Operations and maintenance (O&M) and installation have been identified as significant cost reduction opportunities for the offshore wind industry and savings can be achieved through a wide range of approaches.

However, significant barriers remain to developers and operators in attempting to realise these cost reductions.

Summary of findings

- Cost reductions in operational expenditure (Opex) can be achieved via improvement in operational efficiency, technical innovation and improved contractual arrangements.
- Cost reduction in the installation process can be delivered by understanding the dependencies between installation tasks, in order to identify a global optimum solution.
- O&M cost models allow the investigation of novel asset management approaches to identify their impact on Opex and availability and reduce uncertainty of future operations.
- O&M and installation models can also inform service providers, Original Equipment Manufacturers (OEMs), and financiers to provide a benefit across the industry.

Recommendations

- Asset management strategies should be continually evaluated in light of technical innovation and the evolution of the operating landscape.
- The benefit of any improvement in operational performance should be considered against the cost to implement by way of a Levelised Cost of Energy (LCoE) analysis.
- Greater sharing of learning and collaboration between operators and service providers should be encouraged to hasten the adoption of industry-wide optimal operating approaches.
At present, there is more than 8GW of installed offshore wind energy capacity in the European Union (EU), with a further 2GW under construction. In order for offshore wind to continue this momentum and realise its potential, it is necessary to reduce the levelised cost of energy (LCoE).

The UK has, to date, been the global leader in installing offshore turbines. However, the government have been clear that the industry must continue to reduce LCoE for a sustainable future.

The 2014 Contract for Difference (CfD) auction provided evidence that the industry is meeting the challenge of reducing LCoE to a degree, but there is still a significant need for innovations to reduce costs quicker. The ability and progress of different innovations in reducing costs has been identified in ORE Catapult’s Cost Reduction Monitoring Framework Summary Report (ORE Catapult, 2015).

One specific area identified where an emerging opportunity for cost reduction exists is in operation and maintenance (O&M) of wind farms, particularly as they come out of warranty and are open to a wider range of asset management approaches and service providers. The range of opportunities and specific key issues around O&M have been identified and considered in Operations and Maintenance in Offshore Wind: Key Issues for 2015/16 (ORE Catapult, 2015). That paper identified that some of the highest priorities for the industry developments are in ‘improvements in asset management strategies’, ‘improvement in asset management tools’ and ‘developing new offshore logistics concepts’. There is a strong dependency between these developments and this paper considers the challenges and opportunities around implementing these improvements in more detail.

There are additional complications associated with reduction in O&M costs that relate to the increasing complexity of offshore wind farms. The report The European Offshore Wind Industry – Key Trends and Statistics 2014 (EWEA, 2015) identifies that projects consented and planned are likely to be further from shore and in deeper waters than those online and under construction. Additionally, the size of both the wind farms and their constituent wind turbines will also increase. These trends are being driven by the availability of wind resource, planning constraints and economy of scale savings associated with larger turbines, which have the opportunity to reduce capital expenditure (Capex). All of these factors have the potential to increase operational expenditure (Opex) when compared to constructed sites. This increases the challenge of lowering Opex and increases the need for innovative asset management strategies that are bespoke to offshore wind.

Improving the efficiency of installation also represents a significant cost reduction opportunity and sophisticated modelling can provide new insights, reduce risks and lower costs. Installation campaigns for offshore wind farms are extremely complicated logistical exercises, with bespoke operations for foundations, cables and associated infrastructure, additional balance of plant and the turbines themselves each presenting unique challenges to deliver. Additionally, there are dependencies across these different installation work packages which must be fully understood and carefully managed to ensure optimal delivery of an installation campaign.

Because of these challenges, offshore wind farm installation and associated contingency has been estimated at 20% of Capex, with this dominated by vessel costs (The Crown Estate, 2012). As installation costs are encountered during the early phase of the project lifecycle, improvements have the potential to significantly reduce LCoE of projects.
Unlike asset management, however, there is a single opportunity to realise this benefit within each project, and it is therefore critical to get this right in each case.

The need for new asset management strategies, tools and concepts

Despite the progress that offshore wind has made in installing a significant capacity of turbines, there are substantial challenges to improving asset management approaches, due to the current nature of the industry.

Onshore wind energy benefitted from a long learning process, informed by a wide range of operators with various configurations of turbines and operating conditions who were able to share learning and data. Additionally, constraints around accessing the turbine - one of the principal challenges associated with offshore wind O&M - are relatively light onshore.

Despite these favourable conditions, there remains uncertainty of the contribution of O&M costs to LCoE for onshore wind. There are only a small number of assets that have reached the end of their design life and significant variations exist in reported costs. In Assessing the Lifecycle Costs and Carbon Emissions of Wind Power (climateXchange, 2015), recent estimates put the contribution of operating costs, including O&M, in the range of 15-24%. While still substantial, this is significantly lower than the corresponding offshore range for operating costs, including O&M, of 20-35%. As a result, there has been adoption of standard maintenance strategies onshore and a focus on improving other contributors to LCoE.

Offshore, the market is very different, with a small number of turbine OEMs and prohibitive Capex costs limiting the number of active developers. Additionally, there are almost no offshore turbines that have reached the end of their design life, so there is significant uncertainty surrounding the end of life performance of turbines. While various initiatives such as ORE Catapult’s SPARTA programme and Fraunhofer Germany’s Offshore WMEP are now collecting offshore wind turbine reliability data, uncertainty will remain around asset ageing, specific influences on component performance and the impact of maintenance actions for a significant period.

This uncertainty is compounded by the increasing complexity of new sites. Much of the learning by the industry has been at early, near shore sites, where the short travel times and sheltered location has led to the adoption of onshore maintenance approaches. In practice, this has primarily been the use of crew transfer vessels (CTVs) to access turbines for scheduled and unscheduled maintenance, supplemented by a helicopter in certain cases. Where necessary, specialist heavy lift vessels such as jack-up barges (JUBs) have been required for repair and replacement of major drive train components or blades and have been hired on a needs basis.

While usage of these vessels is infrequent, they have the potential to significantly increase the overall lifetime O&M cost if not carefully managed, as discussed in Jack-up Vessel Optimisation – Improving Offshore Wind Performance Through Better Use of Jack-up Vessels in the Operations and Maintenance Phase (The Crown Estate, 2014). However, it is clear that as wind farms move further offshore and increase in size, such maintenance strategies will become impractical and alternative approaches will need to be considered.
Due to the increased cost associated with downtime for new generation offshore wind turbines in the 6-7MW bracket, there is an opportunity to move away from periodic maintenance towards more sophisticated maintenance strategies. This can be achieved by optimising the intervals between scheduled maintenance at the component level, targeting maintenance on key components based on their condition as well as taking advantage of low wind conditions to carry out opportunistic maintenance, minimising the impact of down time.

Well-designed condition monitoring (CM) to provide the required level of system knowledge is an active area of research and development for wind turbines: see for example (Crabtree, 2010). This may facilitate condition-based maintenance approaches in the future. Manual inspection has a significant cost offshore due to the logistical challenge in getting technicians onto an offshore turbine. Further innovations, such as the use of remote control helicopter cameras, are providing a reduction in the cost and health and safety risk associated with visual inspection, but ultimately it is desirable that improved condition monitoring systems will remove the need for visual inspection altogether.

The factors outlined thus far with regard to lack of variety in OEMs, limited operating experience and uncertainty surrounding long-term reliability performance of assets present significant barriers to change within the industry. Therefore, there is a need to explore where asset management can be optimised; under what conditions new operating strategies become favourable; and how external cost drivers can more effectively be managed. Offshore O&M modelling tools provide a mechanism for investigating these questions and facilitating cost saving opportunities to operators and developers.

Additionally, the ability to accurately carry out a cost benefit analysis of CM systems and the implementation of advanced maintenance strategies can be considered using Opex models. By providing a means to quantify the impact of innovations that reduce Opex, models can inform OEMs of turbines and infrastructure as well as service providers by allowing whole life benefits to be considered alongside Capex impacts.

**Offshore wind O&M and installation modelling**

In response to this industry challenge, a wide range of commercial and academic simulation models and tools have been developed: see (Hoffman, 2011) for a review. Due to the complex nature of offshore wind O&M and installations, as well as the inherent uncertainty from the operating climate and asset performance, the methodology, scope and focus of different models varies widely. There is always a trade-off between simulation accuracy and complexity when modelling complex, real world situations and this is particularly true of offshore wind. Moreover, simulation approaches will not provide a definitive, repeatable value of performance and cost but rather will provide estimated values with an associated uncertainty range.

If sufficient simplifications are made, or sufficient knowledge of the performance of the access, failure and repair process are present, it is possible to use probabilistic analytical approaches such as (Feuchtwang, 2012) to rapidly assess the sensitivity of availability and Opex to site characteristics and resource impacts.
However, when such a level of system knowledge is not available or there are complex dependencies such as during the installation campaign, it is necessary to perform a full time series simulation of the process in order to determine the performance of a wind farm under a range of external conditions, site configurations and operational strategies. This increased fidelity comes at a significant computational penalty and the more detailed the simulation time resolution, the greater the corresponding simulation time. Regardless of the modelling methodology adopted, there is a fundamental challenge associated with using models to represent real world problems and this is compounded when the model is used to investigate hypothetical scenarios.

Models of complex operations over the life time of a wind farm will never completely replicate the real world scenario they are simulating due to the requirement of simplifications, as well as the epistemic uncertainty in the operating climate and failure behaviour of turbines. Therefore, models can never be considered validated for these applications.

A number of steps can, however, be taken in order to provide confidence in the results. Firstly, comparing simulated results to observed real world performance over a well-defined operating period or installation campaign allows the simulation logic and ability of a model to recreate real world scenarios to be verified. Once this has been established, the model can be tested by simulating scenarios that deviate only slightly from this base case and ensuring that the final results are logical. For example, an increase in vessel access threshold should result in an increase in accessibility to, and availability of, the wind farm or reduction in installation campaign duration.

Finally, model-to-model verification with alternative simulation approaches of a wide range of operating scenarios can increase confidence as well as identify the impact of model simplifications and logic implementations. In order to support future model developments for commercial and academic applications, a range of model-to-model verification cases is presented in (Dinwoodie et al, 2014) with more detailed discussion on the key assumptions for O&M cost models.

Case studies

In order to accurately consider the impact on energy yield and Opex from different installation and asset management strategies, a robust analysis should consider the full impact on LCoE.

The installation modelling approach is fully described in (Barlow et al, 2015). The O&M cost model used for this study is a full time series simulation model developed by the University of Strathclyde described in detail in (Dalgic et al, 2015).

In both cases, the models were developed in conjunction with industrial partners to ensure that the functionality, operating logic and key results are aligned with the current practices and future needs of industry. ORE Catapult used the output from the installation and Opex models with their in-house LCoE modelling expertise in order to determine the LCoE changes under different asset management innovation scenarios.
The baseline scenario uses a wind farm comprising 100 6MW wind turbines 50km off the south east coast of the UK, where a number of current and future wind farms are planned. The baseline maintenance resource levels, operating strategy and all associated wind farm costs were informed by industry partners to provide a representative wind farm for analysis.

Three different operational scenarios aiming to improve wind farm asset management were considered to represent contractual, operational and technological innovations and the current barriers to implementing each considered against any LCoE improvement. Two approaches to reducing installation costs, enabled via the developed installation model, are also presented, which consider improvements through integration of different work streams within the whole wind farm installation process.

**O&M Model Case Study 1**

The first case study examined the impact of adopting a change in contracting position for specialist vessels, focusing on the JUB which have been identified as a key cost risk.

The baseline scenario assumed that utilisation of JUBs would be carried out on an ad-hoc basis whenever required. In practice, this means that when a maintenance action requiring the use of a JUB occurs, the operator goes to the spot market to hire one. There is an associated mobilisation cost and delay drawn from a triangular distribution, based on the operational experience of early UK sites and University of Strathclyde expertise of the market. This approach has the advantage of only requiring a JUB and, consequently, only paying the high associated costs when maintenance actions are required.

The principal disadvantages associated with this approach are the increased exposure to the volatile vessel market which is outside of the operator’s control and has the potential to result in long down-times of assets, high day rates and mobilisation costs.

The alternative strategy modelled for this paper was a seasonal jack-up strategy, having a JUB available for a fixed annual operating period at a significantly reduced day rate cost. Each year, the JUB was available to use within the wind farm for repairs for the months of April and September, which is a simplified representation of the ‘jack-up club’ scenario, where a JUB is shared between a number of wind farms in a larger development zone.

In practice, a hybrid strategy where a JUB would still be obtained on the spot market under certain conditions, such as a failure immediately after an annual charter period, to take advantage of depressed market conditions or an impending winter season with higher energy potential may be optimal. Additional complexity to quantify the benefit of such a strategy could readily be incorporated into the modelling approach.

This seasonal jack-up strategy has the potential to reduce Opex, but without additional flexibility, a negative impact on wind farm availability occurred. One of the principal challenges facing offshore wind operators is being able to adapt operating strategies to ensure they are optimal, given the external market and emerging wind turbine reliability. O&M modelling allows the sensitivity to these different externalities to be considered and ensure adopted strategies and contractual decisions fully take account of risk exposure as well as necessary costs for each approach to be considered optimal.
For the baseline assumptions, which are informed by the current operating conditions and reliability of the industry, a negligible IRR improvement and LCoE reduction were observed when applying the seasonal jack-up strategy. However, valuable insights can still be obtained, as shown in Figure 1.

O&M models can inform real world decisions in this way by showing the expected range of annual costs under each scenario. In this case, the improved contractual approach can facilitate a reduced JUB cost and uncertainty at the expense of increased exposure to lost revenue and uncertainty in production.

**O&M Model Case Study 2**

An investigation has been carried out into the potential for improvement in utilisation of CTVs. Under the baseline scenario, the number of CTVs available in each month comprised a fixed number, based on historical corrective maintenance requirements and additional vessels for scheduled maintenance campaigns. The baseline numbers were conservative, prioritising availability of vessels to avoid delays from lack of resource. However, this led to an overall utilisation of CTVs of 63%. Under the alternative scenario, vessels were chartered for a month only if they had utilisation above 80%.

Although this situation is highly desirable and the operational teams will strive to achieve it, a number of barriers exist to implementation. These barriers include a lack of understanding of reliability performance, particularly for ageing assets, and uncertainty around operational climate and forecasting.

![Figure 1: Range of simulated annual costs for baseline and seasonal charter](image-url)
A number of research and operational improvements can provide help to overcome these issues, but there is an associated cost to obtaining this level of system knowledge. For example, industry-wide failure databases, detailed recording and analysis of individual failure mechanisms, investment in CM, increased inspection, paying OEMs for more information under warranty and more sophisticated forecasting approaches are all feasible.

The use of O&M modelling enables these changes by identifying the appropriate resource levels and allowing investigation of the consequences on performance. Again, it is necessary to consider the full lifecycle impact via an LCoE analysis in order to fully inform any asset management decisions.

It was identified that there is potential to increase the utilisation of CTVs from 63-92%, although this had an associated 0.38% reduction in availability due to an increase in times when utilisation is close to 100% and, consequently, insufficient maintenance resource was available to carry out repairs. This has the potential to significantly reduce the contribution of CTV’s to overall vessel costs, as shown in Figure 2. The resulting reduction in overall vessel costs is 11%. While significant obstacles remain to implementing these improvements, there is a modest potential to improve IRR and reduce LCoE.

![Figure 2: Reduction in CTV vessel contribution via improved asset management](image)

**O&M Model Case Study 3**

Finally, a radical change in operating practice using a specialist service operation vessels (mothership/SOV) has been considered, taking into account the current depressed vessel market conditions and emergence of new bespoke vessels. The SOV concept enables 24-hour working shifts and significantly increased access thresholds, although this has an associated increase in vessel and technician costs to achieve.

This asset management strategy provided the largest potential improvement in IRR and reduction in LCoE, but has also been identified as presenting the greatest challenge to implement, as shown in Figure 3.
Adopting a radically different operational strategy is highly dependent on the emergence of new technical innovations. For an existing project, it would require a significant organisational change in operating practice to adopt this strategy and there is a potential barrier to adopting such change at future sites associated with changing market conditions.

The annual cost and variability of different components are shown in Figure 4, allowing detailed analysis of the potential benefit to operators and the costs at which technical innovations must be delivered to provide benefit to the market.
Installation Campaign Modelling Case Study

Considering wind farm installation, two examples of how modelling can deliver a reduction in LCoE are presented. The first case study examines the impact from sharing vessels across different installation streams.

From a practical implementation, this would mean using the same vessel to install jackets, offshore service platforms and infrastructure as well as turbines as opposed to attempting to optimise each work package in isolation.

For the baseline in this case, every installation package is considered in isolation. The improved case shares vessels across streams whenever it would be possible in practice.

While the base case can be considered pessimistic, there is a necessity for a suitably sophisticated tool that fully considers the impact of logistics interactions between streams in order to accurately evaluate and optimise the duration of the installation campaign.

The resulting reduction in total installation cost and variability is shown in Figure 5.

![Figure 5: Range of simulated lifetime costs for shared and separate installation streams](image)

Additionally, for both of those installation campaign configurations, the optimal scheduling between mobilisations of the vessels used for pile and jacket installation has been investigated. This considers likely weather delays and the dependencies between work streams.

The total cost was considered over a range of 1-400 days and the reduction in cost associated with those installation actions then fed through to total costs previously identified.
Despite a smaller absolute reduction on costs, the improvement to IRR and reduction in LCoE achievable is of a similar magnitude to those identified with the O&M model, shown in Figure 6.

A detailed evaluation of the capability of installation models to reduce project costs including detailed methodology of the model used for this paper is presented in (Barlow, 2015).

![Figure 6: Performance improvement with increasing analysis complexity](image)

**Conclusion**

Improvements in operations and maintenance and installation strategy provide an exploitable opportunity to realise LCoE cost reductions for offshore wind. Three O&M asset management improvement approaches have been considered representing improvement in operational efficiency, technical innovation and improved contractual arrangements.

Based on the scenarios in this paper, the greatest savings can be delivered via technical innovation, although this is currently furthest from realisation. A similar level of LCoE reduction is feasible through optimisation of the installation process but this requires complex analysis to implement.

Modelling tools can provide new insights and understanding of different asset management strategies in order to hasten their adoption and ensure that optimal approaches are implemented based on technological developments, increased knowledge and the current operating environment. In order to ensure that optimal decisions are made, whole life impact of changes should be considered via an LCoE analysis.
Recommended reading


Author Profile

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The asset management models that informed the analysis in this paper were produced with industry partners as part of completed LCPE projects AM02 and FI03 and were developed by the following researchers:

O&M model:  Dr Yalcin Dalgic, Dr David McMillan, Dr Iraklis Lazakis, Dr Matthew Revie, Dr Jayanta Majumder

Installation model:  Dr Euan Barlow, Dr Diclehan Tezcaner Öztürk, Dr Matthew Revie, Dr Evangelos Boulougouris, Professor Alexander Day, Dr. Kerem Akartuna

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