The optimal access system for future far-offshore wind farms

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Summary

Operation and maintenance (O&M) of offshore wind turbines is one of the main cost drivers of offshore wind energy. One of the aspects critical for an efficient and cost-effective O&M strategy is the selection of the access system which is used to transfer technicians and, optionally, small spare parts. Currently, most offshore wind farms are located close to shore, and their size is relatively small. For these farms the typical access system consists of catamaran-like workboats, which are used to transfer both technicians and small spare parts. As wind farms move further offshore this O&M concept might no longer be cost-effective.

Currently, different alternative O&M concepts are being considered for the future far-offshore sites. In this paper an extensive and holistic comparison of different O&M concepts including different access system solutions is presented. This analysis has been performed using the OMCE-Calculator, ECN's software for advanced O&M cost modelling. Different sites have been considered, which are typical for the future offshore wind farms that will be commissioned during the next five years.

The results of the performed analyses indicate that when moving further offshore harbour-based O&M strategies are no longer economical, even when helicopters are added to the mix. Looking at farm-based O&M concepts a supply vessel with a compensated access gangway offers great potential. However, the calculations also indicate that its ability to transfer small spare parts, in addition to technicians, is crucial.

1 Introduction

Operation and maintenance (O&M) of offshore wind turbines is one of the main cost drivers of offshore wind energy. At present, the OPEX costs contribute for approximately 25% to the Levelised Cost Of Energy (LCOE). ECN is recognised as the leading R&D institute on the optimisation of O&M strategies of offshore wind farms. As an example: since 2006 ECN has been developing software tools for modelling the OPEX costs of offshore wind farms and these tools are now in use by the vast majority of leading project developers and turbine manufacturers. The bulk of all the offshore wind farms in Europe have been analysed and optimized with these tools.

One of the aspects critical for an efficient and cost-effective O&M strategy is the selection of the access system which is used to transfer technicians and, optionally, small spare parts[1].

Currently, most offshore wind farms are located relatively close to shore, and their size is relatively small. This is illustrated in Figure 1. For these farms the typical access system consists of catamaran-like workboats, which are used to transfer both technicians and small spare parts (see Figure 2). As wind farms move further offshore, two main problems arise. Firstly, with increasing distance from the harbour travel times increase, which significantly limit the effective time technicians can perform maintenance work on the turbines. Secondly, weather conditions become

[1] Small spare parts typically have a maximum weight of a few hundred to 1000 kilograms. An example are pitch and yaw drives, or parts of the hydraulic system.

harsher when moving further offshore. This limits the accessibility of the wind farm, which can lead to very long downtimes in case unexpected failures occur.

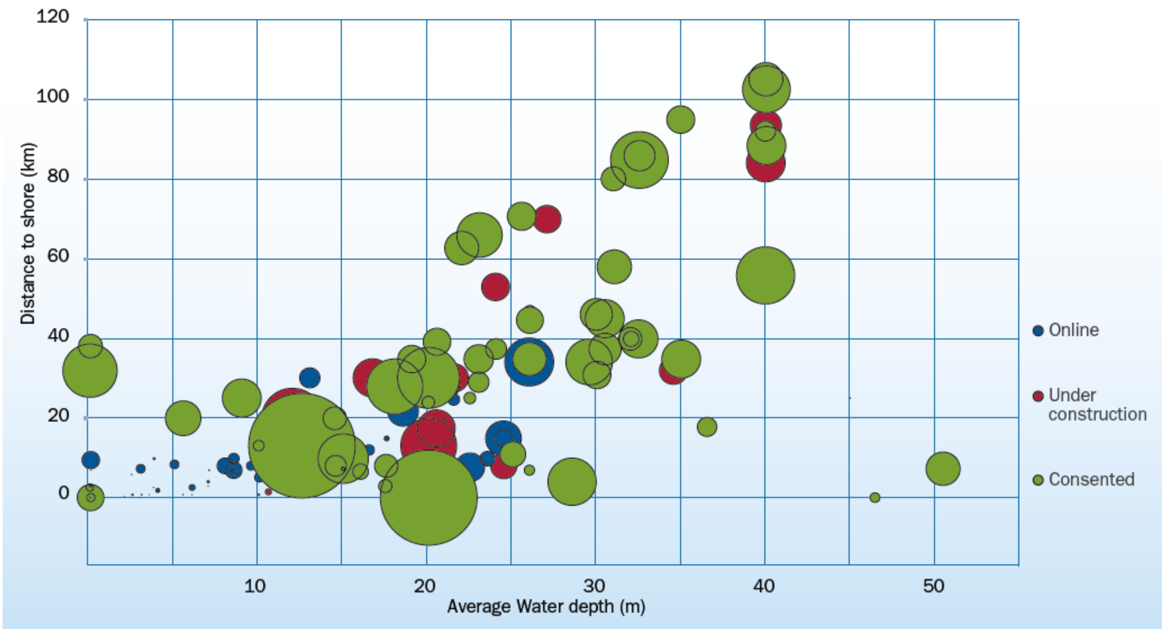

Figure 1: *Graph illustrating the farm size, distance to shore and average water depth for offshore wind farms currently being online, under construction and consented [1].*

Figure 2: *Examples of catamaran-like workboat access vessels: the WindCat MKIII on the left [2] and the CTruk 20T on the right [3].*

Currently various alternative access systems are being considered and developed, each with their specific advantages and drawbacks (see

Figure 3 for examples). Some aim at improving the workability of the catamaran-like workboats (f.i. MaXccess, TAS, Z-Catch), others consist of a large vessel with a compensated access gangway (f.i. Ampelmann, Z-Bridge, UPTIME, OAS). Furthermore, using a strategy with mother and daughter vessels or applying helicopters also offers potential.

Figure 3: *Examples of alternative access systems. In anti-clockwise direction starting top left: the MaXccess [4] system for enhancing workboat workability, helicopter transfer [5], the Z-Bridge access system [6] placed on the Damen W2W vessel [7] and Ampelmann [8] compensated access gangway.*

When highlighting the advantages of the different access systems the focus often lies on the improvement in the significant wave height limitation for transferring technicians to the wind turbine and how this affects the accessibility of the wind farm. Although a good indicator, it does not tell the whole story. In order to truly quantify and compare the benefits of the different access systems it is essential to consider them as part of the complete O&M strategy in which both preventive and corrective maintenance, with the full range of small to large failures, is taken into account.

In this paper an extensive and holistic comparison of different O&M concepts including different access system solutions will be presented. This analysis has been performed for a number of sites, which are typical for the future offshore wind farms that will be commissioned during the next five years.

2 ECN's OPEX cost modelling software

For the comparison of the different O&M concepts ECN applied their in-house developed software for OPEX cost modelling: the OMCE-Calculator.

The specifications for the OMCE-Calculator have to a large extent been based on the experiences with the ECN O&M Tool. This tool is at present being used by more than 25 leading project developers, turbine manufacturers and independent service providers, and is considered as the industry standard for analysing O&M aspects of offshore wind farms in the early planning phase [9].

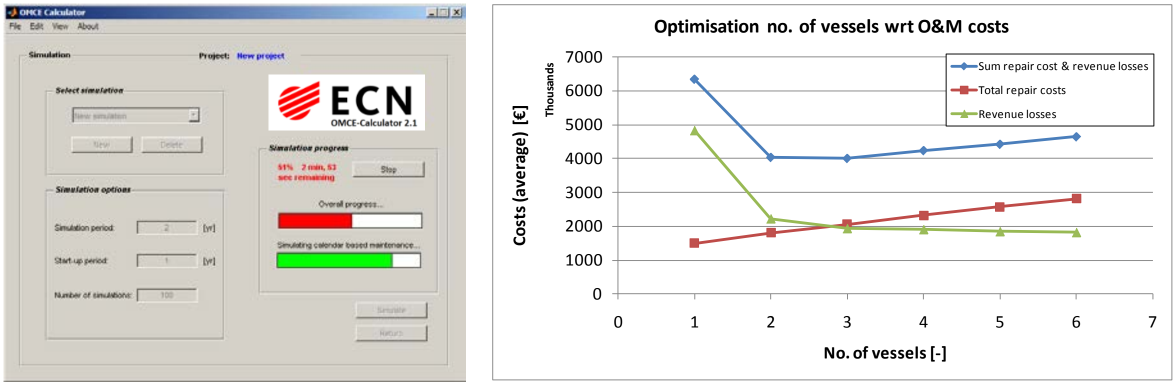

Figure 4: *The OMCE-Calculator: ECN's software for advanced OPEX cost modelling. On the left an example of its GUI, on the right an example to find the optimal number of access vessels.*

The OMCE-Calculator is a time-domain simulation program which has been developed in MATLAB and is designed to assist operators of wind farms to determine the optimal O&M strategy during the advanced planning and operational phase of a wind farm. The tool is best used with operational data from the wind farm, although it can also be used with generic data as input in order to use the tool's advanced features for optimisation of the maintenance strategy. Data required as input for the tool includes: failure rates, expected time-to-failures, preventive maintenance, repair strategies, wind and wave statistics, costs, lead time of vessels and spare parts etc. Compared to the O&M Tool the OMCE-Calculator offers the following advantages:

- Suited for application during the operational phase of an offshore wind farm, where predictions for a few years ahead are required instead of numbers representative for the wind farm lifetime.
- Logistic aspects are included in detail:
    - The number of available equipment can be specified and the software takes into account that additional downtime can occur due to an insufficient number of equipment being available.
    - Stock control is included. For the different types of spare parts it can be considered to keep a number in stock. The simulations take into account that additional downtime will occur in case the stock runs empty.
    - Hybrid repair strategies can be modelled. An example could be that for a certain repair default a workboat is used, but in case its weather limits are exceeded a helicopter is used instead to transfer technicians to the turbines.
- Output includes both time-based and energy-based availability, whereas the O&M Tool only considers the former.
- The OMCE-Calculator contains a flexible maintenance model, where different combinations of repairs, replacements and inspections can be specified.

3 O&M Strategies

As discussed in the introduction the typical way of transferring technicians and small spare parts for most of the wind farms currently in operation consists of catamaran-like workboats, where the turbine's platform crane is used to pick up these spares from the workboat.

This scenario will act as a reference as is therefore included as the baseline O&M scenario. In addition to this four alternative O&M strategies are considered, which will be compared against the baseline scenario.

All five strategies are described in more detail below:

Baseline: *Large workboats from harbour*

A harbour-based concept where large catamaran-like workboats[2] travel from shore to the wind farm. The large workboats allow transportation and transfer of technicians and small spare-parts in significant wave heights up to 2.0 m.

Alternative I: *Mother/daughter vessel combination*

The first alternative is a farm-based O&M concept where a large mother vessel is at all times present in the wind farm. The mother vessel accommodates a number of daughter vessels (medium-size[3] workboats), which are assumed to be able to transfer both technicians and spare parts to the wind turbines.

Alternative II: *Mother vessel with compensated access gangway (techs & spares)*

As a second alternative another farm-based strategy is considered, where a mother vessel is now equipped with a compensated access gangway which is capable of transferring both technicians and small spare parts up to wave heights of 3.0 m. Furthermore, the mother vessel also accommodates two small daughter vessels which can transfer technicians up to significant wave heights of 1.0 m.

Alternative III: *Mother vessel with compensated access gangway (techs only)*

The third considered alternative is very similar to the previous, with the key difference that the compensated access gangway is only capable of transferring technicians. In order to transfer small spare parts it is assumed that the mother vessel has to sail close to the wind turbine so that the spare-part can picked up by the turbine platform crane. As this is a very delicate operation the wave height limit for transferring spare parts was estimated at 1.5 m for this scenario.

Alternative IV: *Large workboats from harbour with helicopters*

The last considered O&M scenario is a harbour-based O&M concept similar to the described baseline scenario. The difference is that in addition to the large workboats helicopters are available to transport and transfer technicians to the wind farm in case the workboats cannot sail out due to harsh weather conditions. It was assumed that the helicopters can be stationed at a helideck at the wind farm transformer substations.

The five strategies only differ in the way how technicians and small spare parts are transferred to the wind turbines. Large component replacements are for all five strategies carried out by a jack-up heavy lift vessel. However, also for these type of replacements technicians have to be transferred to the turbines, which of course is done in a different way for the five considered strategies.

For all considered scenarios realistic assumptions were used for the costs of the used equipment. In order to not influence the comparison of scenarios I, II and III the yearly charter rate for the mother vessel was set equal for all three scenarios, although in reality this parameter might vary depending on with what kind of access system the mother vessel is equipped with.

[2] A large workboat typically has a length of 24-28 meters.
[3] A medium size workboat typically has a length of 16-20 meters.

4 Wind farms

In order to evaluate the benefits and drawbacks of the five considered O&M concepts a number of representative offshore wind farms were identified. It was chosen to perform the comparison for more than one farm, as it can be expected that the location, size and distance to shore will influence how the different O&M concepts compare.

As already illustrated in Figure 1 the wind farms currently under construction or consented will typically be larger and located further from shore than most of the wind farms currently in operation. An analysis was made of the wind farms that will be installed over the next 5 years, where the focus was mainly on the 'German bend' area of the North Sea. Based on this analysis 4 different wind farms were defined which are representative for most of the future offshore wind farms that will be installed in this area. In addition to this also a fifth farm, located closer to shore, was selected in order to evaluate the five O&M concepts for a farm more typical for the offshore wind farms currently in operation.

The location and characteristics of these farms are illustrated in Figure 5.

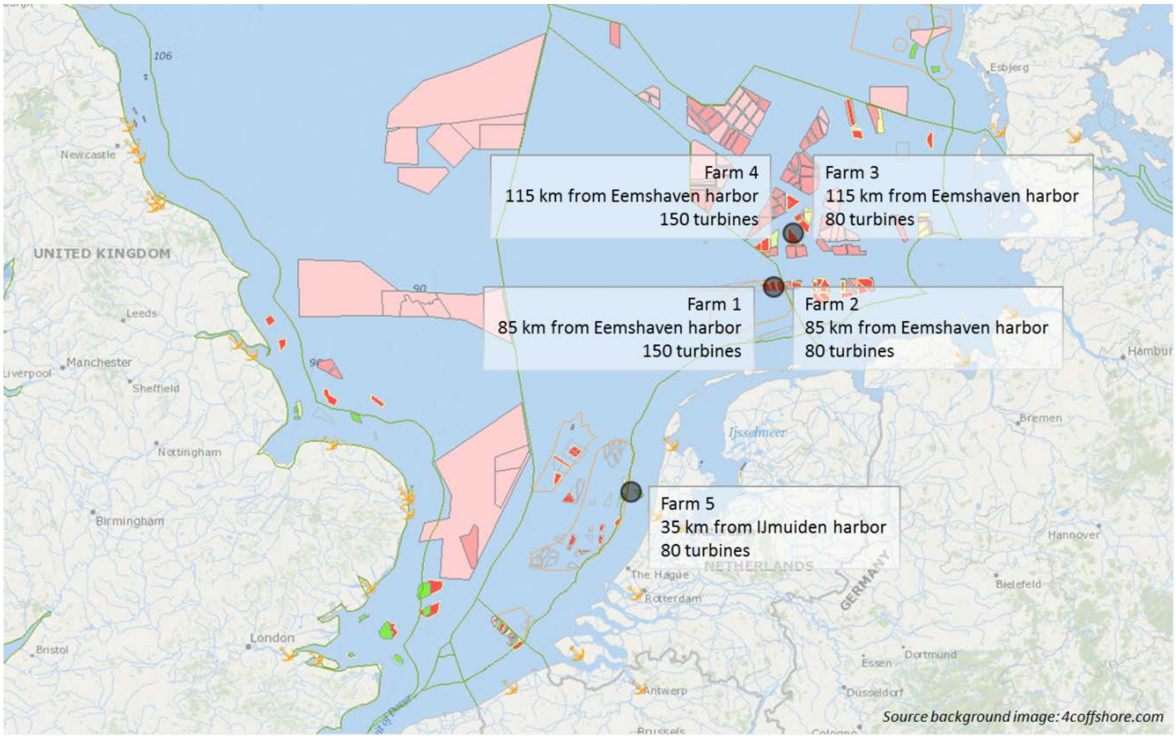

Figure 5: *The five wind farms considered for the comparison of O&M concepts for future far-offshore sites [11].*

Met-ocean data for farms 1-2 and 3-4 were obtained from BMT Argoss [12]. For farm 5 data from the Rijkswaterstaat YM6 measurement station were used [13]. For all five farms a generic 4 MW offshore wind turbine was considered. For calculating revenue losses a fixed feed-in tariff of 0.13 €ct/kWh was taken into account.

5 Results comparison

All five scenarios were modelled separately for each of the five considered wind farms, resulting in 25 OMCE-Calculator models. For the harbour-based strategies (baseline & alternative IV) additional optimisation studies were performed in order to assess how many workboats (and helicopters) are required. For all 25 OMCE-Calculator models 100 simulations of 20 years length were performed in order to fully take the uncertainties into account.

The key simulation results in terms of availability and costs of repair are displayed in Figure 6.

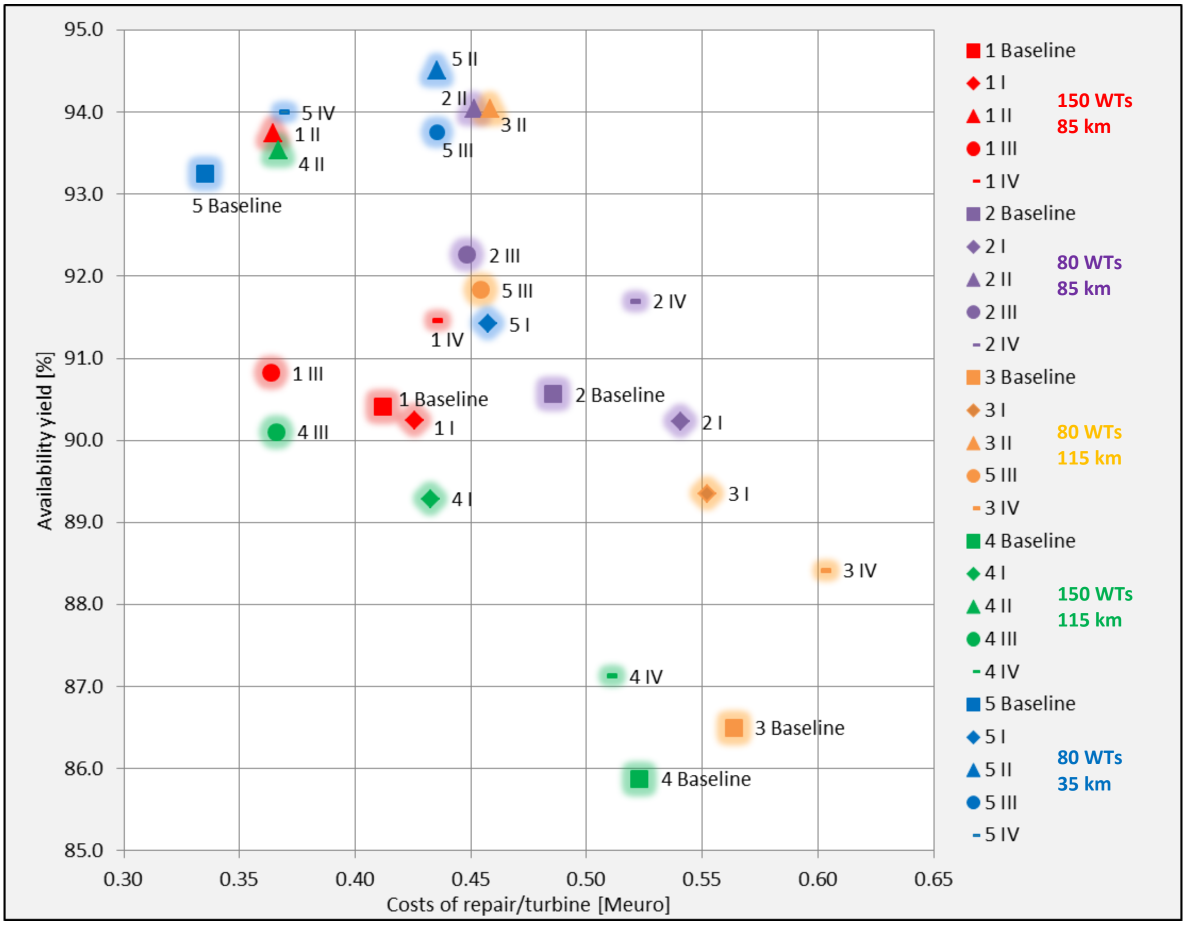

Figure 6: *Key simulation results for the five considered O&M concepts for each of the five modelled offshore wind farms.*

It can be seen that for all considered farms each O&M strategy results in a different availability and cost of repair. However, the differences are largest for farms 3 and 4, which are furthest away from shore. On the other hand for farm 5, which is more typical of an offshore wind farm currently in operation, the differences between the five O&M concepts is much smaller.

When looking at the different O&M concepts it can be observed that strategy II (compensated access gangway for technicians and spares) is least sensitive to variations in the location, size and distance to shore of the wind farm. For all five farms the results for this scenario can be found in the top left corner of the graph, indicating high availability and low cost of repair per turbine.

Shore based O&M concepts (baseline and alternative IV) are most sensitive to the wind farm characteristics. For a farm relatively close to shore these are the most cost-efficient solutions, but especially for farms 3 and 4 the availability drops dramatically, which can be explained by the very long travel times combined with the harsher met-ocean conditions for these sites. Adding a helicopter results in a higher availability but also increases the cost of repair. When adding up the lost revenues and the direct cost of repair the difference between these two concepts is marginal.

Using a mother/daughter vessel concept (strategy I) significantly increases the useful time technicians can work on the turbines. However, the considered daughter vessels are assumed to only allow access when wave heights are below 1.5 m, which means that significant weather downtime can be expected, especially for the farms further offshore. Compared to the shore-based strategies this approach is only economical for the farms at 115 km from shore.

Focussing on the scenarios with compensated access gangways (II and III) it immediately becomes clear that the ability to transfer small spare parts in addition to technicians is crucial. When this is not possible wind farm availability is significantly reduced, which is visible for all five considered farms. This is a consequence of the long weather downtimes caused by the delicate operation of transferring small spares directly from the mother vessel to the turbines in case this cannot be done via the compensated access gangway.

Besides comparing the different O&M concepts for the different type of farms additional studies were performed in order to quantify the effect of design decisions on the calculated downtimes and costs of repair. An example is illustrated in Figure 7, which shows the influence of the wave height limit for transfers via a compensated access gangway on the wind farm lost revenues and costs of repair. The analysis was performed for wind farm 1 (150 WT's; 85 km from shore) and considering strategy II (compensated access gangway for technicians and spares).

The original assumption was that both technicians and small spare parts can be transferred in wave heights up to 3.0 m. The left graph illustrates the effect of a slightly lower or higher limit. It can be seen that when moving to a 3.5 m limit the gains in terms of increased revenues are small. However, if the limit would be 2.5 m the wind farm downtime and associated revenue losses will increase more significantly. With this information it can be seen that for this wind farm the design target of a 3.0 m wave height restriction is indeed a good choice.

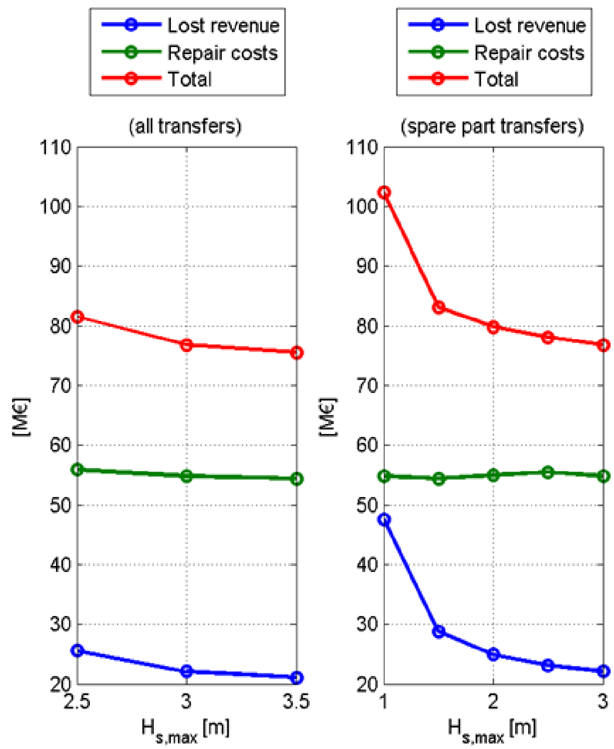

Figure 7: *Analysis of the influence of the wave height limit for transfers via a compensated access gangway on the wind farm lost revenues and cost of repair.*

It was however considered that for the transfer of spare parts it might not be realistic to assume a wave height limit of 3.0 m. Therefore additional studies were carried out to investigate the influence of the wave height limit specifically for those transfers. This is shown in the right graph in Figure 7. From the numbers it can be concluded that it should at least be possible to transfer the small spare parts in wave heights up to 2.0 m. If this is not possible downtime and lost revenues will increase significantly.

6 Conclusions

The benefits of newly developed vessels and access systems can only be quantified when considered as part of a total O&M concept including preventive and corrective maintenance with the full range of small to large failures. This approach was followed for five different O&M strategies, each using a different solution for personnel and spare part transfer, and for five different offshore wind farms. The results show that the 'proven' concept of using workboats for transferring technicians and small spare parts is indeed most economical for farms relatively close to shore. However, this concept is not suited for a lot of the farms currently consented, which are located further from shore and larger in size. For these farms a mother vessel equipped with compensated access gangway offers potential. However, the performed calculations also indicate that the capability of transferring small spare parts is crucial for achieving a high wind farm availability.

The results of these analyses can be used to quantify the business case of new concepts, compare them against the industry standard, evaluate for which type of farms (location, size, distance to shore) the concept is most suited and to identify the best ways to optimise the concept in the design phase.

In these studies only limitations on significant wave height and wind speed were considered. In reality the accessibility is influenced by other parameters as well. Other parameters that could be important are for instance wave period, wave direction, tides and currents. In order to improve the comparison between different concepts for each of them it should be known exactly under what conditions (in terms of the listed parameters) transfer of technicians and small spare parts can be performed and when not. It is foreseen that the functionality to perform such analyses will be implemented in the OMCE-Calculator in the near-future.

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(http://www.tki-windopzee.nl/)

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