THE CROWN ESTATE

Jack-up vessel optimisation

Improving offshore wind performance through better use of jack-up vessels in the operations and maintenance phase

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This study has been prepared by Sally Shenton of Generating Better Limited and Chris Mallett and Mike Frampton of London Offshore Consulting. Assistance was given by Mick Turner of Sinnodyne Ltd and Edward Wood of E W Energy Ltd. This report was commissioned for and by The Crown Estate.

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Using this report
This report has been prepared to assist those with little experience of jack-up vessel use as well as practitioners who are involved in managing strategic and operational aspects of jack-up vessel work in the O&M phase of an offshore windfarm.

Contents



1 Executive summary

This study has been commissioned by The Crown Estate and addresses the use of jack-up vessels in the operations and maintenance (O&M) phase of UK offshore windfarms. It presents experience of the use of jack-up vessels at operational offshore windfarms and considers the potential to improve windfarm performance through better use of jack-up vessels. The report reviews the role that increased collaboration between windfarm owners could play in reducing the Levelised Cost of Energy (LCOE) and puts this in context with other potential improvements. The study focuses on the UK offshore wind portfolio but considers vessel availability and demand in the European context and beyond.

More than 500 jack-up vessel interventions at operational offshore windfarms have taken place in the UK to date. There is evidence of long periods of turbine downtime in some cases while repair campaigns are planned and delivered. **Production downtime losses while campaigns are planned and implemented have ranged from a few hundred thousand pounds to several million pounds per event.**

Jack-up vessel deployment and mobilisation costs can form a substantial proportion of repair bills and can make fast repairs of single turbines challenging to justify in isolation. In addition to supporting work on offshore wind turbines jack-up vessels also have a role to play in the maintenance of offshore substations and associated transmission infrastructure.

Experience gained so far in the use of jack-up vessels in the O&M phase highlights opportunities to contribute to reductions in the LCOE through

- Faster response times to undertake repairs
- More efficient project planning
- Reduced charter costs through a more structured, proactive approach in the O&M phase and greater optimisation of geographical campaigns

With the increasing scale of deployment and the geographic clustering of offshore windfarms in the UK and elsewhere, there are now greater opportunities for collaboration which can speed up repair times, reduce repair costs and minimise lost production revenue. **Improved planning and collaborative approaches, aided by improvements in the use of condition-based information, could increase revenues by £52m – £110m per year across currently operational UK offshore windfarms.** As larger turbine models are introduced and the size of the operational fleet grows, the benefit of better jack-up vessel use will make an even greater contribution to reducing LCOE.

Uncertainty about long term failure rate trends makes it challenging for owners to make commitments to long term vessel charters. A collective full time jack-up vessel charter may offer benefits if there is a large take-up of club membership and failure rates are relatively high but alternatives exist.

A flexible charter club offers an alternative proactive approach to collaboration, with owners pre-planning for vessel-sharing without engaging a full time shared vessel. This form of flexible jack-up club offers the simplest starting point to improve readiness and facilitate rapid ad-hoc shared vessel charters. This is achieved through: proactive site assessment, contractual readiness, improved communication between windfarm owners, alignment of repair practices/working methods and contracting approaches. This approach avoids owners being required to commit significant budget to charter a vessel that they may not fully require and also enables rapid deployment. This improves the efficiency of jack-up vessel deployment and offers cost savings on mobilisation and usage.

A flexible charter club introduces a lower risk, lower cost option to increase benefits to windfarm owners and takes its lead from a successful vessel collaboration seen recently on the east coast of the UK. The use of a 'club' based approach extends the concept to ensure heightened readiness with the potential to reduce vessel availability risk and associated production downtime. Some specific recommendations for progressing this concept are at section 7.

A marked reduction in the need to use a jack-up vessel to repair operational wind turbines through increasing in-situ repair capability and improvements in turbine reliability is also key in delivering sustainably high performance. Further development of condition based monitoring and predictive failure modelling will increase proactive repair intervention and extend planning windows for jack-up vessel work resulting in higher levels of wind turbine availability. Realistically, however, there will be a continuing role for jack-up vessels in the maintenance of offshore windfarms and their associated offshore transmission infrastructure. Collaborative approaches have the potential to reduce costs and increase production income and should be considered further.

Figure 1: Specific recommendations for progressing this concept are contained in section 7

Recommendations are grouped in three themes		
1. Facilitate increased efficiency and collaboration in the use of jack-up vessels	2. Eliminate barriers to collaboration	3. Wider recommendations to reduce main component repair risks

2 Introduction

Until recently, the market for operations and maintenance (O&M) jack-up vessels was limited to a small number of users and suppliers. Original Equipment Manufacturers (OEMs) have been the predominant user of O&M jack-up vessels with much use focused on meeting warranty commitments and guarantees. This landscape is rapidly changing as more offshore windfarms move beyond the initial warranty period and newer strategies emerge for sharing jack-up vessel risk within more recently agreed warranty contracts. Windfarm owners and operators are increasingly taking more responsibility for delivering arrangements for O&M jack-up vessels which is leading to an increase in the number of users and a potentially larger number of individual jack-up campaigns which are smaller in scope.

Increased collaboration and the sharing of good practice to speed up jack-up vessel deployment now has the potential to improve the way jack-up vessels are used during the O&M phase. With increasing numbers of turbines now installed and clear geographical clusters emerging, this study identifies opportunities for industry-wide collaboration and other potential improvements in the use of jack-up vessels which could speed up repair times, reduce maintenance costs and improve overall levels of electricity production.

The number and capability of jack-up vessels has increased over recent years but with corresponding increases in charter costs for larger vessels designed for efficient construction campaigns, there are still relatively few lower-cost O&M-focused jack-up vessels. As a result owners are seeking to optimise the strategic use of jack-up vessels in the O&M phase to address main component failures in an efficient and cost-effective manner.

This study focuses on the post-construction period with both warranty and post-warranty periods included. The construction and decommissioning phases of the windfarm development lifecycle are not covered by this study. Simulations are used to illustrate potential benefits based on forecast build out rates to 2020 using a simplified approach and using assumptions based on industry experience.

Through the development of models for collaboration, removing barriers and sharing examples of good practice, it is likely that increased collaboration can contribute to reducing the Levelised Cost of Energy (LCOE).

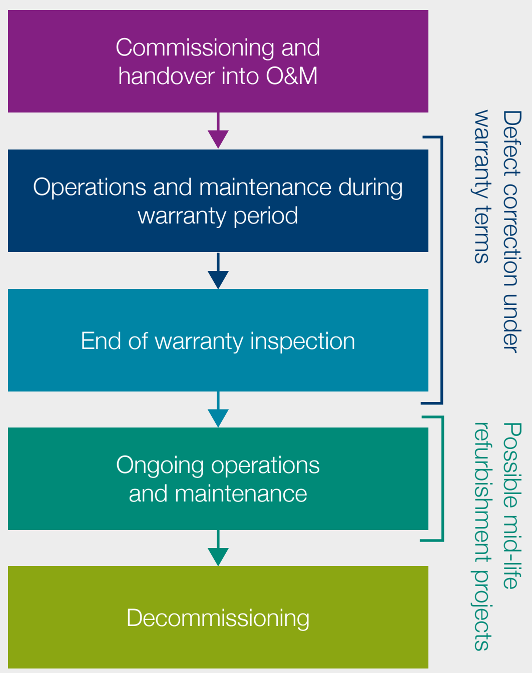
2.1 The operations and maintenance lifecycle

The current typical design life of offshore windfarms is between 20 and 25 years. Through this period, routine operation and maintenance tasks will be required to ensure asset performance is optimised. Specific maintenance campaigns will be designed to ensure continued high levels of performance throughout the lifetime of these assets. The lifecycle of an operational windfarm is shown in Figure 2. In the early stages of the asset life, owners will usually enter into contracts with the OEM which will include warranties on the performance of the assets. Initial warranty periods generally span the first two to five years and place responsibility and liability for early-life plant failures with the OEM.

Once the initial warranty period has ended, owners have a range of options for delivering O&M activities which range from extended OEM warranty contracts, use of independent service providers and deliver maintenance with their own teams.

O&M costs are estimated to make up at least a quarter of overall offshore windfarm lifetime costs and O&M could become a £2bn per year industry across the UK offshore wind sector by 2025 (GL Garrad Hassan, 2013). Efficiencies and cost savings in the O&M period represent a strong opportunity to make a material contribution towards industry targets to reduce LCOE (The Crown Estate, 2012).

Figure 2: The O&M lifecycle of an offshore windfarm



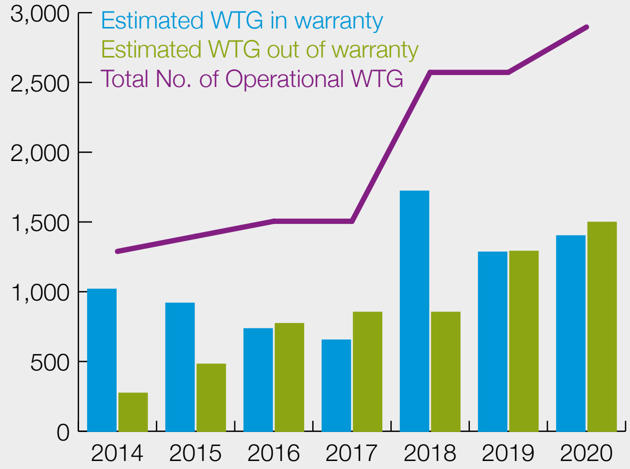
2.2 The growing importance of O&M in offshore wind

The offshore wind sector in the UK has seen considerable growth since the first Round 1 windfarms were constructed in 2002/3. The Crown Estate has overseen two rounds of offshore windfarm development which has resulted in large scale deployment of offshore wind turbines off the coast of the UK. There are currently 1,239 operational offshore turbines in UK waters with a further 213 under construction (figures correct as at 25 July 2014).[1]

Preparations for extensions to several Round 1 and Round 2 windfarms are ongoing along with the implementation of Round 3, Scottish Territorial Waters and Northern Ireland developments. Depending on development and construction timetables for future planned offshore windfarms there could be more than 3000 turbines operational or under construction by 2020 representing a significant fleet of assets within the UK.

The total number of operational turbines to 2020 has been estimated (Figure 3) and this has been used in simulations of jack-up vessel demand later in this report. Estimates are based on one of many possible scenarios and represent a mid-case assessment of potential build out rates, drawing on information published by Renewables UK (Renewable UK, 2013).

Figure 3: Assumed number of operational offshore wind turbines based on mid-case estimates of build-out to 2020



1 Operational data as at 25 July 2014. Those sites classed as under construction include: a proportion of Gwynt y Môr and West of Duddon Sands (which are partially operational) and all of Westermost Rough and Humber Gateway which have not yet started generating electricity.

3 The use of jack-up vessels in offshore wind operations and maintenance

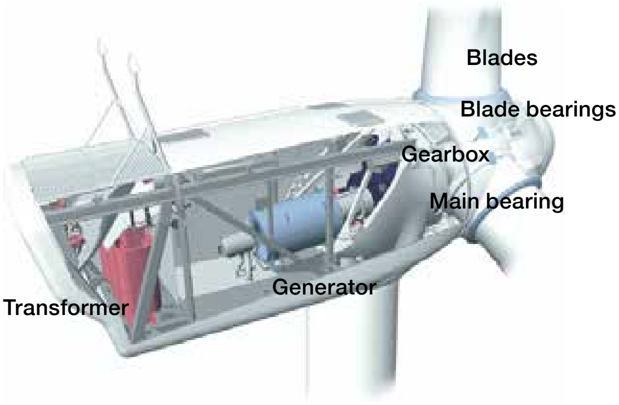
The O&M phase of an offshore windfarm will invariably require some use of jack-up vessels to replace main components located at the top of the turbine tower. Experience from early operations in the offshore wind sector points to a range of uses of jack-up vessels in the O&M phase. In addition to single turbine repairs, there have been some large-scale retrofit campaigns to address type faults thereby reducing the risk of failures later in life and improving long term yields. There have also been examples of isolated single-turbine failures which have resulted in some period of extended down-time while a jack-up vessel is sourced.

3.1 Repairing offshore wind turbines – is a jack-up vessel required?

A wide range of maintenance activities is required at offshore windfarms to ensure high availability and resulting commercial benefits. In 2013, The Crown Estate and Scottish Enterprise published A Guide to UK Offshore Wind Operations and Maintenance (GL Garrad Hassan, 2013) which describes the approaches to operating and maintaining offshore windfarms and sets out the various activities required. A key aspect of O&M requiring access to jack-up vessels is responding to defects and faults with main turbine components – blades, gearbox, generator and in-turbine transformer. In an offshore wind turbine these are commonly located at the top of the tower either inside or connected to the nacelle (the only current exception being the turbine transformer which can be located in the tower base on some models).

Although turbines are often supplied on the basis that the main components have a design life of 20+years, experience in smaller, mature onshore turbines has shown that, in reality, failures will occur. Some of the common defects offshore can be repaired in-situ using teams that travel out to the turbine in a normal crew transfer

Figure 4: Main components requiring jack-up vessel for replacement



vessel, using cranes located on the turbine. However, not all repairs can be made this way. Owing to the weight and size of some components there are repairs which require a larger crane or need to be carried out externally to the turbine (Figure 4).

There are also situations which require a replacement of the entire component to be made. Each of these components is heavy and typically cannot be lifted with the crane installed in the turbine. It is necessary to bring a heavy lift jack-up vessel fitted with a crane onto the site to act as a lifting platform. Not all main component failures require the replacement of an entire component and some turbine designs allow main components to be disassembled in-situ and repairs made using parts which can be deployed using standard crew transfer vessels. The degree to which in-situ repairs are possible will vary with turbine type and examples of in-situ repairs are shown in Table 1 (noting that these examples will vary between different turbine designs).

For in-situ repairs it is possible to lift spare parts and tools from a crew transfer vessel using a crane mounted in the nacelle. Given the size and weight of the components, the lifting operation requires planning to ensure high standards of health and safety – this may mean that it can only be

There are examples of extended periods of turbine downtime while repair plans using jack-up vessels are put into place. In some cases single turbine events have resulted in over £1m lost production income.

Table 1: Examples of main component failures and associated repair action

Examples of failures where in-situ repair is possible	Examples of failures where a complete main component replacement is required
Damage to gearbox bearings in high speed section	Design fault in generator
Damage in final (high speed) stage of gearbox	Damage or defect to 1st or 2nd planetary stage of gearbox
Damage to high or low speed shaft	Replacement of main bearing / blade bearing / yaw ring
Damage to generator bearings	Earth current fault in generator
Minor blade defects	Significant blade damage following lightning strike

carried out during calm seas or low winds. Even with these restrictions the speed of repair is likely to be considerably faster and at significantly lower cost than using a heavy lift jack-up vessel.

There are numerous examples from existing operational sites where in-situ repairs on main components have cost less than undertaking full component replacement using a heavy lift jack-up vessel. Many of these depend on detecting technical issues early through the combined use of condition-based monitoring techniques and inspections in order to avoid more extensive damage to the turbine (See Section 4.3)

3.2 How are jack-up vessels used?

When it is necessary to replace a main component, heavy lift jack-up vessels provide a stable lifting platform and can hold a crane with sufficient reach to replace components in the nacelle. The large deck space on a jack-up vessel can be used to store multiple spare parts and avoid or reduce the need to transit back and forth to collect parts from a port.

Once the jack-up vessel is in position, the crane located on the vessel is used to lift the defective component out of the turbine and place the new component into position. Prior to the jack-up vessel arriving on site, work will have been undertaken to prepare the turbine, which may include the disconnection of electrical and control cables, draining of oil and preparations for the safe delivery of the lifting operation. The tasks to prepare the turbine for main component exchanges are usually carried out using standard windfarm crew transfer vessels.

The stages of jack-up vessel operations carried out in connection with O&M activity on offshore windfarms are shown in Figure 5.

The time taken for lifting operations to exchange components can be a relatively small proportion of the whole process.

Operational procedures will be put in place to ensure effective management of health, safety and environmental issues during the work and industry standard guidelines have been developed to aid this (Renewable UK, 2013) (Renewable UK, 2012). These procedures will also include measures to coordinate heavy lift jack-up vessel entry onto site and movements around the site with particular focus on the approach route to each turbine, selection of the position where the vessel will stand and minimising the risk of any collateral damage to subsea cables and the turbine structure. Further details can be found in Annex 2.

3.3 Planning jack-up vessel operations

Windfarm owners have a range of options when planning to replace main components. These are largely driven by the high cost of jack-up vessels in relation to the total cost of the repair. Choices about how and when to deploy a jack-up vessel are driven by the mobilisation cost of the vessel (which may vary depending on the vessel reaction

Figure 5: Stages in jack-up vessel deployment and typical durations

Early detection of defects, enabled through the use of condition-based monitoring techniques and inspections, can remove the need to use a heavy lift jack-up vessel if the turbine is designed to enable in-situ repairs.

time) balanced against the cost of lost production revenue incurred from any downtime. For single or low numbers of turbines requiring repairs, a fast vessel mobilisation may not always be the most cost-effective action especially where there is a long period of advance warning of a fault through alarms provided by condition monitoring systems.

Main components can be replaced as a single turbine repair, repairs can be grouped together (so-called 'batch repairs') or campaigns can be run across the whole site to install an updated design, for example. These scenarios are illustrated in Table 2.

There will be a break-even point between the additional cost of undertaking a fast repair and the additional lost revenue risked by waiting for further turbines to fail before mobilising a jack-up vessel. However, it is often not possible to predict when the next turbine will fail and strategies to wait for a number of defective turbines can be more costly if the average time between failures is considerable. It is difficult to predict the remaining life of main components at present owing to lack of operational experience although predictive tools are being developed and there are already many examples of effective early warnings.

Regardless of the strategy chosen, project planning needs to combine jack-up vessel activity planning with the maintenance tasks required to complete the repair. This is illustrated in Figure 6 and shows the need to coordinate the arrival of spare parts at the load-out port, preparation of the turbine for the removal of the faulty component and the time taken after the jack-up vessel has been used to rebuild and re-commission the turbine so that it can be returned to an operational state. Figure 7 also shows the stages of project planning. The complexity of the planning activity will increase as the number of turbines in any campaign increases.

The basic operating specifications for the jack-up vessel in terms of requirements for load capacity, deck space, lifting capacity, services and accommodation can reasonably be finalised once there is a clear definition of the O&M tasks to be carried out. From this assessment a short list of jack-up vessels can be drawn up; however, the selection of a suitable jack-up vessel cannot be based on this initial assessment alone and a site-specific assessment is required. The site-specific assessment is discussed in detail in section 3.4. Failure to apply the relevant technical expertise to this preliminary assessment can result in the selection of an unsuitable jack-up vessel with consequential delay or increased campaign risk.

Formal planning consent or marine licensing is not required to deploy a jack-up vessel during the O&M phase of an offshore windfarm. However, there may be site specific environmental considerations which require liaison with regulators and their statutory consultees. There may also be requirements to undertake surveys or assessments, but windfarm owners have been working with regulatory bodies to streamline this process and ensure high standards of environmental care while not incurring costly delays to jack-up vessel deployment.

A comprehensive exchange of technical information between the site owner and the jack-up vessel owner is an essential part of project planning. An outline list of the information to be exchanged is illustrated opposite in Figure 7. The availability of this information and the time taken to prepare and distribute it has a direct impact on the project timeline.

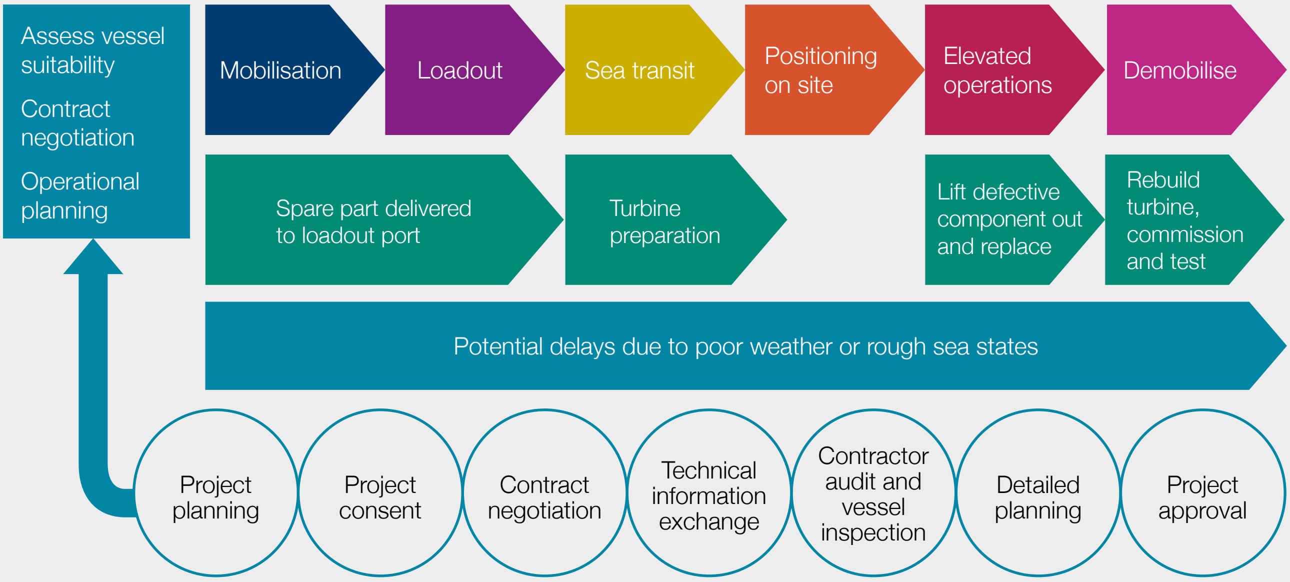
Efficient planning depends on the availability and quality of the metocean data, site geophysical surveys and the soil investigation reports. Omissions or deficiencies in the quality of this information may not be identified until later in the planning process; this can result in delays caused by the need for clarification, additional data processing or new site surveys.

Detailed planning must include a competent assessment of not only the environmental, geophysical and geotechnical conditions existing at the site, but also the layout of fixed structures, subsea pipelines and cables and scour protection materials. For this reason it is essential that all the relevant information has been entered on the site plans.

Table 2 : Main component repair strategy options

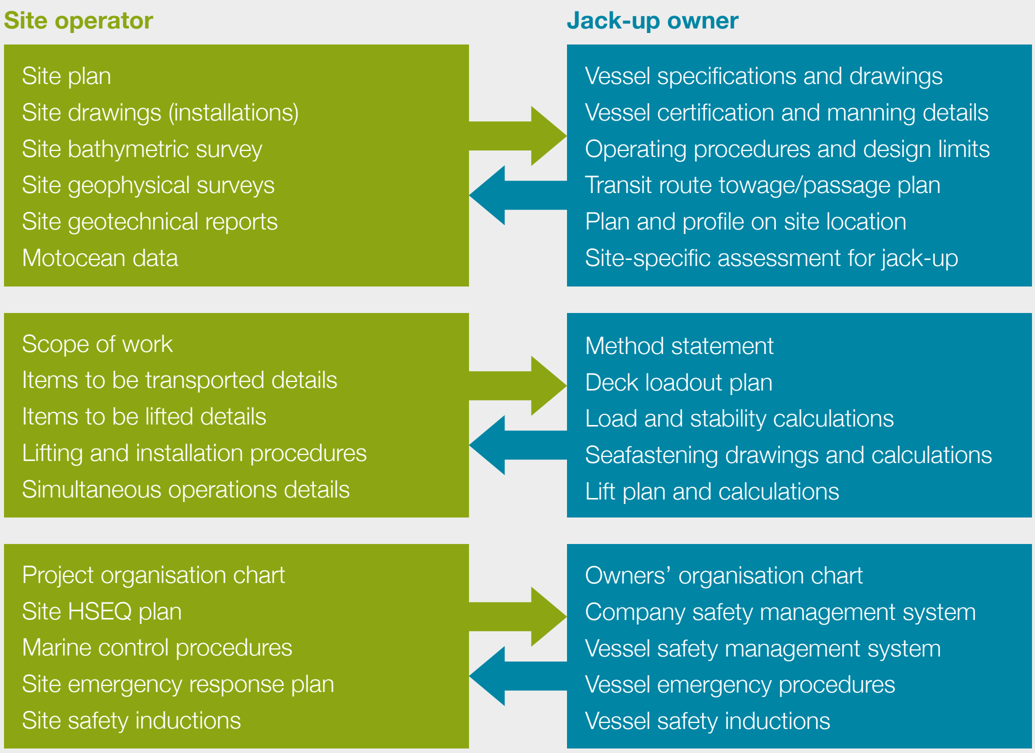
Type of operation	Key features	Problems and benefits
Single turbine repair	A jack-up vessel is deployed to repair a single turbine that is stopped due to a defect	• Production losses are minimised • Mobilisation costs can be high for single turbine repair events
Reactive batch repairs	A small number of turbines are repaired at the same time by waiting until a number of turbines have failed and require repair before deploying a jack-up vessel	• Extended periods of downtime can result in higher lost revenue • Mobilisation costs per turbine are lowered
Proactive batch repairs	A small number of turbines are repaired prior to failure based on early warnings from condition monitoring systems	• Downtime is considerably lower • Mobilisation costs are reduced
Serial defect campaigns	All the turbines on a site or number of sites are upgraded to improve the design and prevent failures (this can include turbines which have failed and/or proactive action to prevent failures)	• Downtime is lowered • Mobilisation costs are lowered • Costs are high due to duration of charter of heavy lift jack-up vessel

Figure 6: Interaction between planning, jack-up vessel operations and turbine maintenance tasks



The wide range of geophysical, geotechnical and environmental differences that exist between different offshore windfarms and different turbines locations on a single windfarm means that there is currently no single jack-up vessel in the current market that can work at every UK turbine location.

Figure 7: Technical Information Exchange



Delays can be avoided by maintaining a robust set of information that is easy to transfer to others involved in the repair. Delay in information exchange can also be reduced by arranging non-disclosure agreements, if required, well in advance.

The final stage of planning is a formal review by the site owner/operator, key contractors , jack-up vessel owner and marine warranty surveyor to ensure that all parties agree in detail with the procedures to be adopted. This can be completed within 14 days or less if relevant parties have been involved at an early stage of the planning cycle.

3.4 Jack-up vessel suitability

Certain types of jack-up vessels are more capable of working on particular seabed types, for example soft soils, whereas others are more suitable for deployment on hard rock or boulders. Some jack-up vessels can be modified (although this is likely to incur considerable expense) to make them more suitable for greater water depths and different seabed conditions but it is stressed that there is currently no single jack-up vessel that is capable of accessing every offshore turbine installed or in planning.

Each class of jack-up vessel is subject to a different set of limiting criteria which governs their operations and these limitations can have a significant effect on the feasibility of carrying out O&M projects in a timely and economical manner. The vessel needs to be assessed to understand if it is technically and commercially suitable to undertake each project and the stages in this assessment are shown in Figure 8.

The suitability of the jack-up vessel for elevated operations at any location offshore is determined by the site-specific assessment in accordance with the international industry standard contained in ISO-19905-1.

The site-specific assessment evaluates the stability and structural integrity of a jack-up vessel in relation to the environment in which it is to be used. The assessment is a complex analysis which combines detailed information about the jack-up vessel structure with site-specific geophysical and geotechnical data (from the site survey and soil investigation reports) and the extreme environmental conditions described in metocean reports. Using all of this information it is possible to assess the predicted behaviour of the jack-up vessel and analyse the impact of wind, wave and current loads on it. This can be used to determine whether the vessel can remain safely elevated on location in severe weather conditions.

In cases where the jack-up vessel may not be able to remain safely elevated in extreme storms, it is possible for limits to be set which determine the most severe environmental conditions that it could safely withstand at a specific location. Any forecasts exceeding these limits will constrain operations and may even require the vessel to take shelter before weather fronts are experienced. In practice this can result in lengthy operational delays if weather forecasts are uncertain or where there are only limited windows of acceptable weather.

Parts of the site-specific assessment can be carried out in advance of planning a specific project. However, the detailed nature and characteristics of each turbine location need to be considered before the jack-up vessel capability

Figure 8: Technical studies required to determine suitability of jack-up vessel for working at an offshore windfarm

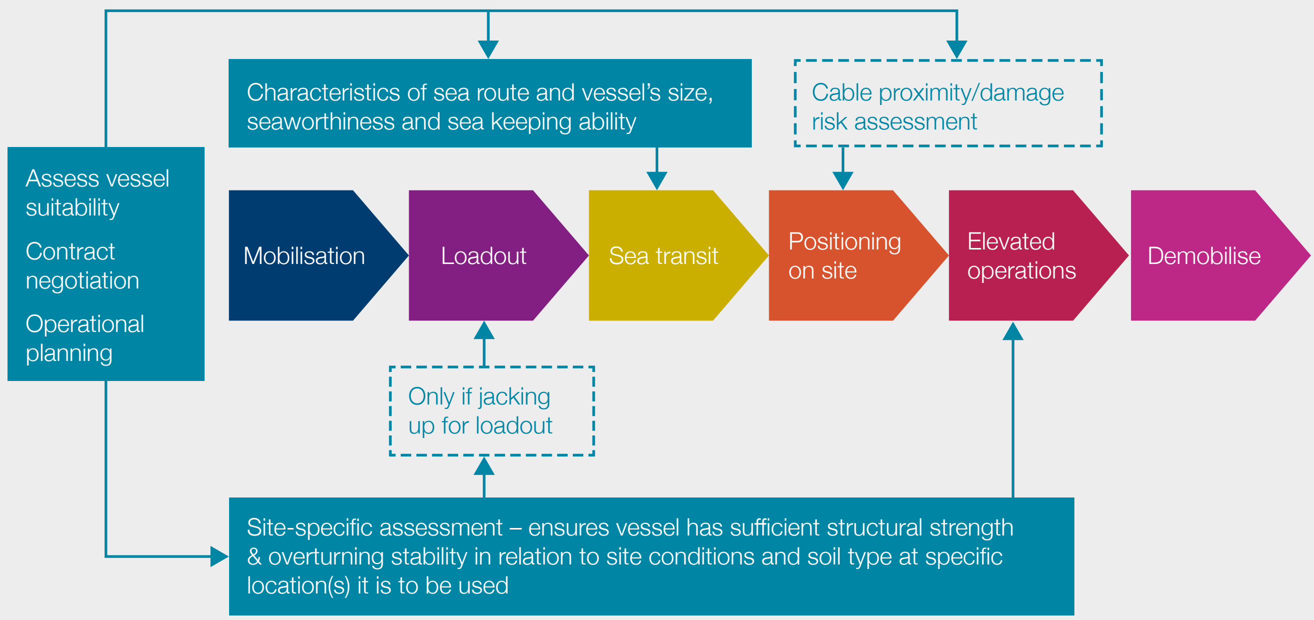


Figure 9: Examples of jack-up vessels used in the O&M phase of offshore windfarms

is confirmed. This is because each location may present a different set of challenges.

The reliability of the site-specific assessment depends upon the accuracy of the data supplied. Any location-specific survey data must be updated regularly as seabed changes can occur over relatively short periods of time. These changes can have an adverse impact on the feasibility of installing and operating the jack-up vessel.

3.5 Experience to date of using jack-up vessels in O&M

Post-construction vessel operations at UK offshore windfarms have ranged from single turbine repairs to site-wide engineering upgrade programmes. A wide variety of vessels have been used and based on this experience, the current fleet available to UK operational offshore windfarms has been collated. Vessels have been grouped[2] to illustrate the nature of each vessel's principal service in the marine renewable energy industry. Vessel information has been provided based on publicly available sources[3]. Criteria for selecting vessels and further information on vessel groups are given in Annex 1.

Group 1 – versatile and economical self-propelled or propulsion-assisted vessels built or modified specifically for servicing offshore wind turbines during the O&M phase

Group 2 – Self-propelled dynamically positioned self-elevating jack-up vessels specifically designed to transport, lift and install wind turbine generators (WTG) and their foundations during the construction phase, typically attracting higher charter rates than Group 1 because of their larger capacity – these can also be used on O&M tasks

Group 3 – multi-purpose self-propelled jack-up vessels which are capable of working in offshore wind and the oil and gas sector.

In groups 1, 2 and 3, ship-shaped vessels have typically higher transit speeds than self-propelled barges.

Group 4 – jack-up vessels which are not fitted with propulsion systems and which are towed by tugs and positioned using anchors and moorings

In all groups, the deployment of jack-ups in very shallow water presents a challenge. Most self-propelled jack-ups require deeper water to operate the propulsion thrusters than non-propelled barges but non-propelled barges must deploy anchors for positioning. The high risk of damage to subsea cables caused by the mooring operations may prevent non-propelled jack-ups from approaching turbines located in very shallow water.

3.6 Jack-up vessel costs

The costs of a jack-up operation are split into mobilisation, charter and demobilisation costs, as shown in Figure 10.

The overall cost will be a factor of:

- **Site & task specific factors** including windfarm location and transit distance[4], number of turbines requiring jack-up vessel operations and extent of any ''wait on weather'' time during load-out, transit and on-site operations
- **Vessel related factors** including vessel size, capability and vessel capital cost/owners target utilisation
- **Market related factors** including type of charter (spot vs long term), demand within the market and time of year

2 The nominal boundaries of the groups are by no means rigid or absolute as it will be recognised that most of the listed vessels can legitimately be listed in more than one category because they are capable of, or can be modified to suit, a wide range of offshore services in all aspects of the marine industry.

3 The listed maximum operating water depth is a nominal value because the actual limiting depth for each deployment will depend upon the installed leg length, the leg penetration, the minimum safe air gap and the required operating air gap. This can only be defined by the site-specific assessment for each location and the results of the assessment will determine whether installation and operation of the jack-up is feasible and whether any operating constraints or weather restrictions will apply which might affect the efficiency of the operation. The listed load and capacity data has been extracted from the vessel owner's published information. The data is general in nature and should not be used for project planning without confirmation from the owners because the actual load capacity will depend upon the type of load, the deck layout and the vessel's floating and elevated stability. The lifting capacity may change depending upon the crane boom configuration and other factors.

Improving knowledge of the use of jack-up vessels through training and experience gained during prior jack-up vessel campaigns can reduce the planning and information exchange timeline by up to 70%.

Group 1: Jack-ups and leg stabilised vessels particularly suitable for O&M projects

Owner/Operator vessel name	Water depth (max)	Deck load capacity	Crane load capacity	Remarks
DBB WIND	35 m	430 m^2 492 t	30 t @ 30 m	Self-propelled and dynamically positioned jack-up barge fitted with a retractable bow thruster to allow operation in very shallow water
DBB WIND PIONEER	34 m	530 m^2 650 t	232 t @ 19 m	Propulsion-assisted and dynamically positioned jack-up barge fitted with 4 retractable thrusters and a mooring system to allow access to shallow water locations. Available Jan 2015
DBB WIND SERVER	45 m	1000 m^2 1500 t	400 t @ 20 m	Self-propelled and dynamically positioned ship-shaped jack-up. Available Aug 2014
A2SEA SEA POWER	24 m	1020 m^2 2386 t	230 t @ 22 m	Self-propelled (non-DP) ship-shaped leg-stabilised vessel uses two anchors to assist positioning

Group 2: Windfarm Installation Vessels (WIV) that could also be used during O&M

Owner/Operator vessel name	Water depth (max)	Deck load capacity	Crane load capacity	Remarks
MPI RESOLUTION	35 m	3200 m^2 4875 t	600 t @25 m	World's first ship-shaped wind turbine installation vessel
MPI ADVENTURE	40 m	3600 m^2 6415 t	1000 t @ 25 m	Ship-shaped enhanced WIV vessel based on RESOLUTION
MPI DISCOVERY	40 m	3200 m^2 6541 t	1000 t @ 25 m	Ship-shaped enhanced WIV vessel based on RESOLUTION
A2SEA SEA INSTALLER	60 m	3350 m^2 5000 t	800 t @ 24 m	GustoMSC 9000G class ship-shaped jack-up vessel
A2SEA SEA CHALLENGER	60 m	3350 m^2 5000 t	900 t @ 24 m	GustoMSC 9000G class ship-shaped jack-up (available 2014)
Van Oord AEOLUS	–	3300 m^2 6500 t	900 t @ 30 m	GustoMSC 9000G class ship-shaped vessel Construction in progress 2014
RWE Offshore Logistics FRIEDRICH	45 m	4500 t	1000 t @ 25 m	Construction vessel purpose-built self-propelled jack-up barge for offshore wind
RWE Offshore Logistics VICTOR MATHIAS	45 m	4500 t	1000 t @ 25 m	Construction vessel purpose-built self-propelled jack-up barge for offshore wind
Bard Engineering WINDLIFT -1	45 m	2000m^2 2000 t	500 t @ 31 m	Construction vessel purpose-built self-propelled jack-up barge for offshore wind

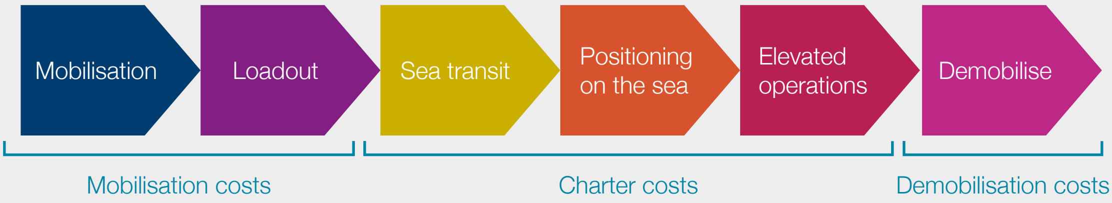
Group 3: Self-propelled multi-role heavy lift jack-ups

Owner/Operator vessel name	Water depth (max)	Nominal load capacity	Crane load capacity	Remarks
Swire Blue Ocean PACIFIC ORCA	75 m	4300 m² 8400 t	1200 t @ 31 m	Self-propelled DP2 ship-shaped jack-up fitted with helideck
Swire Blue Ocean PACIFIC OSPREY	75 m	4300 m² 8400 t	1200 t @ 31 m	Self-propelled DP2 ship-shaped jack-up fitted with helideck
Hochtief/GeoSea INNOVATION	50 m	8000 t	1500 t @ 31 m	Self-propelled DP2 ship-shaped jack-up fitted with helideck
Fred Olsen Windcarrier BRAVE TERN	45 m	3200 m² 600 t	800 t @ 24 m	Self-propelled DP2 ship-shaped jack-up fitted with helideck
Fred Olsen Windcarrier BOLD TERN	45 m	3200 m² 600 t	800 t @ 24 m	Self-propelled DP2 ship-shaped jack-up fitted with helideck
Gulf Marine Services ENDEAVOUR	65 m	1035 m² 1600 t	300 t @ 11 m	Self-propelled DP2 jack-up barge fitted with a blade rack
Seajacks ZARATAN	55 m	2000 m² 3607 t	800 t @ 24 m	Self-propelled DP2 jack-up barge fitted with helideck
Workfox SEAFOX 5	65 m	6500 t	1200 t @ 25 m	Self-propelled DP2 jack-up barge fitted with helideck
Seajacks KRAKEN	41 m	900 m² 1436 t	300 t @ 16 m	Self-propelled DP2 jack-up barge fitted with helideck
Seajacks LEVIATHON	41 m	900 m² 1666 t	400 t @ 18 m	Self-propelled DP2 jack-up barge fitted with a blade rack
Seajacks HYDRA	41 m	900 m² 1666 t	400 t @ 18 m	Self-propelled DP2 jack-up barge. Optional helicopter deck or blade rack
Hochtief THOR	50 m	1850 m² 2700 t	500 t @ 24 m	Self-propelled DP1 jack-up barge fitted with helideck
Hochtief VIDOR	50 m	3100 m² 6500 t	1200 t @ 28 m	Self-propelled DP2 jack-up barge fitted with helideck
Geosea (DEME Group) NEPTUNE	40 m	1600 m² 2500 t	600 t @ 26 m	Self-propelled DP2 jack-up barge
Geosea (DEME Group) GOLIATH	40 m	1080 m² 1400 t	400 t @ 15 m	Propulsion assisted DP2 jack-up barge towed by tug in transit

Group 4: Non-propelled jack-up barges

Owner/Operator vessel name	Water depth (max)	Nominal load capacity	Crane load capacity	Remarks
Jack-Up Barge BV JB-114	40 m	1000 m² 1250 t	300 T @ 18 m	GustoMSC SEA2000 class Jack-up barge
Jack-Up Barge BV JB-115	40 m	1000 m² 1250 t	300 T @ 18 m	GustoMSC SEA2000 class Jack-up barge
Jack-Up Barge BV JB-117	45 m	2500 m² 2250 t	1000 t @ 22 m	GustoMSC SEA2000 class Jack-up barge DP propulsion units optional
Jack-Up Barge BV JB-118	45 m	2500 m² 2250 t	1000 t @ 22 m	GustoMSC SEA2000 class Jack-up barge DP propulsion units optional
Jack-Up Barge BV JB-119	35 m	900 t	300 t @ 15 m	Jack-up barge
A2SEA SEAWORKER	40 m	750 m² 1100 t	308 t @ 22 m	GustoMSC SEA2000 class Jack-up barge
A2SEA SEAJACK	30 m	2500 m² 2500 t	800 t @ 20 m	Ravenstein HLV barge purpose built jack-up barge for offshore wind in 2002

Figure 10: Cost breakdown for heavy life jack-up vessel usage



> Deployment costs to the West Coast of the UK are higher and weather risk is greater – this may prevent a jack-up vessel being deployed for single turbine repair tasks.

Charter costs for jack-up vessels for use in O&M typically range from £45k to over £100k per day (Dalgic, 2013). Longer-term charter agreements will typically attract a lower charter rate whereas unplanned short term tasks will see higher rates based on conditions in the spot-market at the time of negotiation. Market conditions at the time of the charter can greatly affect costs, leading to potential long term uncertainty. Studies to model jack-up vessel costs suggest that there can be up to 40% difference in costs between a long-term agreed charter and rates on the spot market. This is accentuated during periods of high demand for jack-up vessels and can also vary seasonally. Costs of heavy lift jack-up vessels during the O&M period, therefore, represent a large risk unless contractual rates can be locked in through long term arrangements (Hagen, 2013), (Dalgic, 2013) or by other means.

There are examples of some jack-up vessel owners offering fixed cost jack-up operations in other parts of Europe although this is not currently widespread. As cluster sizes grow and if sea bed conditions allow, this may become a more common, alternative form of contracting in the future.

> Jack-up vessel charter rates are a high-risk cost item in the O&M phase of an offshore windfarm if long-term charter agreements are not used due to the uncertainty around spot-market rates.

Figure 11: Transit route from North Sea to Irish Sea – three to eight days plus up to several weeks of potential weather delays

The overall cost of deploying a jack-up vessel includes fuel, port fees, sea fastenings and any expert advice required for site-specific assessment. The windfarm location can impact on the cost and availability of the jack-up. For example, longer transit times to the west coast of the UK could either result in potentially higher mobilisation fees or the deployment of a jack-up not being considered feasible at all. There is also increased risk of weather-related delay during transit.

4 While charter agreements often start at the load-out port, the distance that a barge needs to travel will be reflected in the charter rate and/or mobilisation charge. In practice this is subject to negotiation although jack-up owners will seek to engage with other potential users in an area to try and establish further work for the barge if large transit distances are involved which can reduce mobilisation costs.

4 Factors causing delays and opportunities to improve repair times

The value of lost revenue due to a turbine that is stopped with a main component fault will depend on the size of the turbine, the capacity factor of the windfarm and the incentive regime under which the windfarm operates. There are many different factors which result in repair delays and experience from early repair projects has demonstrated that improvements in repair planning can deliver value to owners. It is also possible to avoid or limit losses caused by turbine downtime if faults can be identified early and turbines can safely continue to operate often with careful monitoring whilst a repair is planned.

4.1 Impact on cost, revenue and LCOE

Experience of current operational offshore windfarms indicates that capacity factors typically range between 34% and 47% with later Round 2 projects at the higher end of this range. Operational windfarms and those currently under construction qualify for Renewable Obligation Certificates (ROCs) of between 1 and 2 ROCs/MW depending on when the windfarm was commissioned and also earn income from selling the power they generate.

The value of long-term turbine downtime has been estimated using capacity factors that reflect the fleet of offshore windfarms in operations and under construction. Typical market rates for electricity and Renewable Obligation Certificates have been used to demonstrate the potential value from better use of jack-up vessels for main component repairs. Value is estimated for three different scenarios, detailed in Figure 12 using standard project requirements for planning a jack-up vessel intervention.

Calculations of the typical value of lost production per turbine downtime event under each scenario are shown in Table 3.

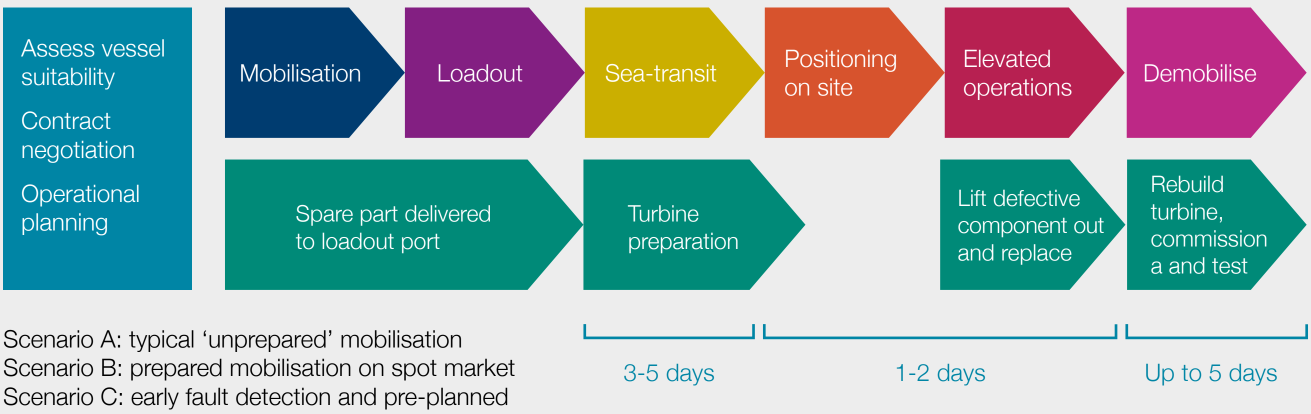
There are isolated examples within the industry of single turbine events resulting in turbine downtime of over a year, sometimes approaching 18 months. In these individual cases the value of this lost production revenue could be as high as £2.5m per event. There are also more isolated examples of very rapid repairs being undertaken, utilising condition-based monitoring information and proactive charter arrangements but currently these are far from being the norm.

4.2 Causes of delay

In order to deliver high levels of electricity production, owners seek to minimise turbine downtime by ensuring any repairs are carried out quickly. Delays to heavy lift jack-up vessel repairs can arise from:

- waiting for a suitable vessel to become available to undertake the repair
- time taken to undertake site surveys and any environmental approvals
- time to undertake procurement activity and negotiate contracts, undertake planning and complete site-specific assessments
- transit times to the operational site and weather-related delays
- lead time on spare parts
- poor project execution

Figure 12: Overview of planning requirements and potential for delays depending on repair scenario utilised



Scenario A: typical 'unprepared' mobilisation
Scenario B: prepared mobilisation on spot market
Scenario C: early fault detection and pre-planned vessel arrangements

Waiting time for a suitable vessel

The principal factor causing delays to the completion of early major repairs and/or replacements in the sector has been the higher than anticipated requirement for intervention coupled with the lack of available jack-up vessels capable of carrying out the required tasks. Those vessels capable of carrying out the replacement of turbine components were already engaged in the construction of new offshore windfarms. The distance between windfarms in construction and operating created a situation where the vessels engaged in construction could not easily be released under short-term spot charter agreements to carry out repairs to individual turbines.

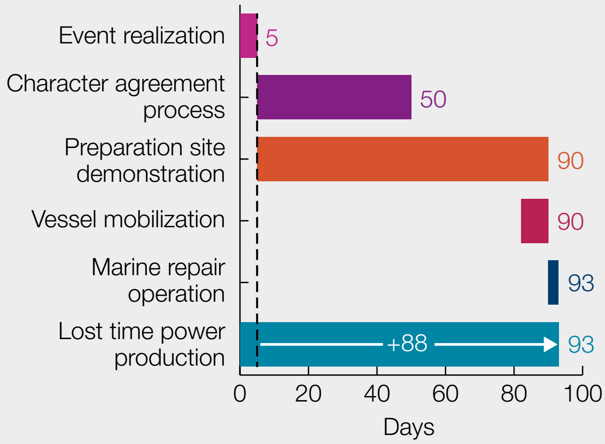
Site specific constraints limit the use of particular vessels and can lead to extended waiting periods until a suitable vessel becomes available. Experience to date has highlighted particular problems with very shallow locations and turbine sites with challenging sea-bed conditions, both of which have seen delays identifying and securing a suitable jack-up vessel during the O&M phase. However, notwithstanding the variation in site conditions, performance of the jack-ups listed in this report to date has demonstrated that most will be capable of servicing the great majority of turbines already installed.

Surveys and environmental approvals

The seabed hazards identified during site investigation campaigns carried out before construction continue to present a challenge for the deployment of jack-up vessels for O&M projects. These hazards result in jack-up vessel installation problems caused by:

- seabed slope, sand waves, scour pits, local holes and depressions
- settlement or sliding
- punch-through and soil bearing failure
- shallow gas and unexploded ordnance
- seabed obstructions such as rocks, boulders, wrecks, debris

Figure 13: Experience of planning jack-up vessel operations – duration of pre-operational stages (reproduced with permission of DBB Jack-up Services Ltd)



The presence or emergence of on-site hazards could restrict the number of suitable jack-up vessels that can work on a site; understanding and tracking such hazards is important and will impact on the potential for any future jack-up vessel clubs or other forms of collaboration. Further information about on-site hazards can be found in Annex 2.

The lack of up-to-date survey information, especially on a site with significant hazards or where frequent changes in water depth are likely, has been a cause of delay on some projects and sites located on shallow sand banks present a particular challenge.

As previously described in Section 3.3, there may be site specific environmental considerations which require liaison with regulators and their statutory consultees. This liaison, along with any requirements to undertake

Table 3: Estimated Value of Lost Production arising from single Turbine Downtime event

Scenario	Value of lost production (£)[5]	
	Round 1/Round 2	Future development
A: 'unprepared' Six month wait for jack-up vessel while turbine is not producing power	£885k	£1.7m
B: 'spot market – prepared' Three month wait for jack-up vessel while turbine is not producing power	£443k	£867k
C: 'fault detection – pre-prepared' Condition monitoring predicts defect before failure and jack-up vessel arrangements in place to ensure no downtime during jack-up vessel mobilisation[6]	£53k	£100k

5 Based on typical revenue expectations and production-weighted average capacity factors of 39% (currently operational) and 44% (late Round 2 developments onwards) and assuming a typical turbine capacity of 3.6MW for Round 1/Round 2 and 6MW for Remaining Round 2 / Round 3 / Scottish Territorial Waters / Northern Ireland

6 In this scenario the only downtime experience is while the turbine is stripped down and prepared for the replacement of a main component, the time taken to undertake lifting operations and then to rebuild and recommission the wind turbine

environmental surveys or assessments, may result in repair delays.

Time taken in negotiation, planning and site-specific assessments

Between two and six months is a typical period for planning once a potentially suitable vessel has been identified and there are examples of longer waiting times in some circumstances. This is been confirmed in a recent study by a jack-up vessel operator (MAKE, 2014), which reported 88 days lead time to prepare a selected vessel to undertake a project. The largest amount of time taken was in the planning phase and in preparing site documentation, as indicated in Figure 13.

In many early O&M jack-up vessel operations, jack-up vessels without prior site specific experience were employed. Consequently, the poor quality of planning for some early O&M projects led to delays caused by difficulties that had not been foreseen. In recent years, this has been rectified by the windfarm operators, turbine suppliers and jack-up vessel owners/operators. The efficiency of the O&M process has rapidly improved as a result of:

- publication of a technical guidance document through RUK for the marine renewable industry
- provision of jack-up vessel training seminars
- development of competent O&M planning procedures

The provision of a jack-up vessel site-specific assessment may involve more than one outsourced service and can require a comprehensive review of the jack-up vessel structural drawings and specifications and the production of a finite element (FE) model. This process can take in excess of 30 days to complete and longer delays should be expected if the outsourced services have not been secured in good time.

Delay can be avoided in circumstances where the results of a previous site-specific assessment for the same jack-up vessel, or another jack-up vessel of the same design, can be applied to the proposed turbine locations that are to be visited during the O&M project. Production of the site-specific assessment can also be expedited in cases where the contractor performing the analysis has completed previous similar assessments so that the vessel-specific data and the FE model are ready and available.

Geographical location, clustering and impacts on transit times

Where offshore windfarms are clustered, there is greater potential to take advantage of a jack-up vessel that finishes working on an adjacent site. There are large clusters of wind turbines in the Wash, around the Thames Estuary and in the Irish Sea area which can take advantage of this increasing aggregation. Figure 14 shows a number of wind farm clusters which may be able to optimise jack-up vessel usage through collaboration.

Selection of a vessel that is located in the North Sea for an O&M project in the Irish Sea will involve transit time and could incur considerable delay in mobilisation. A selection of typical transit routes and times from the North Sea to offshore windfarms located in the Irish Sea is shown in Table 4 and excludes weather delays. This information will be used as part of the case studies in Section 6.3.

Weather conditions through the western part of the English Channel and around Land's End frequently exceed the prescribed limits for transit for most loaded jack-up vessels. Weather delays of seven days would not be unusual on a coast to coast transit at any time of the year and delays of several weeks can be expected during the winter months.

Weather delays during on-site operations

Jack-up vessels not capable of withstanding extreme storm conditions on site will not be able to remain

Table 4: A selection of typical transit times to west coast windfarms EXCLUDING weather delays

From North Sea	To Irish Sea	Approx. distance nautical miles	Approximate MINIMUM transit time with zero weather delay		
			Self-propelled ships: 10 knots	Self-propelled barges: 6 knots	Towed barges: 5 knots
Esbjerg, DK	Robin Rigg	965	4.0 days	6.7 days	8.0 days
Teesside, UK	Mostyn	830	3.5 days	5.8 days	6.9 days
Ijmuiden, NL	Mostyn	710	3.0 days	4.9 days	5.9 days
Gt. Yarmouth UK	Robin Rigg	695	2.9 days	4.8 days	5.8 days

Grouping geographically close jack-up vessel operations will reduce the repair costs as mobilisation costs are shared by a larger number of operators.

Figure 14: Offshore wind map – potential clusters

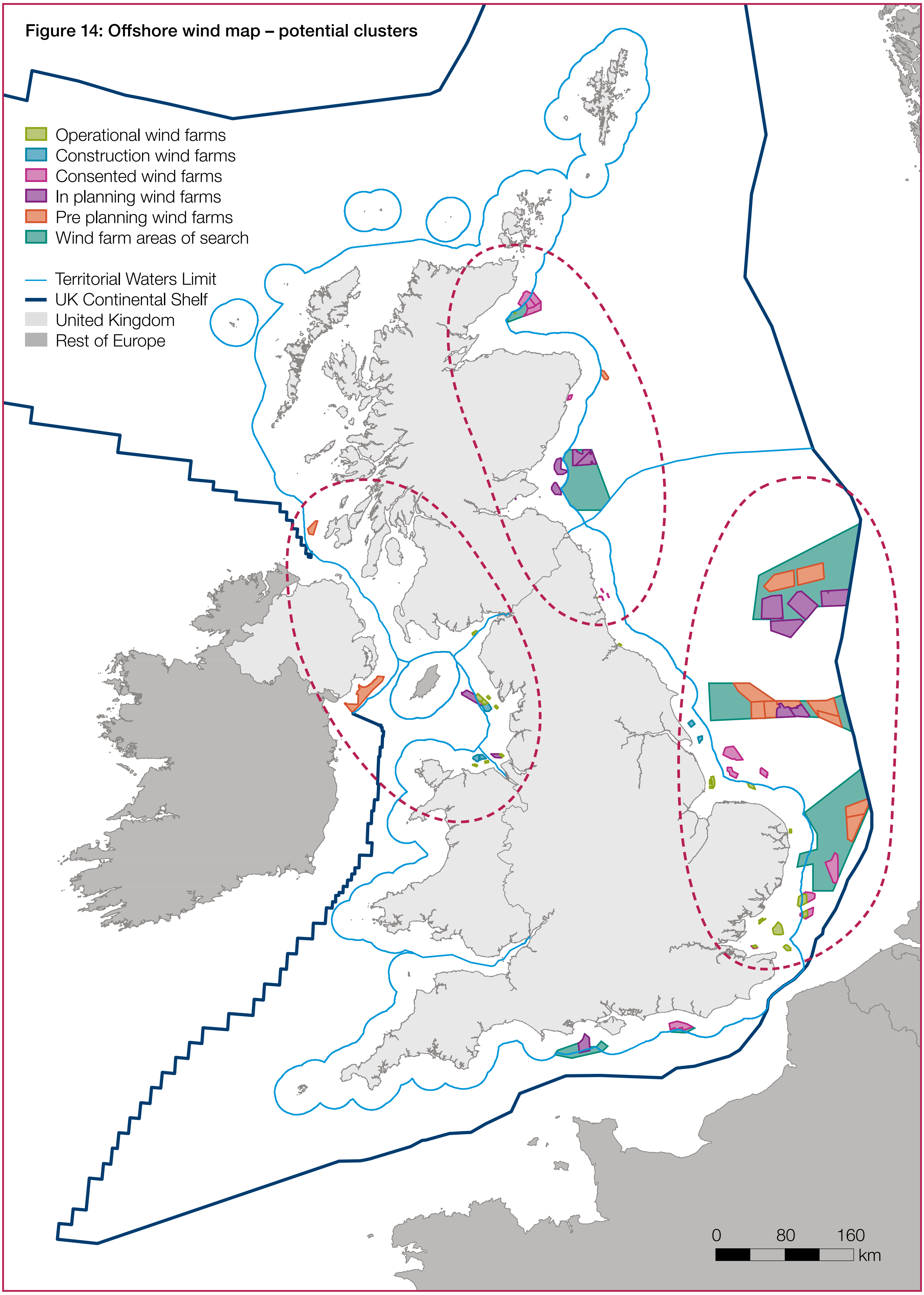


Table 5: Illustrated impact on long term turbine downtime (in event of main component faults) from availability guarantee-based warranty contracts

Number of turbines which could be stopped for 12 months and still meet 95% contractual availability guarantee given an assumed "background" contractual availability	"Background" availability (contractual availability excluding main component downtime)		
	96%	97%	98%
50 turbine site	0	1	2
100 turbine site	1	2	4
150 turbine site	1	3	6
200 turbine site	2	4	8

elevated during periods of bad weather due to constraints introduced as part of the site-specific assessment (described in Section 3.4). These jack-up vessels must be moved to a safe area or place of shelter prior to the onset of severe weather. This requirement can have a considerable impact on O&M projects in terms of delay, particularly in the winter months.

Similarly, jack-up vessels incapable of remaining elevated on site in extreme storms cannot be deployed for O&M in exposed offshore areas where deep leg penetration into the seabed is anticipated. This is because the time required for extraction of deeply penetrated legs cannot be accurately predicted. Consequently, any significant delay in removing the jack-up vessel from site could result in exposure to weather conditions which exceed safe limits before the move to shelter can be completed.

Offshore operations will inevitably incur weather downtime and other unpredictable delays which will accumulate throughout the progress of any O&M campaign. Even work sensibly planned for execution during the benign summer weather season may not be completed as winter approaches. The consequence of this would be that operators of windfarms scheduled for attendance later in the sequence might suffer significantly greater delays than were experienced by the operators of the first windfarm to be visited. This risk would need to be addressed if vessels are being used as part of a collaboration agreement.

Lead time on spare parts
Figure 12 highlights the need to coordinate the turbine maintenance plan with jack-up vessel deployment planning. It is essential that the spare parts required are available in time at the chosen load-out port. There have been examples of owners missing the opportunity to utilise a jack-up vessel because spare parts were not available. This is being addressed by owners through contractual arrangements with suppliers.

4.3 Opportunities to reduce delays to repairs

There are generally two ways that jack-up vessels are used to repair offshore turbines – through a reactive repair in response to a sudden failure or as a proactive tasks using condition-based monitoring information or in response to learning in relation to engineering/design issues.

There are good examples of repairs being undertaken quickly and efficiently during the O&M phase. It is important to learn lessons from these successful projects in order to minimise lost production revenue and add value throughout the O&M lifecycle.

Other opportunities to reduce delays in carrying out repairs are discussed below and include:
- use of condition-based monitoring and inspection to provide extended warning of future failure
- windfarm maintenance contract terms, conditions and incentives
- heavy lift jack-up vessel sourcing strategy including collaboration

Use of condition-based monitoring
Use of condition-based information will result in a greater proportion of repairs being undertaken proactively and gains time when repairs can be planned whilst the affected turbine is still operational. This opens up greater possibilities of developing O&M task pipelines which has the potential to reduce LCOE.

Condition-based monitoring and inspection techniques include vibration monitoring and analysis, oil debris analysis, temperature/pressure measurement (usually through the SCADA system), thermal imagery, partial discharge testing and specialise inspections (for example endoscope inspection of gearboxes). Such techniques can play an important role in helping to identify faults early, allowing, in some cases, in-situ repair thus preventing more widespread damage which may require replacement of a main component. This has been successfully used at early operational offshore windfarm sites and can significantly reduce production downtime. Maintenance regimes can also be adjusted to extend the time to failure, this might include grease purging at regular intervals to remove hard damage causing materials or increasing the capacity of in-line oil-filtration systems.

Early fault identification also provides a longer time window to source and plan for jack-up vessel deployment where in-situ repair is not possible. There is evidence that use of more advanced condition-based monitoring can detect faults between three and nine months prior to a downtime failure event occurring.

Predictive failure modelling enables a proactive replacement strategy for main components which are close to the end of their useful life – this could add value to repair campaigns by using vessels more efficiently. Although there are pilot projects underway, the development of 'remaining life' models is still in its infancy in the wind industry.

Windfarm maintenance contract terms, conditions and incentives

In the initial years of the life of an offshore windfarm, it is usual to operate under some form of warranty provided by the original equipment manufacturer, usually with guaranteed performance on an availability or yield basis. Availability-based contracts have been the most commonly used and typically include a number of "permissible events" which are excluded from the guarantee – for offshore wind, access issues, weather delays and sometimes jack-up availability can be excluded resulting in a "contractual availability" calculation upon which the guarantee is based. The availability guarantee is most commonly set at 95% (based on the contractually defined availability).

As offshore windfarms have increased in size and the reliability of smaller components has improved, availability guarantees (defined as an average across the site) can be met even when a number of turbines are stopped for long periods due to main component failures. In early years post commissioning, wind farm performance generally improves. This means there are effectively more hours available for O&M teams to manage breakdowns whilst still achieving a fixed availability guarantee; Table 5 helps illustrate this.

Availability guarantee mechanisms are not always an effective driver for the warranty provider to repair defective turbines quickly, especially where jack-up vessel mobilisation costs are relatively high and there is a relatively small number of affected turbines. As the warranty provider is not exposed to the production losses felt by the owner there can arise situations where repair objectives are not aligned.

Some owners are starting to take on responsibility for providing jack-up vessels to warranty providers during the warranty period. It is increasingly common for windfarm owners to be responsible for sourcing jack-up vessels after the warranty period expires even when ongoing maintenance services are provided by the turbine manufacturer.

To attempt to align repair objectives more closely, some turbine manufacturers are now offering maintenance contracts without availability guarantees. Instead, they will provide a guarantee of the output that a windfarm will produce – expressed in terms of the percentage energy yield from the available wind resource. Due to difficulties in measuring yield-based availability and the exclusions applied within guarantees, some operators are focussing on other measures to ensure improved availability. This might include compensation mechanisms based on target turbine down hours for planned service and incentives on extending Mean Time Between Failures and reduced Mean Time To Repair.

Vessel sourcing strategies and collaboration

As owners increasingly take on responsibility for jack-up vessel arrangements, they are beginning to enter into framework agreements with jack-up vessel suppliers to pre-arrange contractual terms and conditions and build effective working relationships. There is also early evidence of owners collaborating with one another and supporting case studies are presented later in this report.

Collaboration offers the potential to deploy jack-up vessels more quickly and reduce charter costs. There are clear drivers to take advantage of clusters and use this to reduce mobilisation costs and address risks from the geographic location of some offshore windfarms, as shown in Table 6.

Collaboration has proven to be successful in other industries and three examples are given opposite which illustrate different established methods of collaboration from the oil and gas and telecoms sectors.

The process of developing collaborative working arrangements can be complex and time consuming in the early stages and must provide attractive working practices which deliver value to potential members. The considerations for any 'club' arrangement are:

- how to levy charges to cover management and administration
- how to manage the liabilities of its members
- how to ensure the total cost of service is calculated for each member
- setting and meeting performance standards
- ensuring priorities are clearly set out and are seen as 'fair' by members
- clearly identifying the value of membership

Definite costs incurred through any upfront charges for collaboration (such as club management fees and charter commitments) must be balanced against the increased revenue earning potential from reduced jack-up vessel deployment times, potential cost savings and potential costs associated with improvements to condition monitoring equipment.

Long term jack-up vessel charters and investing up-front in site-specific assessments are difficult to justify financially on an individual site alone, owing to the relatively high costs involved and the relatively low expected number of failures. However, if these costs can be shared among a larger number of club members then they become cost-effective strategies as illustrated in the case studies later in Section 6.3.

Key influences on repair risk, also the feasibility and cost-effectiveness of any collaborative approach, are the likely supply and demand for jack-up vessels (short and long term) (discussed in Section 5).

Table 6: Potential collaboration opportunities

Opportunity	Benefit
Collective charter through jack-up club which contains sufficient turbine numbers to enable an ongoing long-term charter to be secured	• No exposure to spot market • Site-specific assessment can be done in advance • Reduced mobilisation costs
Tactical charter arrangements across multiple windfarms	• Increased charter periods should reduce costs
Ad-hoc vessel sharing in a geographical cluster	• Reduced waiting time, mobilisation and transit costs
Undertake initial parts of site-specific assessment for wide range of jack-up vessels	• Shared costs and increased readiness

Example 1: Flightshare – collaboration in oil and gas for shared helicopter usage

Flightshare provides a mechanism for companies to share excess seat capacity on North Sea helicopter flights. Sharing companies are required to have at least one contract in place with the three service providers and, once signed up, may share flights with companies holding contracts with the respective service provider.

Flightshare provides the legal mechanism for such shares by establishing the legal matrix between sharers including payment and indemnification in the event of an incident. The 'club' provides administrative services including initial sign-up, holding records of the signatories and ensuring continued service provision. Payments are calculated using a standard formula and club members see cost savings from reducing the number of unused seats.

Example 2: ACMA – a successful collaborative arrangement for subsea telecommunications cable repair

ACMA – the Atlantic Cable Maintenance & Repair Agreement was founded in 1965 and is a non-profit cooperative cable maintenance agreement acting purely in the interests of its members. ACMA has 61 members who are predominantly telecoms companies responsible for the operations and maintenance of undersea communications cables in the Atlantic, North Sea and southeastern Pacific Ocean. Using a dedicated fleet of vessels which are available all year round, members benefit from certainty of repair timeframes and lower costs than those seen on the spot market. Members pay a fixed fee to cover the management of the club and also a fee based on the length of cable covered. Repair costs are also charged and members receive rebates if a club vessel is used to undertake agreed non-club repairs.

Example 3: Oil and gas sector – examples of information-based collaboration

Oil & Gas UK Ageing and Life Extension Network: This is an information exchange 'club' run through Oil & Gas UK which comprises 90 members including operators, contractors, designers and the Health & Safety Executive. It seeks to share good practice, identify key elements in the ageing process and develop guidance.

Decom North Sea: The decommissioning sector is at an early stage of its development, with only 7% of the infrastructure in the UK sector of the North Sea having been decommissioned to date. Early projects were executed singly and the industry has not been able to benefit from any continuity or repetition. Knowledge transfer and the sharing of experience are limited. Decom North Sea was set up in 2009 to tackle the main areas of weakness and the bottlenecks which are inhibiting the decommissioning supply-chain capability. It has 200 members drawn from around the North Sea and beyond.

5 Predicting demand and supply of heavy lift jack-up vessels

In order to understand the market for O&M jack-up repair vessels it is necessary to consider demand for vessels (by assessing failure rates) and the factors which can influence the supply of jack-up vessels. Improved knowledge within the market can lead to improvements in the repair planning process and deliver increased efficiency. Available sources of information have been collated and analysed to present information on historical failure rates. Factors affecting the supply of suitable jack-up vessels to the O&M market have also been reviewed.

5.1 Estimating the number of heavy lift jack-up vessel operations required at operational windfarms

Review of historical failure information

Estimating failure rates of main components in wind turbines for the entire operational lifecycle is difficult because of lack of experience – most offshore windfarms in the UK are less than five years old and there is only 10 years of operational experience at the oldest commercial sites in the UK.

The UK has seen a growing contribution of wind power to the energy generation mix and many offshore windfarms are operating with high levels of availability. Power plant assets of any type will experience a higher number of failures in early life because of manufacturing and design problems. Later in the asset life some components will wear out and require replacement. This type of maintenance activity is factored into the normal operating plans of owners and operators.

Understanding and predicting failure rates for offshore wind turbines is important in order to identify the likely demand for jack-up vessels. Operational experience to date has shown that heavy lift jack-up vessel interventions have been required at operational windfarms to correct failures in relation to main components both for isolated defects and to introduce design improvements. Most of the interventions have been in relation to early operational life and there is currently only a limited experience from offshore wind turbines on longer term wear-out rates and the typical length of life for critical main components including blades, generators, transformers and gearboxes.

To correct design defects and improve performance, redesigned components may be fitted to replace original parts within the turbines. Analysis suggests that there have been over 500 jack-up vessel related deployments on operational offshore turbines with around 70% directly attributable to design improvement retrofit campaigns.

Figure 15: Known historical repairs requiring jack-up vessel operations

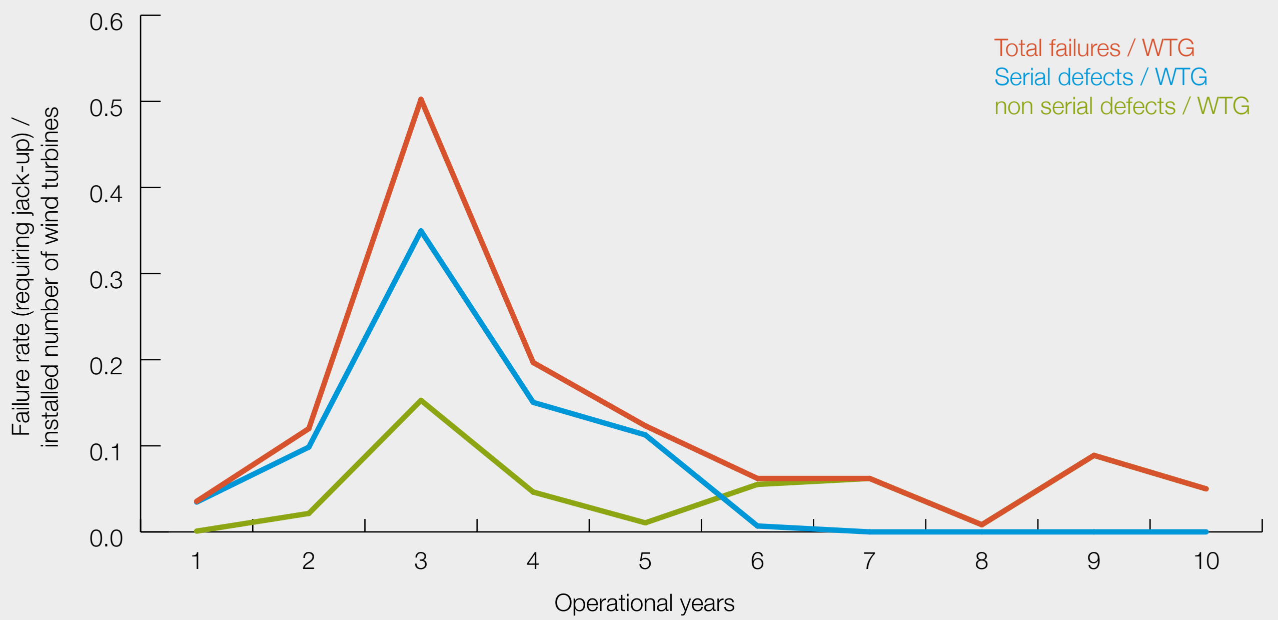
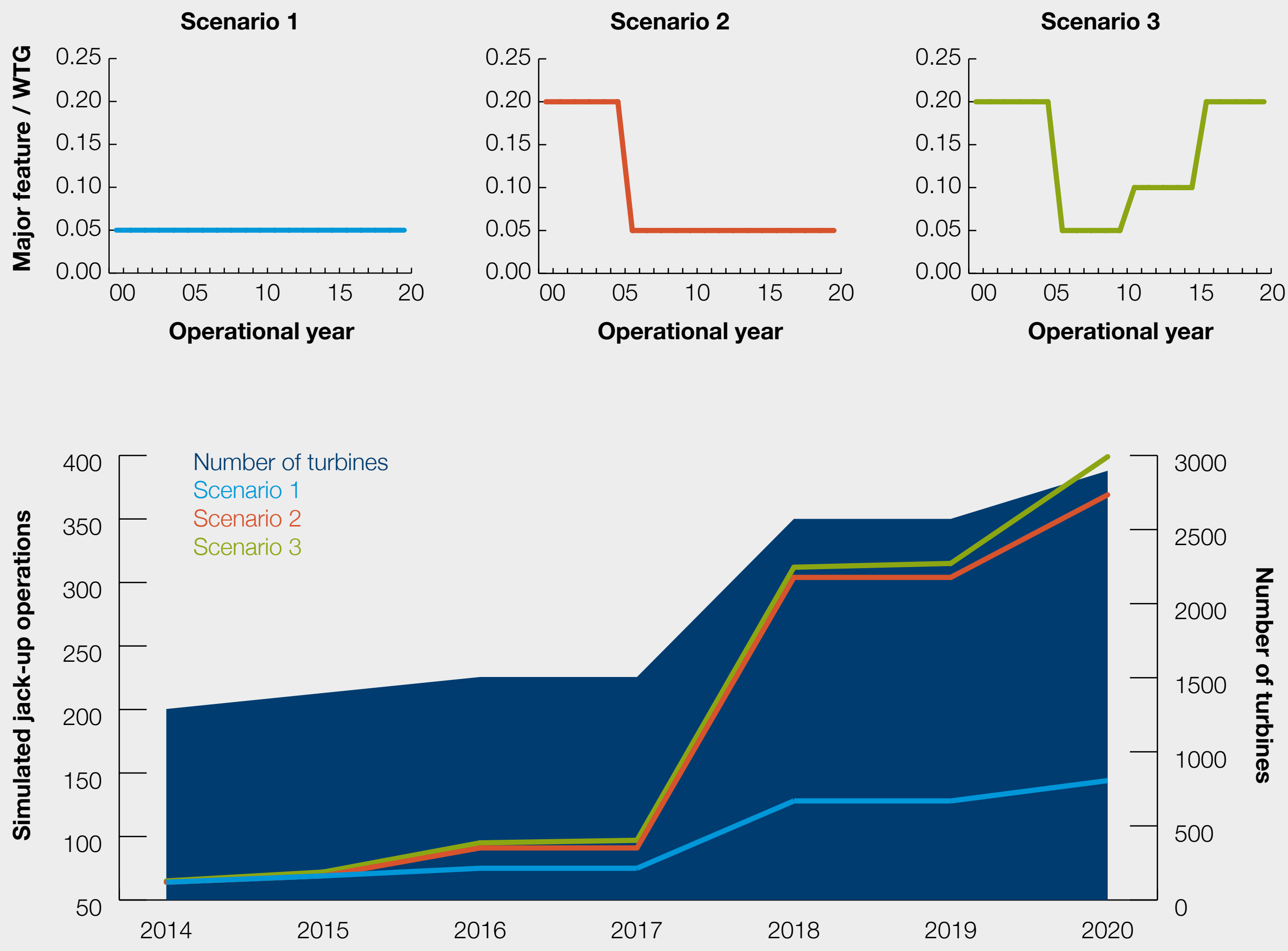


Figure 16: Simulated number of jack-up vessel operations for turbines installed up to 2020



Failure behaviour has been reviewed based on operational experience and readily available information. Onshore windfarms have operated for longer than their offshore equivalents but the older onshore sites have turbines which are different in both design and size from those common at offshore windfarms. It is therefore not possible to readily use onshore experience to determine the failure behaviour through the whole life of an offshore windfarm. There is also limited information on failures in the public domain.

A number of university studies have provided some information (Dinwoodie, et al., 2014), (Dinwoodie, et al., 2013), (Smolders, et al., 2010) but otherwise failures have been identified from publicly available information – hence the reported data is likely to underestimate the actual observed number of failures. The results of this analysis are shown in Figure 15. Failure rates are presented as the number of failures for every installed offshore windfarm and they have been grouped according to the operational year in which the repair was undertaken. This allows a picture to be built up of how jack-up vessel use varies with the age of a windfarm.

Demand for future O&M jack-up vessels will come from a combination of repairs at sites which are currently operational (some of which will be out of the initial warranty period) coupled with any early-life defects at newly constructed windfarms. In recent years, as turbine designs have improved, there have been fewer early-life design defects. However, future windfarm sites are likely to be using new turbine designs with a higher installed capacity. Although there has been testing and use of prototypes for these new designs, it is not yet known what (if any) early-life defects there may be.

Due to the lack of knowledge about both long term failure behaviour of main components in existing turbine models and potential early-life defects in new turbine designs, three different scenarios have been modelled (Figure 16). They cover the possibility that design defects have been largely removed by testing/design improvements (as seen in Scenario 1); an example where there is a similar level of early-life defects as in previous turbine designs (Scenario 2) and a third case where there is a relatively high wear out rate as turbines age (Scenario 3). Simulations have been prepared for turbines that are expected to be operational by 2020.

Failure Rates

Annual failure rates of 0.05 failures /WTG installed (a main component replacement is required on average once in the life of each turbine); 0.1 failures / WTG (a main component replacement is required on average twice in the life of each turbine) and 0.2 (a main component replacement is required on average four times in the life of each turbine). These rates have been simulated based on experience from current failure history and the opinion of industry experts and academia.

Although a simplified model has been used, the demand forecasts are based on the best failure rate information available and provide indicative trends without introducing unproven complex interactions or underlying factors which affect demand for jack-up vessels.

There is considerably more experience of operating offshore wind turbines in the early operational years as many UK sites are under four years old and remain within the initial warranty period – only one quarter of turbines included in the study have operated for five years or more. Despite any potential inaccuracies, the results are based on some of the best real-life information available from the fleet of UK offshore turbines and have allowed simple estimates to be made which are rooted in real experience.

During the initial warranty period, previous experience indicates typical failure rates of 0.25 failures/WTG per year with failure rates dropping to a lower range of 0 – 0.1/ WTG per year in the post warranty years. Most experts agree that over the operational life of a wind turbine between one and two main component replacements will be required. This equates to an average rate of 0.05-0.1 failures/WTG per year. Simple modelling taking into account the potential build-out rate and life cycle stages of operational windfarms indicates that there could be at least 80 failures per year across the UK portfolio rising to 150 as the number of operational turbines increases towards 2020.

Uncertainty about new turbine models

If early-life serial defects emerge in new turbine models demand for jack-up vessel increases across the sector. Given the larger sites expected in Round 3, 300-400 jack-up vessel operations per year could be possible.

There have been different approaches to managing the risk of early-life failures with some owners taking on responsibility for sourcing jack-up vessels while others place this responsibility with the wind turbine manufacturers as part of the warranty contract. If the wind turbine manufacturer is responsible for sourcing jack-up vessels in this early-life phase, they may charter jack-up vessels on long term agreements to carry out retrofit campaigns which may restrict access to vessels for older out of warranty sites.

Since the first offshore wind turbines were developed and installed the equipment manufacturers and owners have learnt a great deal about the challenges of operating in the offshore environment. Design changes and improved approaches to manufacturing and testing have already been made and this is an area that continues to develop. Improvements are being made to the next generation of turbines to ensure more extensive testing and easier in-situ repairs. This may reduce the likelihood of early-life serial defects. These factors must be balanced against further significant changes in design concept along with scaling up other existing design aspects. It is not known whether these changes will introduce any new main component replacement risks leading to the scenarios shown in Figure 16.

5.2 Availability of heavy lift jack-up vessels

All jack-up vessels that are currently employed or have been employed in the construction of offshore windfarms, including heavy lift jack-up vessels capable of installation of turbine foundations, are potentially suitable vessels for O&M. The transport and lifting capacity of these large vessels far exceeds what is generally required for O&M work and associated charter costs are typically higher than the smaller vessels designed specifically for undertaking O&M tasks.

The predicted increase in offshore windfarm construction activity associated with Round 3, Northern Ireland and Scottish Territorial Waters sites along with other developments across Europe will limit the availability of some construction vessels for O&M projects in the next five years as they are deployed to undertake work on the construction pipeline. In some cases short-term tactical opportunities may be presented if a jack-up vessel is working in the vicinity of an existing cluster of operating sites and a short term window of availability opens up. There may also be opportunities to use smaller construction vessels for O&M as development projects increase in scale and move into deeper and more challenging locations where they make not be able to work.

Specialised vessels for offshore wind

Most jack-up vessels currently engaged in the marine renewable energy industry would require modification, additional equipment and crew training before mobilising for the oil and gas industry. For these reasons it is anticipated that, with the exception of the jack-ups that have been identified as multi-role in this report, the availability of jack-up vessels currently employed in the marine renewable energy industry is unlikely to be significantly affected by any surge in offshore oil and gas activity. Major international oil companies usually prefer to employ jack-up vessels that have previously demonstrated compliance with UK Safety Case regulations that are in place for the offshore oil and gas industry.

Multi-role jack-up vessels

It is reasonable to assume that multi-role jack-up vessels that are suitable for and/or have worked in both the offshore oil and gas industry and in the marine renewable energy sector would be among the first to become unavailable for offshore windfarm work if there is a surge in offshore oil and gas activity related to construction, asset life extension or decommissioning. Trends in oil and gas field development are uncertain at present owing to complexities and uncertainties over long term oil prices, the amount of fossil fuel reserves remaining and how cost-effective it is to extract them. Newer oil and gas fields are smaller and higher cost and production volumes show a falling trend.

The Wood review, which analysed the amount of oil and gas remaining, the potential economic benefit to the UK and the industry structure, has increased focus on this area (UK Government, 2014), (BBC News, 2014), (Gray, 2013). The complexity in the oil and gas sector is further compounded by a need to extend the engineering life of North Sea oil assets if they are to be used in the longer term to avoid investment in new oil and gas infrastructure. With more than 50% of North Sea oil and gas platforms beyond their original design life and life extension studies currently ongoing, it is expected that the number of oil and gas related life extension projects will increase in the future but it is also likely that further decommissioning projects will also be undertaken. These are large scale projects which pre-plan vessel requirements years ahead and therefore they are unlikely to suddenly disrupt the offshore wind jack-up vessel spot market but they could influence demand and availability in the longer term.

Other jack-up vessels employed in the offshore oil and gas industry

The global fleet includes more than six hundred jack-up vessels employed in the offshore oil and gas industry. Many of these are equipped with cranes and facilities that would make them suitable for offshore windfarm O&M projects. However, most of these units are drilling rigs or other self-elevating platforms used for hydrocarbon processing or offshore accommodation and consequently they are unlikely to become available to the marine renewable energy industry unless there is an unprecedented change in offshore energy exploration or production.

European Demand

The close proximity to the UK of other European offshore wind developments including those in Denmark, Germany, France, Belgium, the Netherlands and Sweden means that it is feasible for jack-up vessels to work across a European market. This is the case in both the construction and O&M phases, and jack-up vessels already move between projects within the North Sea, Baltic Sea and Irish Sea. European demand for jack-up vessels in the construction and O&M phases could therefore influence vessel availability for UK projects.

Growth of offshore wind continues across Europe and beyond, with Germany, France and the Nordic countries particularly active. The European Wind Energy Association (EWEA) suggests that up to 40GW could be installed across Europe by 2020 (EWEA, 2011). These developments have the potential to influence jack-up vessel supply and the vessel lists provided in this report, which include vessels regularly working outside the UK in the wider European offshore wind sector. Further assessment of demand for jack-up vessels across Europe for construction and O&M phases would help clarify this issue.

Renewable energy industry outside Europe

A fledgling offshore wind sector is emerging in the USA with anticipated build out of up to 4GW by 2020. Current laws to encourage a strong home shipping sector in America, enshrined in the Jones Act, could initially act as a barrier to the use of non-USA flagged vessels working across the Atlantic (Douglas Westwood, 2013). The Douglas Westwood study concluded that while the Jones Act does not prevent foreign-flagged vessels from engaging in offshore windfarm construction in US waters, it does prevent foreign vessels from loading cargo and personnel in US ports and then transporting these to a US offshore windfarm construction site. Therefore, foreign-flagged installation vessels will have to be supported by various Jones Act-compliant feeder vessels and other support vessels when operating on US offshore windfarm projects. A large fleet of advanced construction vessels is available in Europe for contracted work in the US, but the limitations resulting from the Jones Act represent a major obstacle for their deployment there.

While some of the established European installation companies are investigating US offshore wind market opportunities, a confluence of factors is holding these companies back at the moment. The most important obstacles are excess demand for vessels in Europe, the lack of a visible US project flow, and the operational difficulties imposed by the Jones Act. Other global areas of growth are concentrated in the Far East and given the buoyant local vessel market, the transit cost and some differences in water depths, it is unlikely they will attract many European vessels.

6 Potential collaboration opportunities

Experience from other industries has demonstrated that collaboration can increase efficiencies and drive down costs through the creation of economies of scale. There are a number of options for collaboration and the potential benefits are highlighted through two case studies.

6.1 Options for collaboration – case studies

Options include:

- 'do nothing' – any opportunities to collaborate or optimise the use of jack-up vessels are left with the vessel owner who will contact other owners to understand their planned workload
- full time vessel charter club – a group of windfarm owners/operators commit to a long term vessel charter and agree rules about how this vessel is used on the sites within the club
- part year vessel charter club – a group of windfarm owners/operators commit to a long term vessel charter but the long term charter is for a pre-agreed number of months each year
- flexible vessel charter club (a 'club without commitments') – members pre-plan how a vessel could be used and develop standard operating practices in order to facilitate tactical ad-hoc charter of a vessel between two or more club members. This could extend to planning future proactive campaigns to enable shared vessel use to be more practical.

Case Study 1: Collaborative Use of Seajacks Leviathan on East Coast windfarms

A recent example of jack-up vessel sharing has demonstrated that O&M projects involving collaboration between different site owners is not only feasible but can be planned and executed with considerable efficiency.

The project cited in this example involved collaboration between three different site operators each sharing a single self-propelled dynamically positioned jack-up vessel. The jack-up vessel carried out component replacements on a total of ten Siemens 3.6 MW turbines located on three different UK east coast windfarms. The project works involved:

- loadout at a northern European port
- transit to 1st windfarm and undertaking work on a single turbine
- transit to 2nd windfarm and undertaking work on multiple turbines
- transit to 3rd windfarm and undertaking work on multiple turbines

The detailed project planning for the deployment of the jack-up vessel was completed and approved within 30 days and this was conducted in parallel with the mobilisation and load-out, thus minimising the lead-in time. The efficiency of the planning in this example can be attributed mainly to the competence and experience of the jack-up vessel owner's management team in general and to the following contributing factors:

- the required site information was already available with one exception where a new seabed surface survey was required at a single turbine location on the 2nd windfarm
- the selected jack-up vessel was a multi-role heavy lift vessel that had originally installed most of the turbines to be visited during the project and was therefore known to be suitable
- the selected vessel was fitted with a 400t crane capable of lifting 50t at 60m radius and was already fitted with a blade rack
- the long lead-in time required to carry out a site-specific structural assessment for the jack-up vessel was avoided as this study was already in place from the previous project
- leg penetration analysis for each turbine location was produced very swiftly by the jack-up vessel owner
- a single marine warranty surveyor was appointed to represent the interests of all three site operators – eliminating any replication of document review or vessel inspection and ensuring consistency in the application of industry guidelines for project approval

All the windfarm owners involved in this collaboration saw benefits both in terms of cost savings (mainly through reduced mobilisation costs estimated to be in the order of £0.5m per participant) and also by securing a credible repair plan. This meant that turbines that were stopped owing to various faults could be returned to an operational state and production downtime losses ended. The collective group of owners faced a risk of around £1.45m per month in production downtime losses if all the affected turbines remained non-operational.

As well as ensuring the repair of turbines was expedited and saving mobilisation costs, the owners and jack-up vessel operators involved were keen to demonstrate that collaboration was possible and to develop experience to encourage future alliances and collaborative working.

Case Study 2: Hypothetical repair club in Irish Sea

Offshore windfarms on the west coast of the UK face greater challenges in securing cost-effective jack-up vessel repairs than the rest of the UK-based offshore windfarms. This is due to longer transit times, greater exposure to weather risk and uncertainty about availability of vessels.

Whether included in mobilisation costs or higher charter day-rates the additional time taken to reach these windfarms is a real cost that needs to be recovered by jack-up vessel operators. In addition, once a task on the west coast is completed a jack-up vessel will need to transit back around the coast to its next assignment. There are examples of jack-up vessels having to wait considerable periods of time (over one month) to transit around Land's End and/or the Welsh peninsulas. For this reason some vessel operators may be reluctant to deploy to the west coast unless there is a campaign of a reasonable size. Thus, there is a risk that a single or small number of failed turbines may face significant periods of downtime.

There are currently nine windfarms in operation or under construction on the west coast of the UK and one offshore windfarm in Irish Waters (see Annex 3). Together these can be considered a West Coast Cluster.

Several models of potential collaboration have been considered as shown in Table 7. Details of the scenarios considered and assumptions used are given in Annex 3.

Full time jack-up vessel club for West Coast Cluster
Annual vessel costs associated with a committed full time repair "club" have been compared with likely costs for an ad-hoc vessel charter strategy with allowance made for the associated increased turbine downtime. Analysis shows that benefits may be marginal, and highly dependent on failure rates and spot market vessel availability. Where spot market availability is good, and vessels are prepared to transit to the Irish Sea to perform repairs it is more cost effective to use a spot-market based strategy so long as failure rates are low (0.05 failures/WTG installed/year). At higher failure rates a full time club could be feasible provided there was wide membership and other barriers such as vessel suitability and organisational issues can be overcome however there are risks associated with uncertainties and further work to understand failure rates and further detailed modelling would be beneficial.

Part year jack-up vessel club for West Coast Cluster
If only a small number of owners in the cluster agree to collaborate, a full 12 month charter may not be cost-effective as fewer members will carry the fixed annual cost. To explore options involving fewer members, a part year jack-up vessel club concept has been simulated. Further information is given in Annex 3.

Where owners may be required to wait (with a turbine stopped) for six months in order to secure a vessel on the spot market then over half the potential failure scenarios modelled demonstrate a benefit over relying on spot market rates. Therefore, this option can also be looked upon as a form of insurance against the risk of unavailability of jack-up vessels on the west coast.

The part time model may be possible if offered in tandem with a similar club arrangement in another cluster, perhaps on the east coast of the UK, to provide a fuller annual programme of work for any vessel. It is also possible for offshore windfarms and oil and gas installations to share a suitably flexible vessel.

Given the shorter charter period, greater consideration is needed of how weather downtime is handled within the club to ensure all members derive benefit. For example, in the recent east coast collaboration, each wind farm owner took on the weather risk from the day the vessel left the previous site. Further work to study turbine reliability to inform failure scenarios would also improve confidence in this option.

Flexible jack-up vessel club for West Coast Cluster
Where there is uncertainty over the failure rate, unwillingness to invest upfront in jack-up vessel time or a relatively low number of owners interested in sharing vessels, collaboration is still possible but may need to be undertaken on a more flexible basis.

One simple concept could be the formation of a club which does not make any upfront commitment to a regular charter. Members could instead work together to align contracting approaches, working methods and activity planning to ensure they could readily take an opportunity to collectively arrange a jack-up vessel campaign across a number of sites within the West Coast Cluster.

This has the advantage of allowing scale to be exploited without any up front commitment and places members at an increased level of readiness to grasp this opportunity. It takes its lead from the vessel collaboration already seen recently on the east coast of the UK but extends the concept to ensure continued regular contact among operators and heightened readiness.

There are challenges with this approach where mixed turbine types are involved which may dilute some of the benefits. Also, as an upfront contractual commitment is not

Table 7: Collaboration models investigated

Type of Club	Assumptions and membership
Full time jack-up club	• Jack-up vessel is available for a full 12 months each year • All windfarms on west coast excluding newer Gwynt-y-Mor and West of Duddon Sands due to their initial warranty period
Part year jack-up club	• Charter periods of 3 months per year with three club members • Charter periods of 6 months per year with six club members
Flexible jack-up club	• Flexible jack-up vessel usage driven by demand using ad-hoc campaigns arranged as the need arises using vessels available on the spot market • Members commit to a high level of deployment readiness

Table 8: Benefits from operating a flexible jack-up charter club

Benefit	Potential value	Comment
Reduced risk of unavailability	Production losses from downtime are reduced. Examples in the industry of waiting time range from three months to over a year.	By increasing the number of repairs in any campaign it is more likely to attract a jack-up vessel to transit to the west coast and reduce overall downtime. Reliance on the spot market means downtime risk is not eliminated.
Reduced mobilisation costs	Up to £0.5m per campaign per owner (which could be up to 50% savings for small turbine numbers).	On the west coast some of these gains may be reduced by the need for new loadout tasks for different turbine types.
Streamlined processes	Up to 65 days reduction in lost production with an average saving of more than £0.3m per campaign.	Reduction in deployment times as highlighted in recent report by DBB Jack-ups.

being made with a jack-up company, there is reliance on the spot market and the associated exposure to the risk that no jack-up vessel is readily available. By relying on the spot market there is also no guarantee that the available vessels will be able to work at all the locations that require repair.

Benefits from a flexible vessel club are more difficult to quantify, but a range of examples is provided in Table 8. While these benefits add value to owners of offshore windfarms they are not as effective at managing all the potential risks to downtime that other options (with greater membership levels) offer.

The West Coast Cluster case studies demonstrate there can be clear benefits from increased collaboration in the O&M phase and possibly more widely. The potential benefits are dependent on the collaboration model chosen and the detailed rules around collaborative arrangements which might include:

- confirming or increasing the likelihood that suitable jack-up vessels will be available to undertake repairs reducing production losses due to extended period of downtime
- reducing jack-up vessel charter rates by increasing the scale of repair campaigns
- more certainty for jack-up vessel owners
- reducing transit/mobilisation costs and any associated weather risk by reducing the individual number of campaigns
- facilitating more cost-effective proactive maintenance tasks requiring a jack-up vessel
- decreased environmental emissions through fewer mobilisation trips and potential to reduce overall distances travelled by jack-up vessels.

6.2 Blockers and barriers to collaboration

Confidentiality/intellectual property concerns

Where a jack-up is used across multiple sites with the same make of wind turbine, there are no insurmountable challenges. However, using the same jack-up vessel for a similar campaign involving turbines supplied by different manufacturers might be technically feasible for some of the larger vessels but would be impractical for others owing to limited space for workshops, special tools and maintenance crews.

Conflicting commercial issues between site operators are usually resolvable but there is unlikely to be an acceptable solution to embarking competitive turbine manufacturer's maintenance crews simultaneously on the same vessel. The need to accommodate more than one contractor's crew, and the requirement for deck space and stowage arrangements for more than one type of supplier's components, equipment, tools and workshops, would render simultaneous operations impractical in most cases.

The location of suitable loadout ports may restrict the flexibility of the club and require more lengthy transit periods to get to a suitable loadout port. This will vary in relative impact depending on the dimensions and specification of the vessel selected.

Site specific constraints and challenges

Site specific constraints may make vessel sharing challenging unless a suitable vessel for all (or the majority) of turbine locations can be found. Depending on the vessel operator involved it may be possible to arrange for additional vessels to be made available to any club, enabling access to the more challenging locations. The number of inaccessible locations resulting from the selected club vessel may provide a barrier to that site joining the club.

Uncertainty about future failure rates

Despite the increased size of the operational offshore wind fleet, difficulty in predicting failure rates means that demand for jack-up vessels is uncertain. In a conventional vessel club, members need to commit to covering the costs of chartering a vessel and uncertainty over failure rates introduces risks to club members. Where failure rates are relatively low, unless the majority of sites join the vessel club, the cost risks of covering a full time vessel may be too great. Often during the warranty phase (and with some post-warranty contracts), arrangements for jack-up vessel use are made by the wind turbine manufacturer who may not be willing to share with other out-of-warranty owners or may make arrangements to service contracts on a Europe-wide scale. This could reduce the benefits of sharing and optimising jack-up use within a geographical cluster and may reduce the pool of potential members unless wind turbine manufacturers were also willing to join.

When negotiating WTG purchases, consideration should be given to the potential flexibility for sharing of jack-up vessels under purchase and warranty contracts.

Joint venture and financing arrangements
The structure of some joint venture ownership arrangements may preclude the organisation from joining a vessel club – examples exist where covenants used to govern allowable activities may not be broad enough to include membership of collaborative vessel clubs. Consideration should be given to the potential breadth of O&M activities when developing joint venture arrangements to remove this potential blocker.

Procurement policies
Internal company procurement policies may also act as a barrier to collaboration, although it is expected this could be overcome through development and presentation of a robust business case.

UK and EU competition law prohibits two main types of anti-competitive activity namely anti-competitive agreements and abuse of a dominant position. Any collaborative arrangements put in place to reduce LCOE and improve efficiency of jack-up vessel usage must be developed with consideration of applicable competition rules.

6.3 Opportunities
To illustrate the potential value from better use of jack-up vessels, case studies have been presented which demonstrate the benefits of improvements and collaborative working and highlight challenges:
- to reduce waiting time for jack-up vessels without incurring excessive charter costs if the vessel is not required
- to reduce the planning time for jack-up vessel operations thereby reducing downtime
- to reduce risk of exposure to high spot market prices due to geography or restricted availability of vessels
- to overcome any barriers introduced through financing or joint venture structures
- to ensure solutions are practical and meet the needs of potential participants

In practice transit times between turbines on the east and west coast can add both cost and risk to the overall annual costs to any club or other collaborative campaign. However, the growing size and location of individual company wind turbine fleets provides an opportunity for collaboration on some level. The degree to which collaboration occurs will be influenced by the degree of flexibility that vessel operators can offer and ultimately the costs for providing this service.

There are opportunities to undertake cost-effective actions to improve the overall readiness of the O&M sector to undertake repairs through:
- improved sharing of ad-hoc collaboration opportunities
- industry-wide work to undertake more systematic site-specific assessment preparation
- undertaking proactive activities with licensing/consenting bodies where site specific environmental requirements exist
- further improvement of condition-based monitoring and component life prediction tools
- use of industry wide standards/common practices to speed up the project planning phase

Regardless of the final form of collaboration, it presents an opportunity to reduce mobilisation costs, provide access to a wider pool of vessels and potentially reduce waiting times for suitable vessels. Coupled with other actions to make jack-up vessel operations more efficient during the O&M phase, cost reduction and an increase in production revenue is achievable. This will lead to a positive O&M phase contribution to reducing the LCOE.

7 Conclusions and recommendations – improving repair times, minimising repair cost and addressing risk

The future demand for jack-up vessels in the O&M phase is highly influenced by the early-life reliability of new wind turbine types and mid-life failure rates whilst the charter arrangements depend on the form of warranty contracts and the approach taken by larger players (owners, operators and the wind turbine manufacturers). The industry has already seen over 500 jack-up vessel interventions in the O&M phase in the UK and there is evidence of long periods of turbine downtime while repair campaigns were planned and delivered. To date, the biggest jack-up vessel campaigns have been to address early-life serial defects and retrofits to improve the designs of main components with serial defects estimated to make up around 70% of all jack-up vessel operations.

Thirty-three jack-up vessels have been identified which have experience of and are suitable for use in offshore wind operations. Of these, two are specific O&M vessels (and a further two are being built at present). Nearly half the vessels identified are multi-purpose vessels and could re-deploy onto oil and gas projects if there was a large surge in demand and corresponding uncertainty in long term windfarm assignments.

Collaborative sharing of jack-up vessels between site owners during the O&M phase has the potential to deliver tens of millions of pounds of value per year, with the potential for significantly higher benefits if long term failure rates rise or jack-up vessel availability is reduced. When combined with advanced condition-based monitoring, inspection and models to predict remaining life of main components, the use of collaborative campaigns can facilitate a more cost-effective approach to proactive maintenance.

The longest experience of operating offshore windfarms is in Denmark and analysis suggests jack-up vessel tasks remain necessary as turbines age (Milborrow, 2013). The total number of global offshore wind turbines in operation for more than ten years is still relatively small and there are key design differences between some of the oldest turbines in operation and those being installed or planned currently, making it difficult to predict long term failure rates. While there is limited experience in the UK of operating offshore windfarms beyond the first five years of their life, emerging industry benchmarking/performance schemes such as SPARTA will help to improve knowledge of long term failure rates, which is key to ensuring owners select robust strategies for main component maintenance.

Jack-up clubs can provide a more coordinated pipeline of work for jack-up vessels in the O&M phase and increase the likelihood that suitable jack-up vessels will be available to undertake repairs when required. The risks of extended downtime due to lack of availability of a suitable jack-up vessel can be effectively mitigated through collaboration; models for achieving this are presented in the report. Campaigns across multiple sites within a cluster have the potential to reduce jack-up vessel costs by increasing the scale of repair campaigns, reducing mobilisation and transit costs, and reducing the associated weather risks. Improvements in information sharing and coordination could help to increase the number of ad-hoc collaborative campaigns.

Experience has shown that streamlined planning; improvements in the availability of site and survey information, and sharing information on future jack-up vessel requirements will deliver value-adding improvements for all owners. This will be helped through contractual alignment or 'in principle agreements' between neighbouring sites, to allow them to contract vessels more quickly. Collaboration has the potential to reduce duplication and increase the efficiency that essential tasks such as vessel due diligence, consenting, vessel audits and owner representation are carried out. There is also scope for more efficient sourcing of specialist tools and skilled, experienced labour.

Table 9: Benefits from operating a flexible jack-up charter club

Source of value	Existing operational sites	Future Sites
Improvements in planning of campaigns	£8m – £10m per year	£15m – £40m per year
Reduced mobilisation costs through collaborative campaigns	£13m – £17m per year	£15m – £67m per year
Reduced production downtime through faster deployment of jack-up vessels from collaborative arrangements	£31m – £83m per year	Estimated £100m – £400m per year

A summary of potential savings through reduced costs and lost-production risk is shown in Table 9. These indicate a strong case for further work to improve the efficiency with which jack-up vessels are deployed in O&M. The total value realised will be dependent on actual failures rates, the structure and risk sharing arrangements in maintenance contracts as well as the availability of jack-up vessels to work at operational sites.

While greater collaboration can reduce the annual investment owners need to commit to secure jack-up vessels through long term charter agreements, it is possible if failure rates drop that some owners may not consistently see a return on this investment in club membership – the key influencing factors are failure rates and availability of suitable jack-up vessels on the spot market. More detailed assessment of likely future failure rates and turbine specific reliability studies are required to help to inform value assessments further.

The flexible jack-up vessel club concept offers a low risk solution to enable the value of both improved planning and faster deployment times to be realised and this has been seen in practice during the recent east coast windfarm shared campaign.

Improvements in the reliability of current and future turbine models, increased ability to undertake in-situ repairs of main components and improvements in predicting failures have the potential to reduce the need for repairs that require a jack-up vessel. There may also be options to modify turbine cranes or utilise new approaches in lifting operations to enable more main component replacement work to be carried out without resorting to a jack-up vessel.

Figure 17: Recommendations

There a number of recommendations to improve repair times, reduce repair cost and address risk which fall into three broad themes:

Recommendations		
1. Facilitate increased efficiency and collaboration in the use of jack-up vessels	**2. Eliminate barriers to collaboration**	**3. Wider recommendations to reduce main component repair risks**
• Discussions are held between windfarm owners and their key service providers to explore options for setting up a flexible vessel club	• Give careful consideration to the structure of warranty and post-warranty service contracts to enable jack-up vessels to be more easily shared between owners	• Promote the need for advances in condition-based monitoring techniques & "remaining life" predictions to improve the earlier detection of faults and enable proactive O&M strategies to be more widely implemented
• Develop tools to promote information sharing and improve planning including information to speed-up site specific assessments	• Consider the impact of covenants and constraints embedded in company and joint venture legal structures which may prevent vessel sharing	• Develop improved turbine reliability models to increase confidence in predictions of jack-up vessel demand
• Explore options with windfarm owners and jack-up vessel suppliers to develop a longer-term pipeline of planned O&M tasks and develop a more mature market-based approach to facilitate efficient use of jack-up vessels	• Seek legal advice on different "club" models for jack-up vessel collaborative charters	• Encourage innovation to develop alternative repair options that do not require jack-up vessels including more wide spread in-situ repair techniques and innovative main component replacement methods
• Disseminate failure data more widely to improve confidence in predicting jack-up vessel demand		
• Share best practice and lessons learnt to promote the efficient planning of jack-up vessels campaigns		

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Annexes

Annex 1: Definition of jack-up vessels suitable in principle for O&M projects

The fleet list contained in this report is limited to jack-up vessels that are suitable in principle for O&M activity and that have a track record of involvement with the marine renewable energy industry in European waters. This includes all jack-up vessels that have been successfully employed in the construction of offshore windfarms as their suitability in principle for O&M activity has already been demonstrated, whether they have been engaged in the installation of foundations or the installation of turbines or both.

The global offshore fleet includes a great many other jack-up vessels that are employed in the oil and gas industry. Many of these units could be considered suitable for windfarm O&M projects but this fleet has not been included on the list of suitable vessels except for the multi-role jack-up vessels that are designed for service in both offshore oil and gas applications and marine renewable energy projects.

For the purposes of this report, jack-up vessels that are considered suitable in principle for O&M are defined as vessels which match or exceed the following minimum specifications:

- Capacity for loading, transport and lifted installation of a number of wind turbine components including blades, blade bearings, hubs, main bearings, gearboxes, generators, transformers, equipment and tools, but excluding tower sections, nacelles, or complete hub and rotor blade sets
- Potential capacity to carry three blades on deck or in an over-side cradle for static elevated operations and weather restricted sea transit
- Entered on a vessel registry maintained by a recognised maritime nation
- Classed by a recognised classification society with class notation 'self-elevating'
- Operated in accordance with a recognised Safety Management System
- Certified for unrestricted navigation and permanently manned in transit
- Fitted with accommodation plus LSA capacity for ≥12 contactor's personnel in addition to the vessel's crew
- Capable of operating in water depth ≥25 metres
- Minimum crane lifting capacity ≥50 tonnes at 25 metre radius

Annex 2: Potential site hazards that could restrict the sharing of jack-up vessels

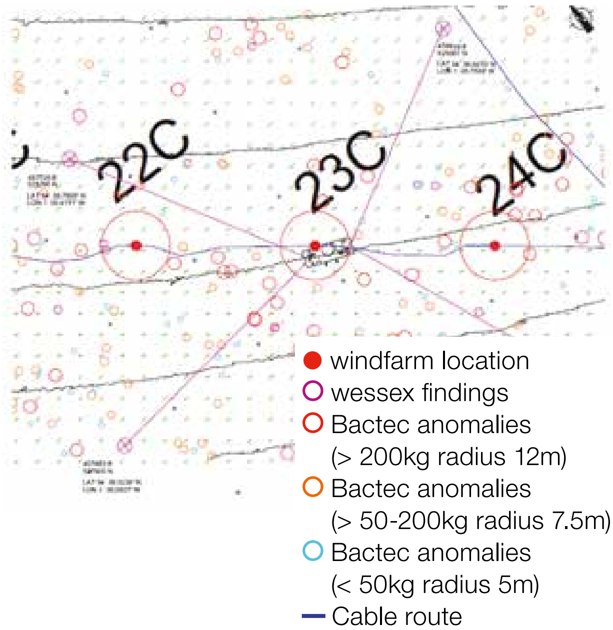
Seabed obstructions

Seabed surface surveys must be repeated at regular intervals to reveal debris or unexploded ordnance that may have become exposed through seabed scour, including objects that may have been dropped or moved into the jacking zones by storm waves and tidal currents.

In some areas, massive scour pits have developed around the WTGs. Jack-up vessels cannot be safely installed on the steep slopes of these pits and therefore they must be positioned at a significantly greater distance from the turbine than was possible during the construction phase. This creates a challenge related to the crane lifting radius and may eliminate the possibility of installing 'walk-to-work' access using a bridge from the vessel to the turbine platform.

Seabed level changes may occur through the removal of soil by current and wave action. This can result in a reduction in the thickness and strength of a strong seabed surface layer which may render the site unsafe for future jack-up vessel installations owing to foundation instability. Seabed level changes resulting in the deposit of soil can be equally problematic if the vessel's deep floating draft prevents an approach in very shallow water.

Fig. 18.1: Example of seabed obstructions to be avoided



Each installation of a jack-up vessel during the construction phase and each subsequent installation for O&M purposes has created local holes or depressions in the seabed known as jack-up vessel 'footprints'. Different classes of vessel are fitted with a different number of legs and each vessel has a significantly different leg footing geometry and footing size. Multiple visits to each turbine create many footprints and jack-up vessels having a different leg footing geometry must be located with their leg footings clear of these depressions so as to avoid sliding and eccentric loading of the spudcans which can over-stress the legs.

Locations at which many jack-up operations have taken place will eventually become so pitted that the seabed may need to be restored to a level condition by rock and gravel dumping

Sub-sea Cables

The original planning of some offshore windfarms made little or no provision for clear seabed jacking zones that would facilitate future access for jack-up vessels during the O&M phase. The installation of subsea cables and scour protection materials has restricted the clear area of the seabed on which vessels can be elevated. The selected position for the O&M jack-up vessel must allow minimum safe clearances between the cables, the leg footings, and the anchors and moorings (if used).

Fig. 18.2 Restricted access to WTG

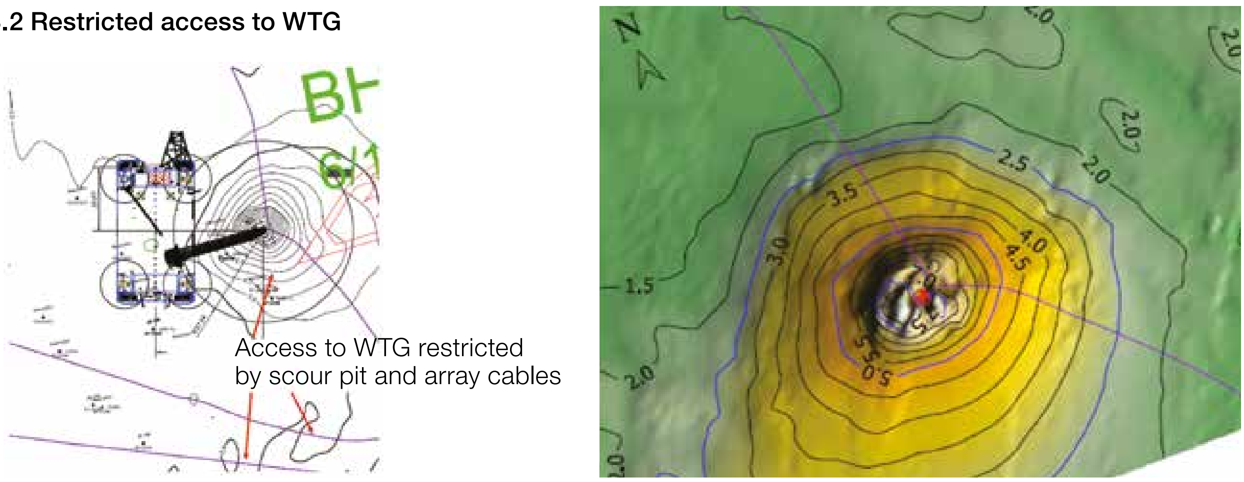
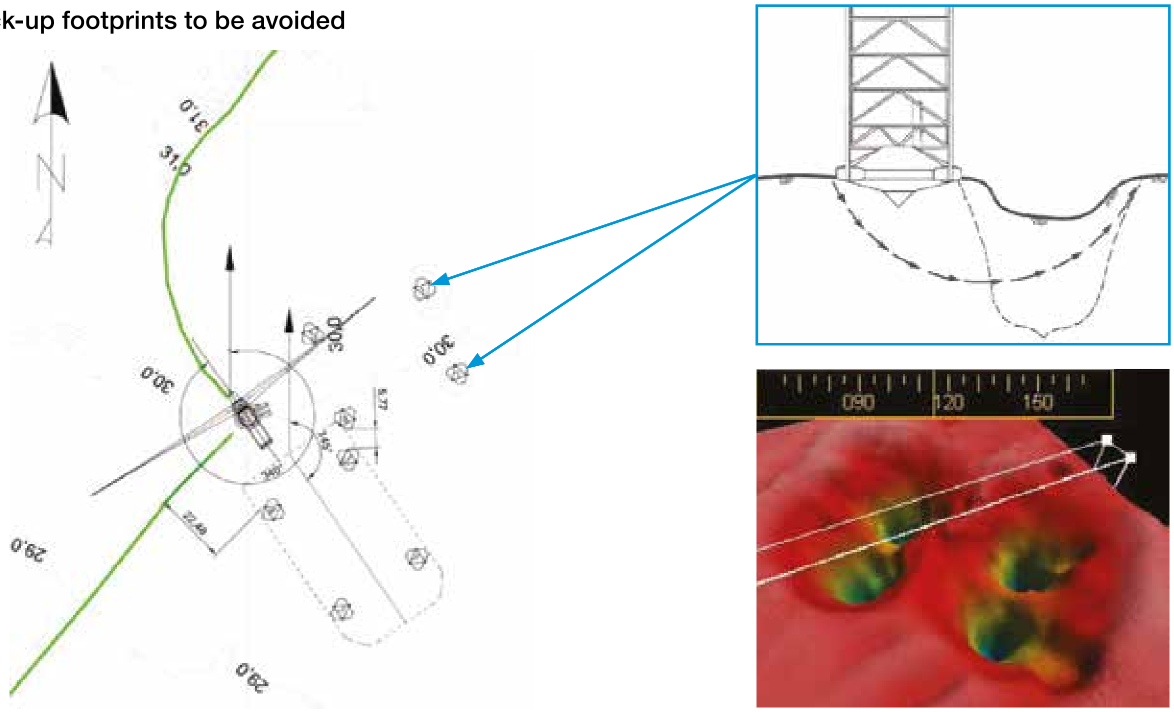


Fig 18.3 Jack-up footprints to be avoided



For some windfarms the installation of multiple array and export cables in the vicinity of the substations means that the deployment of anchors and moorings would incur a high risk of damage to the cables. In these circumstances only self-propelled dynamically positioned jack-up vessels can be used safely.

Seabed mobility has caused shallow-buried array cables to become partly exposed over time in some areas. In shallow water the deployment of anchors and steel wire moorings across these cables will cause damage and for this reason self-propelled dynamically positioned jack-up vessels are more suitable for installation for O&M projects in these areas.

Fig 18.4 Safe distance between the jack-up vessel and moorings

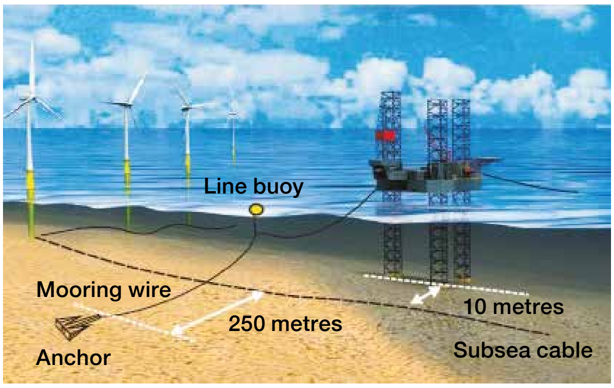
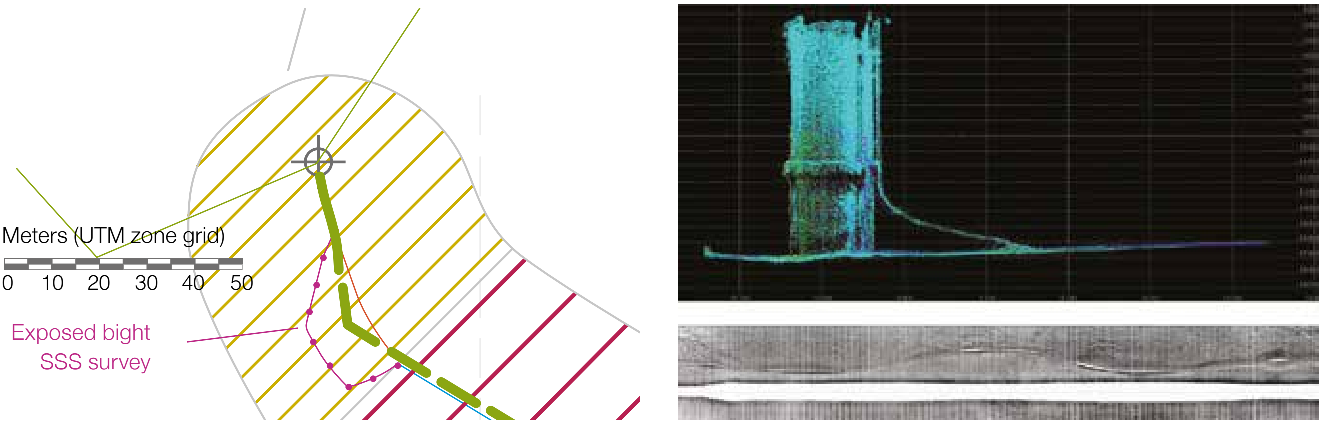


Fig 18.5 Surface laid and exposed array cables



Annex 3: Irish Sea Case Study – Supporting Information

Table 10: Background

Name of Windfarm	Owner	Operational status	Number of turbines	Make and model
North Hoyle	RWE	Operational since 2003	30	Vestas V80 2MW
Arklow Bank	GE Energy	Operational since 2004	7	GE 3.6 MW
Barrow	Centrica, Dong Energy	Operational since 2006	30	Vestas V90 3MW
Burbo Bank	Dong Energy	Operational since 2007	25	Siemens 3.6MW
Rhyl Flats	RWE	Operational since 2009	25	Siemens 3.6MW
Robin Rigg	E.ON	Operational since 2010	60	Vestas V90 3MW
Walney 1 and 2	DONG Energy, PGGM and Ampère Equity Fund, SSE	Operational since 2012	102	Siemens 3.6MW
Ormonde	Vattenfall	Operational since 2012	30	Senvion 5MW
Gwynt-y-Mor	RWE	Under construction	160	Siemens 3.6 MW
West of Duddon Sands	Dong Energy/Scottish Power	Under construction	108	Siemens 3.6 MW

Table 11: Assumptions, issues and features of potential collaboration arrangements used in simulations

Collaborative arrangement	Assumed charter rate	Failure rate and waiting time assumptions	Requirements	Other assumptions
Full time jack-up club	£50,000 per day	• Failure rates of 0.05 – 0.2/ WTG installed • No waiting time	Need to develop fair method of sharing weather downtime; other rules for trading days and agreeing priorities for tasking need to be agreed	Assume fees and allocated charter days pro-rated by number of installed turbines;
Part year jack-up club	£60,000 per day	• 0-2 failures per site per year • Waiting time is incurred out of charter periods		
Flexible jack-up club	£70,000 per day	• Failure rates not used • Assume through readiness the maximum downtime is three months	To maximise advantage need to undertake operational readiness work up front	Close cooperation and readiness to allow ad-hoc joint campaigns to be arranged as
Single site Spot Market with no collaboration	£80,000 per day	• Failure rates not used • Assume wait time of four months to one year for available vessel	No specific requirements	An available vessel may not be willing to deploy to West Coast for short duration work.

Scenarios and assumptions
Simulations of potential failures, repair costs and production downtime have been developed to serve as an illustration of the potential benefits from greater collaboration within the West Coast Cluster. Before developing any firm plans, more detailed modelling would need to be undertaken using the owner's commercial information and available vessel charter rates. In the examples provided, it has been assumed that lower jack-up vessel charter rates are achieved for a long-term year-round charter than for long-term part-year charters, which in turn are lower than the ad-hoc spot market charter rate. Assumptions are shown in Table 11.

Full time jack-up vessel club for West Coast Cluster
A long term year-round jack-up vessel club involving all owners of windfarms on the west coast (with a jack-up vessel on charter in the area for 12 months per year) has the potential to offer considerable benefits to members.

The simulated case study assumes that all currently operational windfarms become club members and agree a functioning set of rules to share weather downtime and to prioritise repairs in order to optimise the benefits to owners and minimise overall downtime. It is also assumed that a vessel is selected that can work across all sites and there are no restrictions due to Joint Venture Company rules, organisation or structure. In practice these are both areas which will require further action to overcome challenges of vessel suitability and any organisational barriers.

The level of benefit is sensitive to the number of failures that each owner experiences. Failure rates of 0.05 failures/WTG; 0.1 failures/WTG and 0.2/WTG over the operational lifetime have been simulated, as described in section 5.1.

The cost of club membership (which excludes the cost of spare parts, service vessels and technician labour)

Table 12: Example of potential savings that could be achieved through use of a full time vessel club

Failure rate	Club cost across the cluster[7] per year	Spot market average turbine downtime	Spot market vessel cost and lost production revenue across the cluster per year	Potential club saving across the cluster per year
0.05	£18.2m	four months	£16.6m	-£1.6m
0.1	£18.2m	four months	£30.4m	£12.2m
0.2	£18.2m	four months	£54.1m	£35.9m
0.2	£18.2m	six months	£67m	£48.7m

has been compared with simulated spot market costs for mobilisation, transit and use of a vessel to repair batches of failed turbines. An assumed average downtime of four months has been used to estimate lost production revenue, with an additional simulation of six months waiting time where failure rates are greater. It is assumed that owners utilise vessels from the spot market once per year to repair any failed turbines and that all owners act independently of each other. Potential savings from the operation of a vessel club on the west coast are shown in Table 12.

If there are very low failure rates it is possible that members could see a small collective loss. However, if use levels are low, it may be possible to charter the vessel to turbine manufacturers for warranty works on the newer sites excluded from this study. It may also be possible to offer the club vessel for short term use on local construction contracts (of which several are in prospect) as a parallel vessel to improve installation speeds.

Where failure rates increase, the simulation indicates that if all owners experience these failure rates they could all realise a net gain compared with a strategy which relies on single spot market repairs. As failure rates and waiting time for a vessel increase, the benefit is forecast to be greater than indicated in Table 9.

There will also be a maximum number of tasks that the club can deliver in any year and this may fluctuate depending on the number and distribution of weather days relative to turbine failures. However, this is not seen as a limiting factor except where site-wide component upgrades are planned.

In reality there will be different failure rates at different windfarms in different years and this complexity is not reflected in the model. The model has also used a reasonably conservative average waiting time of four months in this scenario.

Feedback during the course of this study has indicated that there may be barriers for some owners to be involved in chartering out a jack-up vessel to others due to restrictions placed on joint venture companies through covenants or constraints embedded in the company's legal governance structure. Though not insurmountable this would need to be addressed.

The success of any club in delivering benefits to members is reliant on large -scale membership, which ensures the cost base per member is relatively low. Members of the club would have the potential option to sell additional days to other windfarms (including the newer sites not included in this study) as well as trade allocated days within the club. An example of how days could be allocated based on the relative number of turbines is shown in Table 13.

Any owner can also choose to use additional available days from their allocation (and potentially 'buy' days from others in the club) to undertake additional proactive replacements before any failure occurs. This approach will offer additional benefits to those provided in Table 12. A vessel club of this kind also acts as a form of insurance to reduce or even eliminate the risk of vessel unavailability.

The West Coast Cluster consists of mixed turbine models from four different turbine manufacturers. Even when these windfarms are out of warranty, if the repair/replacement is being supported by the original turbine manufacturer, it is unlikely they will permit their staff to work alongside competitors' staff on the jack-up vessel. Therefore, an allowance has been made within each task duration for the vessel to transit to a local port (Liverpool, Mostyn, Barrow

Table 13: Example of vessel allocation between west coast windfarms

Site	Number of turbines	Turbine size (MW)	Allocated vessel days[8]
North Hoyle	30	2.0	35
Arklow Bank	7	3.6	8
Barrow	30	3.0	35
Burbo Bank	25	3.6	30
Rhyl Flats	25	3.6	30
Robin Rigg	60	3.0	71
Walney 1 and 2	102	3.6	120
Ormonde	30	5.0	35

7 Costs exclude labour and any spare part costs

8 Allocated vessel days include a share of weather downtime and the club would need to agree rules about how this risk is shared between members

or Workington) to collect spare parts and load-out tools, teams and equipment – it is assumed this will be technically possible with the selected vessel.

No account has been taken of any waiting time for repair within the club as it has been assumed that, through a combination of condition monitoring analysis (to provide early warnings) and set rules which prioritise repairs to minimise production losses, waiting time is not significant. There may be short-term repair delays due to poor weather and a consideration of how these will be apportioned in any collaborative campaign or club is an important consideration which needs to be agreed by all involved.

If a club can be formed with commitment from all west coast owners, competitive charter rates achieved, rules are set prioritising reduction of downtime across the cluster and spare capacity is contracted out during low-use periods, participants will derive considerable benefits.

Part year jack-up vessel club for West Coast Cluster
In this example, several owners come together to charter a vessel for part of each year on a long term basis. This provides a means of managing (at least in part) the risk that a jack-up vessel may not be available or willing to transit to the west coast for a smaller ad-hoc repair task. It also offers cost reductions through lower transit/mobilisation times and may attract a more competitive charter rate.

The main risk from this arrangement is the potentially long downtime if a failure occurs soon after the end of an annual campaign and the owner is then required to wait until the next annual campaign before repairing the turbine.

To simulate the impact of this a range of failure and downtime duration events have been simulated for varying charter periods as shown below with only a low number of failures simulated to reflect a worst case.

A range of potential failure date combinations have been simulated, along with the cost of each potential permutation compared with a typical spot market repair cost. In this example there is a benefit from the club where the spot market is constrained. Where the waiting time for a suitable jack-up vessel is 12 months or more, the four and six owner club models offer a benefit to owners – if the spot market is more flexible then benefits are more marginal and more likely to be less attractive than reliance on the spot market. The results are highly dependent on the timing of actual failures in relation to the charter period of the vessel and are summarised in Table 15.

Where owners may be required to wait (with a turbine stopped) for six months in order to secure a vessel on the spot market then over half the potential failure scenarios demonstrate a benefit over relying on spot market rates. However, a part-time vessel club is not a cost-effective strategy when jack-up vessels are available at relatively short notice, although there is little evidence of jack-up vessels mobilising to the west coast for single turbine repairs. Therefore, this option can also be looked upon as a form of insurance against the risk of unavailability of jack-up vessels on the west coast, although the benefits are more difficult to quantify. If it were possible to ensure two shorter campaigns per year were arranged then the benefits of this approach could increase as overall downtime losses are reduced through reductions in repair waiting times.

This is a potentially more challenging club arrangement for jack-up vessel owners to cater for as they need to ensure overall vessel utilisation is maintained across the charter period at the smaller number of sites considered here. This will ensure competitive prices can be offered. The part time model may be possible if offered in tandem with a similar club arrangement in another cluster, perhaps on the east coast of the UK, to provide a fuller annual programme of work for any vessel. It is also possible for offshore windfarms and oil and gas installations to share a suitably flexible vessel.

Given the shorter charter period, greater consideration is needed of how weather downtime is handled within the club to ensure all members derive benefit. For example, in the recent east coast collaboration, each wind farm owner took on the weather risk from the day the vessel left the previous site. Further work to study turbine reliability to inform failure scenarios would also improve confidence in this option.

Table 14: Part year club simulations considered

Total period of club charter	Number of owners	Failures numbers per site[9]	Charter period
Four months	Four	Zero, one or two failures per site	1 May to 31 August each year
Six months	Six	Zero, one or two failures	1 April to 30 September each year

Table 15: Potential benefits of a part-time jack-up vessel club involving part of a cluster

Type of club	Spot market waiting period		
	Three months	Six months	A year
Four-owner	Spot	Highly influenced by timing of failures	Club
Six-owner	Spot	Highly influenced by timing of failures	Club

9 It was assumed that there is an equal likelihood of a failure occurring in any month and that either zero, one or two failures could occur

COURTESY OF SEAJACKS

THE CROWN ESTATE

London
The Crown Estate
16 New Burlington Place
London
W1S 2HX
T 020 7851 5000

Edinburgh
The Crown Estate
6 Bell's Brae
Edinburgh
EH4 3BJ
T 0131 260 6070

www.thecrownestate.co.uk/energy-infrastructure
@TheCrownEstate

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