost).

Any track record in the OW industry (BFOW or FOW specific) may exacerbate the opportunity but is not a prerequisite. Instead the assessment tries to identify opportunities into segments that apply similar vessel capabilities and capacities.

Ownership and operation of specialised ship types such a cable layers, heavy lift/foundation installation vessels and wind turbine installation vessels is subject to high entry barriers due to cost as well as market and technical complexity. These ship types are essential and their supply is limited, hence their opportunity is inherently high, despite the small Norwegian representation.

Bottom fixed OW

VESSEL TYPE	OPERATION SEGMENT
Service Operation Vessel, SOV	OMS, Installation
Wind turbine installation vessel, WTIV	Installation, OMS, Decom
Heavy lift crane vessel, Foundation installation vessel	Installation
Offshore construction vessel, OCV	Cable lay, OMS, Decom
Cable layer	Cable lay
Heavy transport	Project logistics

Floating OW

VESSEL TYPE	OPERATION SEGMENT
Service Operation Vessel, SOV	OMS, Installation
Offshore construction vessel, OCV	Cable lay, OMS, Decom
Anchor handler, Tug, Supply, AHTS)	Installation (incl. anchor and mooring)
Tug	Project logistics, Construction, Installation, OMS, Decom
Cable layer	Cable lay
Wind turbine installation vessel, WTIV	Construction
Heavy transport	Project logistics
Platform supply vessel (PSV)	Cable lay, installation, OMS

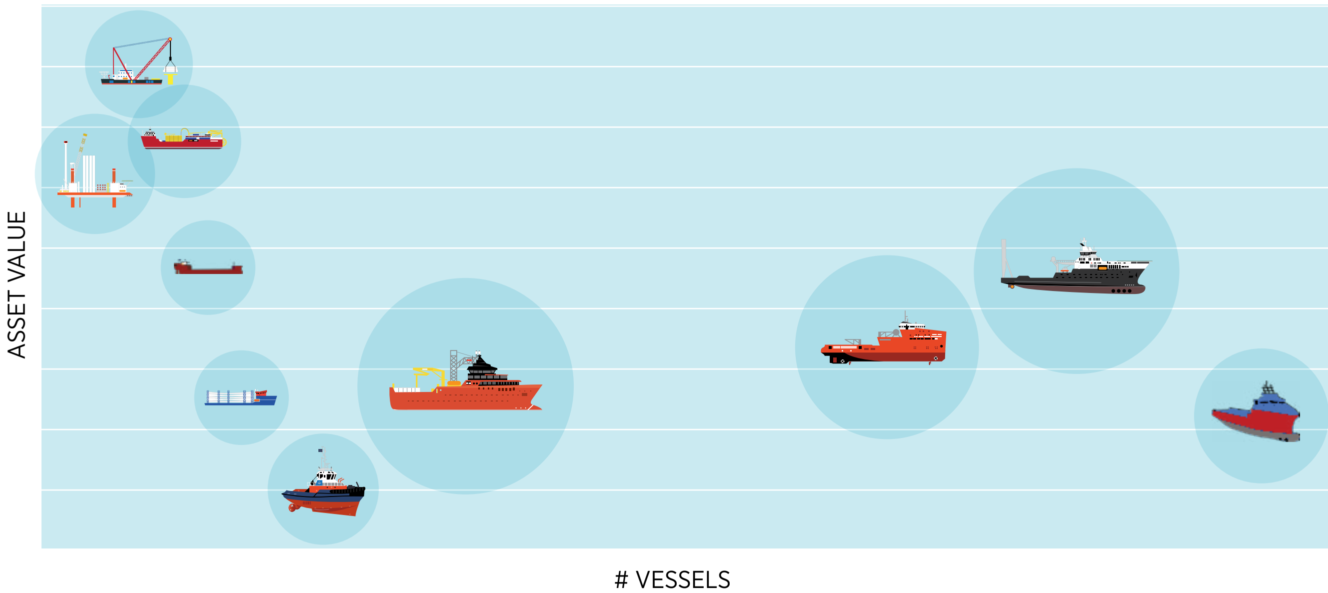
From the diagrams in Appendix 2 (A and B) it may be concluded that the following vessel types represent high potential in the OW industry

Specialised cable layers, wind turbine installation vessels and heavylift/foundation installation vessels are limited in number, both in global and Norwegian terms, but the extent and value of the operation is substantial. As for cable lay operation, a large part of the work may be performed Offshore Construction Vessels.

Other ship types mentioned in this report such as survey vessels, rock dumping vessels are either too few vessels or the value opportunity is too small to represent an opportunity on the scale above.

Tug boats of different bollard pull capacity will be needed for the towing/hold back of floating turbines from harbour to site. Lower capacity anchor handlers (AHTS) may be part of this operation. Higher capacity AHTS will perform the mooring hook-up of the turbine.

Platform Supply Vessels, PSV have an opportunity in the cable laying and installation operations. These relatively inexpensive vessels may also be cost-effective in the Operation, Maintenance and Service segment for floating OW. This may be either as modified to Service Operation Vessels (SOV) – market dependant – or through direct application in inspection and survey support.



Norwegian fleet in OW wind (Bottom fixed and floating offshore wind) – circle size illustrate opportunity

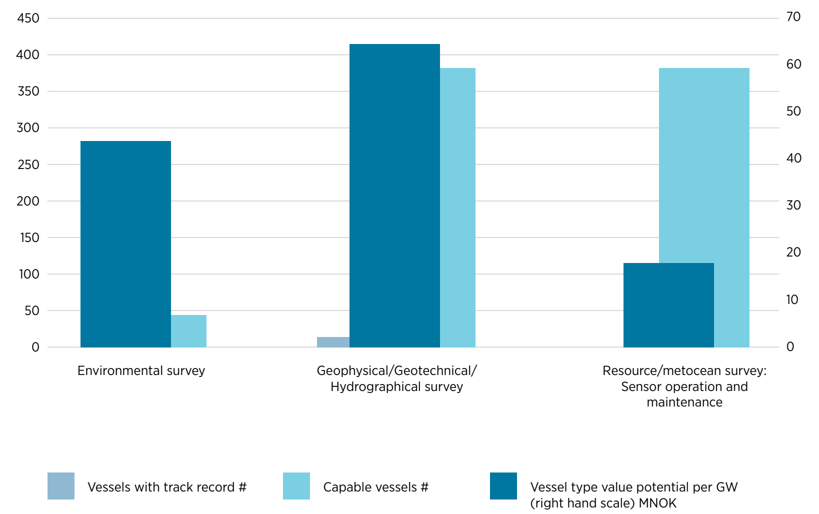
Appendix 1

	1 Planning and survey	2 Project logistics	3 Cable lay	4 Installation	5 OMS	6 Decom
Survey vessel	Endurance>4 wks, seakeeping,					Endurance, seakeeping
Survey Geo survey vsl	Endurance, seakeeping, POB A-frame DP2 laboratory space Multibeam, side scan sonar		Seakeeping Multibeam echo sounder, side scan sonar	Seabed verification to secure jack-up operations: Seakeeping Multibeam each sounder, side scan sonar	Seabed verification to secure jack-up operations: Seakeeping Multibeam, Side scan sonar	Seakeeping Multibeam, side scan sonar
Heavy transport		Deck loading capacity, length and width Covered cargo space for nacelles				
Heavy lift vessel		Transport of foundations, substation topside/foun-dation				
CLV			Deck/Carousel capacity 5-10.000 tons Deck >1400m² (for carousel retrofit) Bundled lay capacity, Cable jointing facilities Dedicated quadrant de-ployment frame , multiple tensioners, ROV hangar A-frame /Deck crane>50 tonnes for positioning of ploughs/trench cutting machines and work-class ROV. (Simultaneous laying and burial) Bollard pull capacity Operability in 3m Hs			
Seabed preparation vessel (OCV)			Deck>500m² ROV hangar Bollard pull capacity A-frame/Crane (Some ploughs may be handled without A-frame/ Crane)			
Cable Burial						
Rock dumper			Rock dumping may be with specialized vessels or through dumping stones/rock in bags by crane, with vessels fulfilling the following criteria: Deck crane >50 tons Deck > 500m², ROV, DP2. (excluding expensive construction subsea vessels)			
Heavy lift/ crane vessel				Deck loading capacity Crane capacity DP2		
FIV				Stability Crane capacity Up-ending tool for MP Pile-gripper/guide/ham-mer for MP; DP2		Stability Crane capacity DP2
WTIV		Crane height/capacity		Crane height/capacity Jacking capacity Elevated weight capacity DP2	Crane lifting height DP2	Crane capacity Jacking capacity DP2
OCV			Deck>500m² A-frame /Crane ROV hangar Trenching cap (deck>500m², bollard pull)		Deck space A-frame ROV/ hangar Cable repair facilities Deck crane for cable handling/ scour protec-tion work	ROV, DP2 A-frame /Crane >15 tonnes Deck for cable storage (Abrasive hp water cutting machines is loose equipment,)
SOV				W2W, DP2, POB>40 + crew, Daughter craft, Age, Vessel deck crane for handling of heavier equipment such as (com-missioning) generator	W2W, DP2, POB>40 + crew, Daughter craft, deck layout, Age Fuel econ and energy storage systems. For future: site charging capability(?)	
CTV				Speed, POB, seakeeping	Speed, POB, seakeeping	
PSV				With possibility for ROV, DP2	With possibility for ROV, DP2	With possibility for ROV, DP2
Tug boat		Bollard pull 60 tonnes		Hold-back tugboat bollard pull 100 tons.	Bollard pull 60 tonnes	Bollard pull
AHTS		Bollard pull>100 tonnes, DP2		DP-2, Bollard Pull >250 tonnes DP2; towing winches >350 tons	DP-2, Bollard Pull >250 tonnes DP2; towing winches >350 tons	
Guard vsl			General seakeeping capabilities	General seakeeping capabilities		General seakeeping capabilities

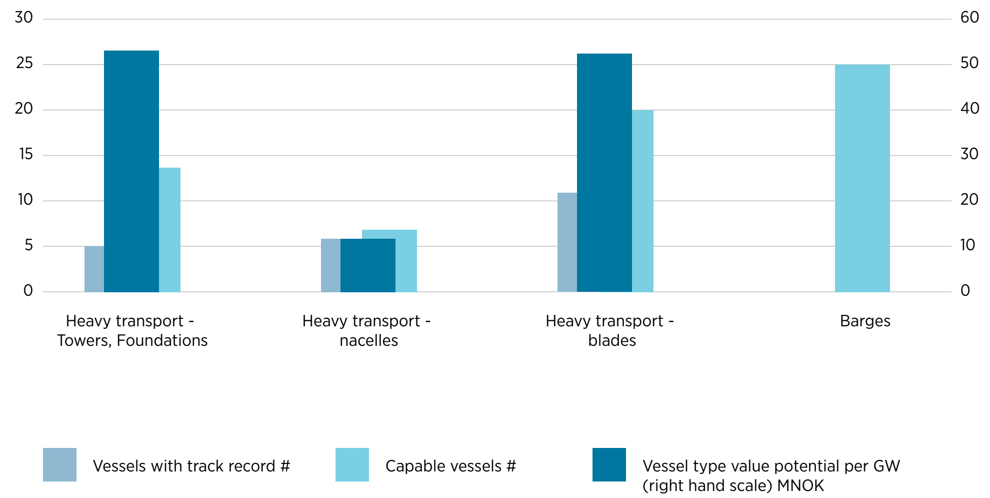
Appendix 2

A. VALUE ESTIMATES FOR BOTTOM FIXED OFFSHORE WIND

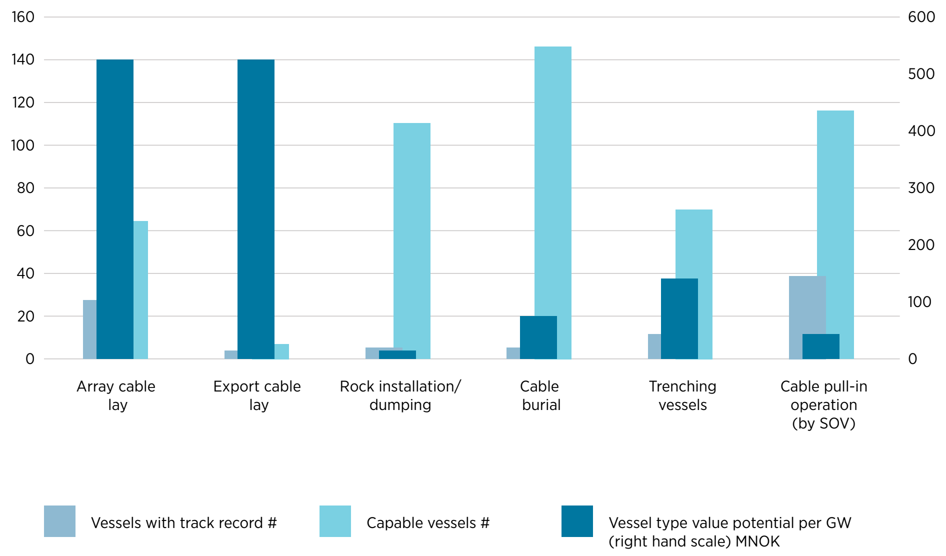
1 PLANNING AND SURVEY



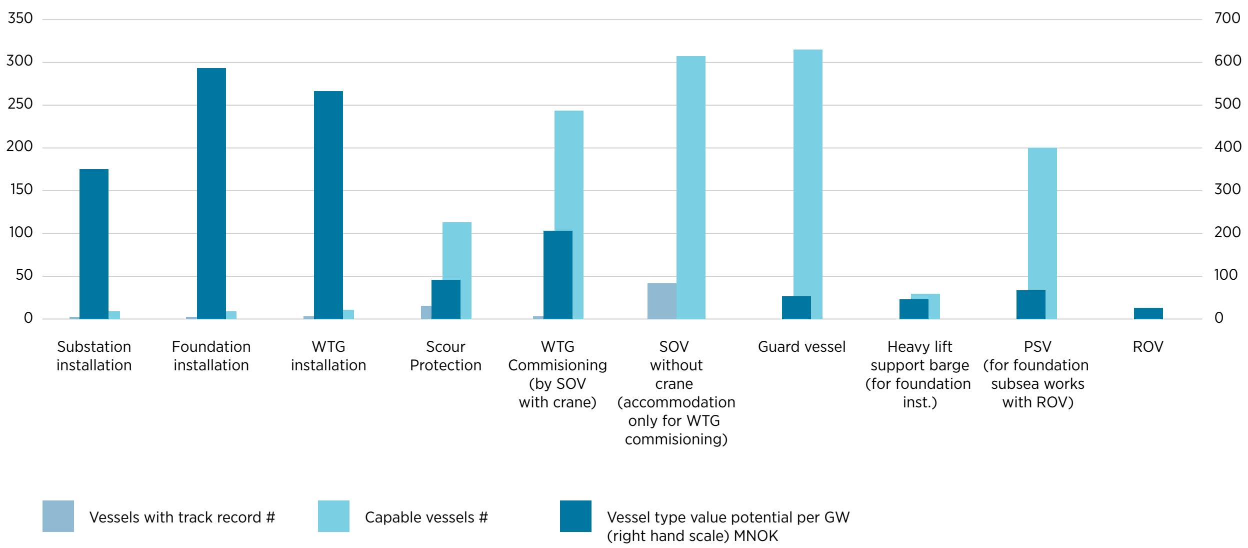
2 PROJECTS LOGISTICS



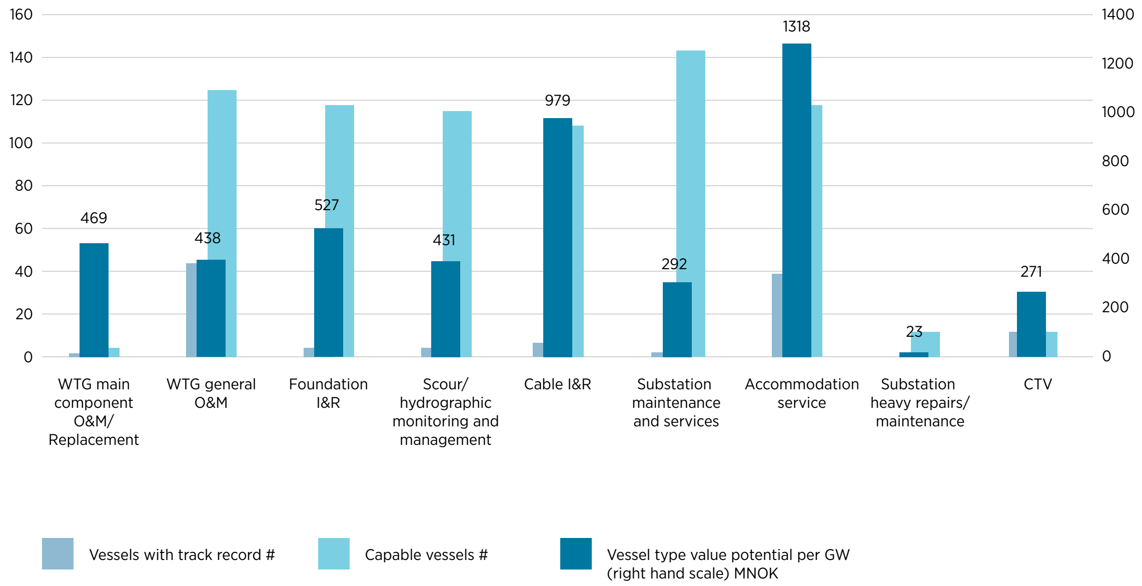
3 CABLE LAY



4 INSTALLATION

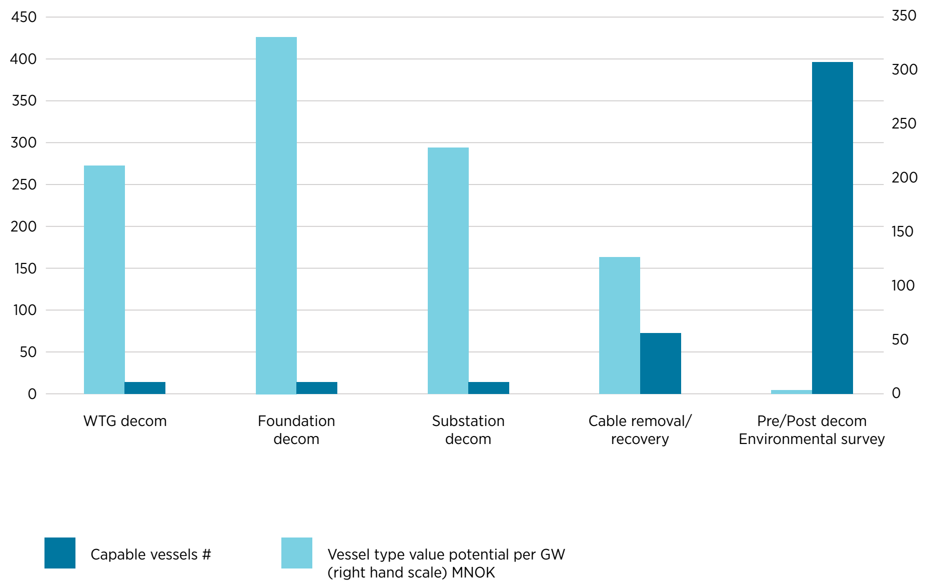


5 OMS



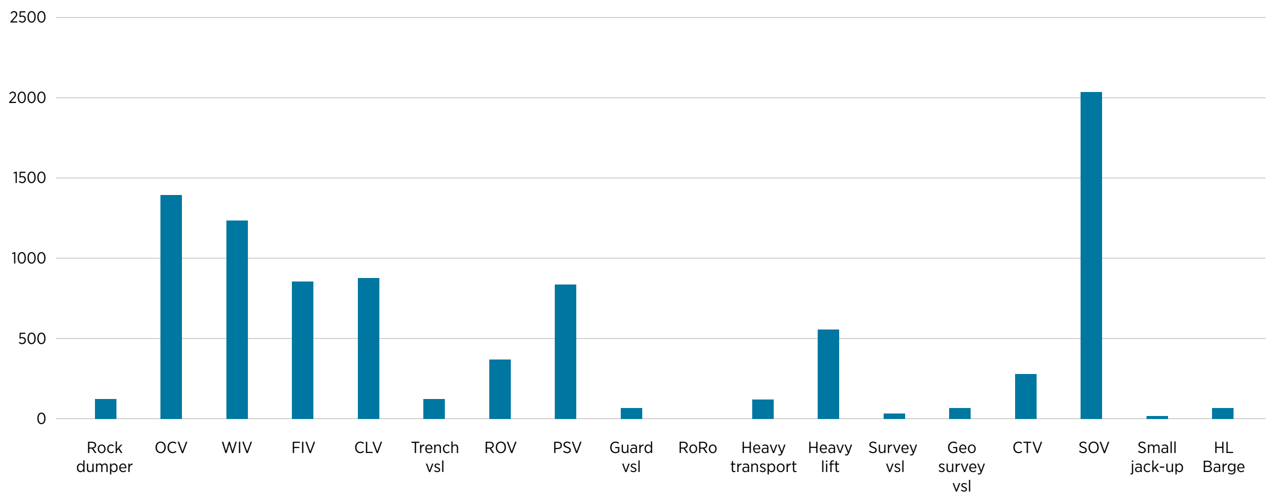
160
140
120
100
80
60
40
20
0
1400
1200
1000
800
600
400
200
0
469
438
527
431
979
292
1318
23
271
WTG main component O&M/ Replacement
WTG general O&M
Foundation I&R
Scour/ hydrographic monitoring and management
Cable I&R
Substation maintenance and services
Accommodation service
Substation heavy repairs/ maintenance
CTV
Vessels with track record #
Capable vessels #
Vessel type value potential per GW (right hand scale) MNOK

6 DECOM



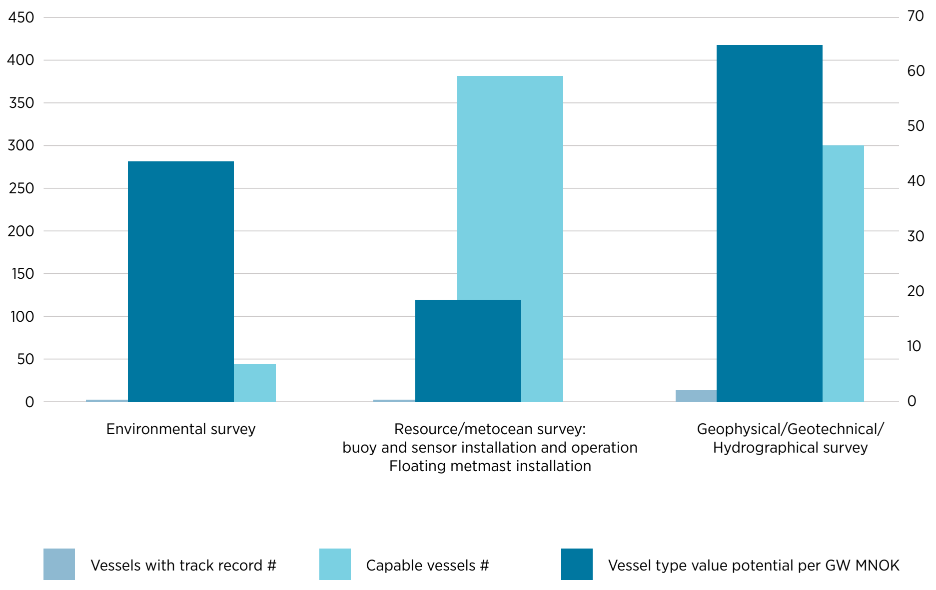
450
400
350
300
250
200
150
100
50
0
350
300
250
200
150
100
50
0
WTG decom
Foundation decom
Substation decom
Cable removal/ recovery
Pre/Post decom Environmental survey
Capable vessels #
Vessel type value potential per GW (right hand scale) MNOK

VALUE OPPORTUNITY PER VESSEL TYPE IN BOTTOM FIXED OFFSHORE WIND

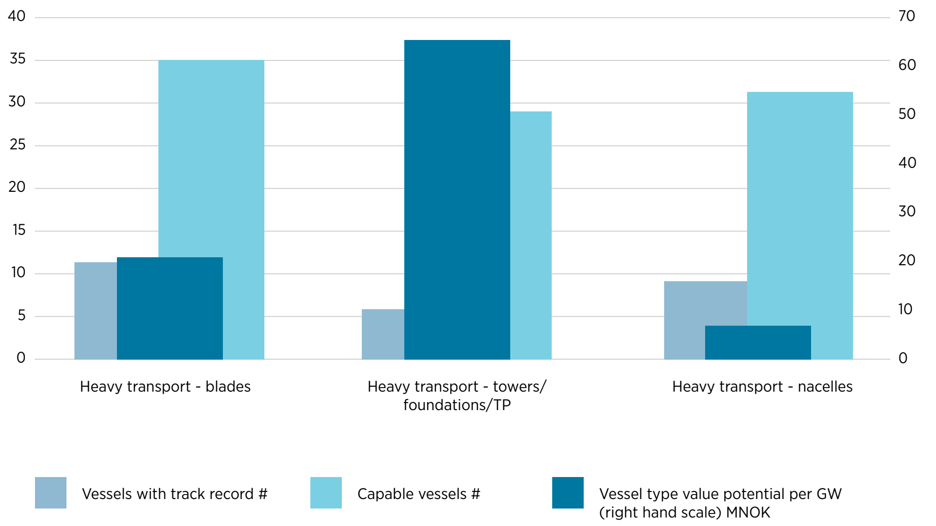


B. VALUE ESTIMATES FOR FLOATING OFFSHORE WIND

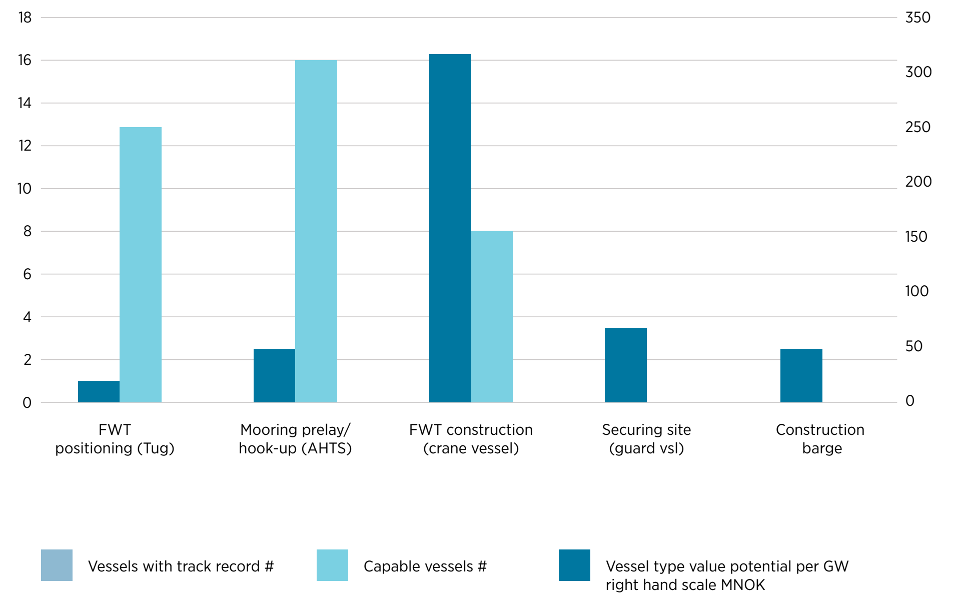
1 PLANNING AND SURVEY



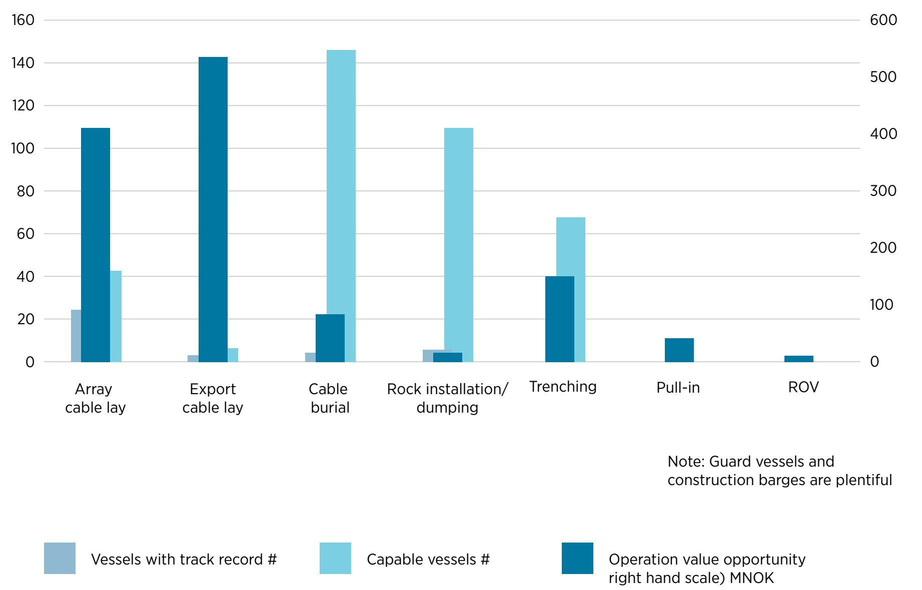
2 PROJECTS LOGISTICS



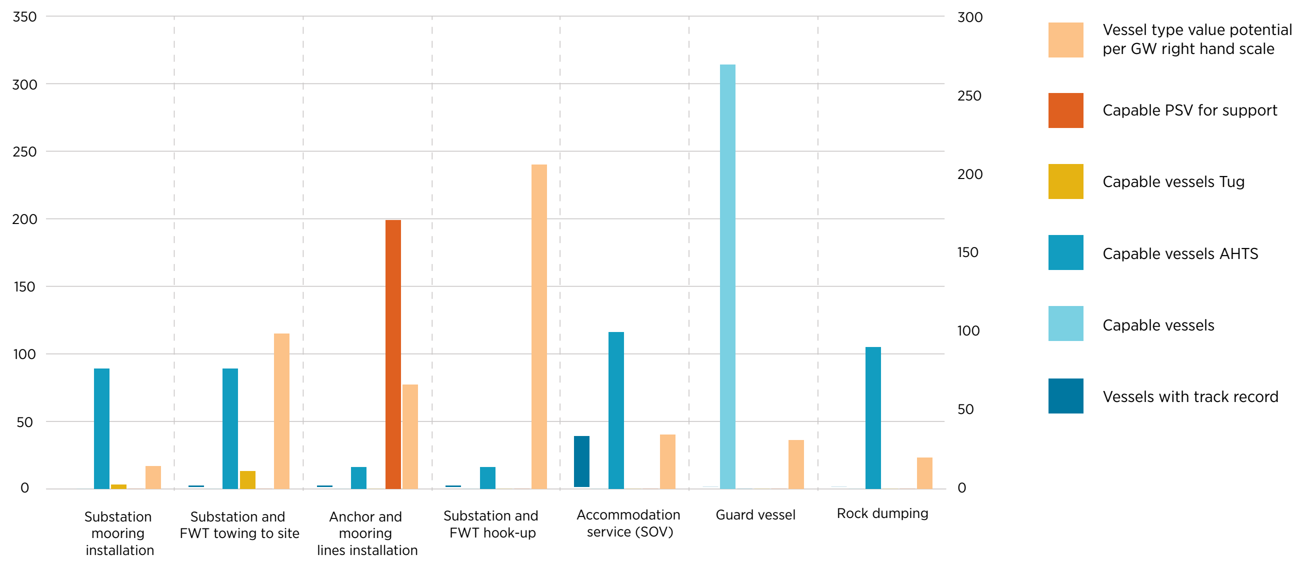
3 CONSTRUCTION



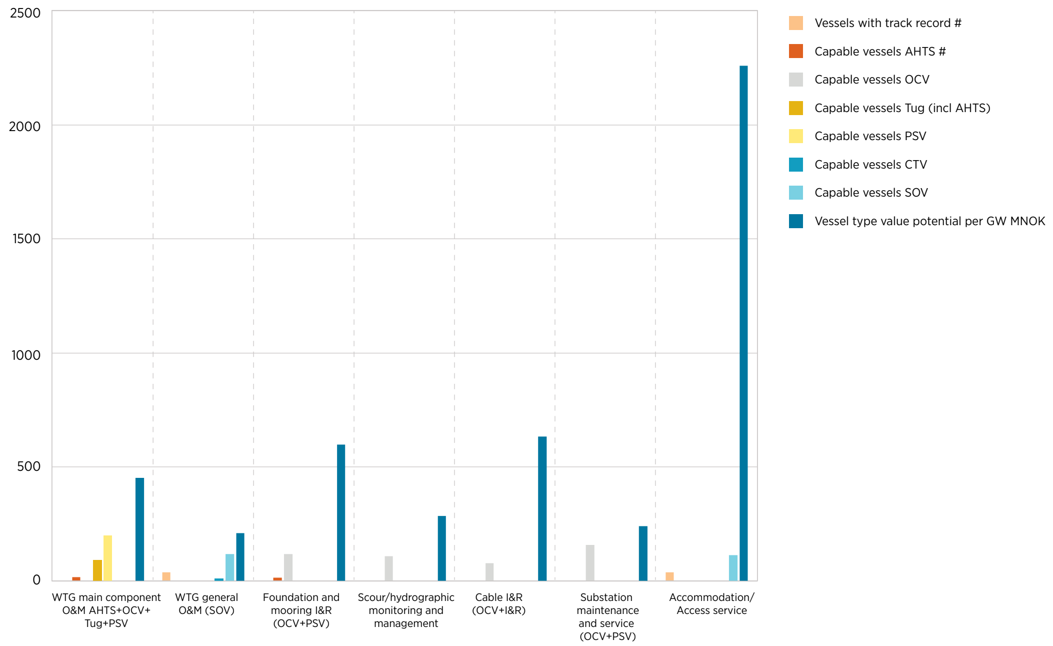
4 CABLE LAY

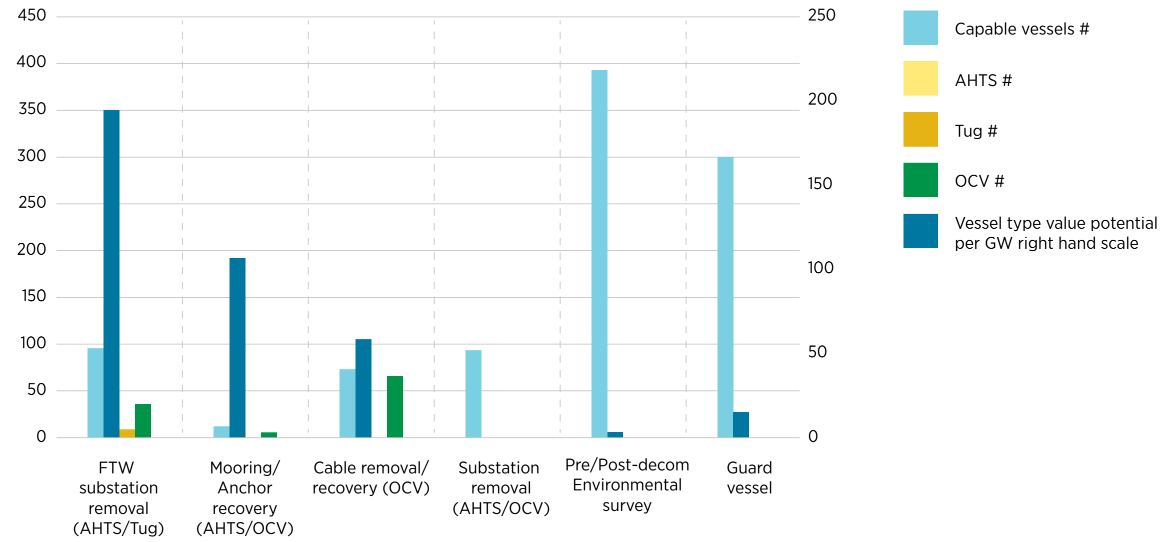


5 INSTALLATION

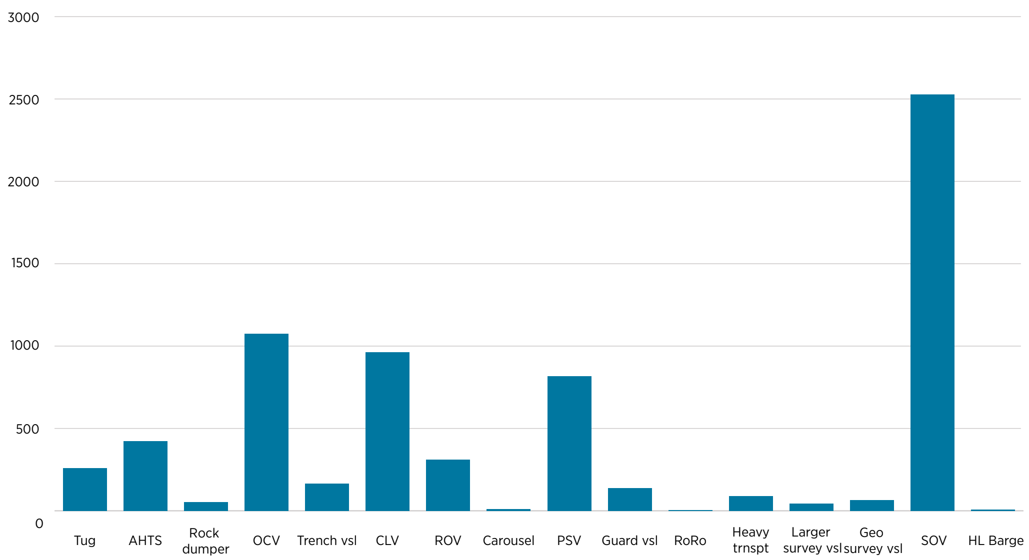


6 OMS





VALUE OPPORTUNITY BY VESSEL TYPE (GW)



Appendix 3

COMPETITIVE FORCES IN OFFSHORE WIND MARINE OPERATIONS

New entrants

Market
- Large interest in installation vessels from players outside the established OW industry.
- Decom-players entering into installation (as reversed decom operation, instead of the opposite threat?)

Technology
- FWT foundation concept development

Incumbents

Market/Strategy
- Consolidation/ Vertical integration of interna-tional players within BoP / WTG installation. Fleet size for flexibility
- Risk- willingness wrt future turbine size
- Embracing zero-emission requirements

Technology/Procedures
- Weather planning/optimization.
- Re-use of tools, seafastening

Power of Clients

Market/Strategy
- Contract models, local content
- Safety and zero-emission requirement for marine operations
- Supply of WTIV with sufficient lifting/ jacking capacity
- Technology
- Industry standard for turbines and foun-dations
- Turbine-size development
- Blade technology (voiding need for blade repair)

Power of Suppliers

Market
- Oil and gas market (cost/availability of Seismic, OCV, AHTS, HLV)
- Supply chain limitations (cable, offshore substation and equipment)
- Interconnections: enhanced need for cable/cable –lay ops

Technology
- W2W solutions for FWT (access from floating to floating units)
- Alternative fuel and Energy Storage Systems
- Infrastructure for alternative fuels

Substituting solutions

Methods
- Construction/assembly of floating OW by crane ships, barges and/or land-based cranes
- Choice of material steel/concrete) will determine construction sites, type and extent of FWT transport
- RoRo vessels for the transport of nacelles replacing special tonnage?
- Survey, Installation, Maintenance, decom meth-odology: co-operation /economy of scale over several farms efficiency.
- SOV replacing CTV (in particular for long distances)

Technology /Market
- Survey, Maintenance: satellite-monitoring of fauna, digitalisation and increased use of ROV og AUV instead of large complex ships.
- Cable –lay integration: single ship for trenching, bundled laylegging, burial, jointing/repair work
- PSV modification to SOV and rock dumping (scour/cable protection)
- Site-base to accommodate technicians and other staff with helicopter for access to WTG
- Seabed- installed substations
- Offshore battery charging (for SOV, CTV)
- HVDC for long distance power cables requiring much larger substations)

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