energies

Article

How Does the Accessibility of Floating Wind Farm Sites Compare to Existing Fixed Bottom Sites?

David Rowell *, Brian Jenkins, James Carroll and David McMillan

Wind and Marine Energy Systems & Structures CDT, University of Strathclyde, Glasgow G1 1XW, UK
* Correspondence: david.rowell@strath.ac.uk

Abstract: Offshore wind is poised for huge growth in the coming years, the UK government has set targets of 40 GW of offshore wind, including 1 GW of floating wind, to be installed in the UK by 2030. Many proposed wind development sites are in deeper waters, farther from shore and will therefore need to be developed as floating wind sites. Developing sites in deeper waters provides access to higher, more consistent wind speeds, however this also means increased wave heights and tougher operating conditions. This makes the challenge of site accessibility critical to the goal of lowering the costs of offshore wind. Accessibility is the amount of time that vessels can safely access a given site. The objective of this study was to make a comparison of the accessibility of potential future floating wind sites to existing fixed bottom wind farm sites. Accessibility was calculated by developing Matlab code using established techniques and definitions found in the literature. A case study was then completed using sites in Scottish waters proposed for development as part of the Scotwind leasing plan. The majority of the Scotwind sites will need to be developed as floating wind sites due to the large water depths. This study assesses the accessibility of the Scotwind leasing sites and compares them to a typical fixed bottom site. The study found that accessibility will be a greater challenge for floating farm wind sites compared to fixed bottom sites. Increased access to vessels that can operate in larger wave heights will likely be necessary to operate and maintain floating wind farm sites.

Keywords: accessibility; floating wind; weather windows; O&M; wind energy

Citation: Rowell, D.; Jenkins, B.; Carroll, J.; McMillan, D. How Does the Accessibility of Floating Wind Farm Sites Compare to Existing Fixed Bottom Sites? *Energies* **2022**, *15*, 8946. https://doi.org/10.3390/en15238946

Academic Editors: M. Salman Siddiqui and Frede Blaabjerg

Received: 14 October 2022
Accepted: 24 November 2022
Published: 26 November 2022

1. Introduction

The installed capacity of offshore wind is expected to grow rapidly. In 2020, 6.1 GW of offshore wind was commissioned, making a total of 35 GW worldwide, which represents 4.8% of total global offshore wind capacity [1]. The offshore floating wind industry is still in an early stage of development; however, it is set for a dramatic increase in the coming years. Many governments have set targets to develop floating wind sites, including 1 GW by 2030 in the UK and 1 GW of tenders per year are to be released by the French government. Floating wind projects are also beginning to be developed in Japan and the US [2,3]. The announcement in early 2022 on the Scotwind application process in the UK exceeded all expectations with 10 floating wind projects being applied for, totaling 14.5 GW of capacity [4]. The UK currently has around 10 GW of installed capacity of offshore wind and less than 100 MW of that is in floating wind farms, which are early stage demonstration projects [5]. The floating wind industry is poised for huge growth in coming years and will have many challenges to overcome in order to be successful.

Existing offshore wind farms are almost all located in relatively shallow water depths (<40 m) and close to shore (<30 km) [6]. To successfully achieve the planned increases in offshore capacity, wind farms will be pushed farther from shore and into deeper waters. Globally there are significant wind resources in deep-water, for example, Scotland has an estimated 100 GW of potential offshore capacity in sites with a water depth of greater than 60 m [6]. Developing deep-water sites raises new challenges that need to be addressed. Primarily, this means reducing the costs of generating wind energy from these sites. A key driver of the costs are the difficulties posed by operating turbines in much harsher conditions with more intense waves and higher wind speeds [7]. In order to reduce the costs of offshore wind energy the wind turbines must maximize their availability. Availability is the percentage of time in the year in which the turbines are able to operate and generate electricity. To maximize availability the turbines must be kept in operating condition by regular maintenance, in offshore wind, the access to turbines is often limited by factors such as weather. In order to keep wind turbines operating it is critical to be able to safely access a wind farm or turbine with technicians and materials. Access is limited by variables including weather, wave heights and vessel capabilities. Key definitions including accessibility and other terms are described in Box 1.

Box 1. Key definitions.

Significant wave height (Hs): Significant wave height (H_S) is defined as the mean of the largest one third of waves and is a standard method of categorizing wave heights.
Weather window: A weather window is a discrete time period where access is possible.
Approachability: Approachability is the normalised amount of time that that access is possible. So, when considering Hs as the limiting factor, it is the normalised amount of time that Hs is below the limiting wave height.
Accessibility: Accessibility is the approachability of a wind farm while considering the weather window. It is the normalised amount of time that access is possible, but only including the time periods that are within a weather window of a required length.

Research indicates that to achieve wind farm availability of 90% then an accessibility of 80% is required [8]. The accessibility of offshore sites is therefore a critical factor that will determine the cost of operating an offshore wind farm. Information about the accessibility of potential sites is important in establishing costs of future floating wind developments. Operations and maintenance costs are around 20 to 30% of the lifetime costs of a wind farm, and accessibility is a significant driver of this cost [9].

Previous studies have used different methods to calculate accessibility, these are generally split between statistical methods and time series methods. The main difference is the data used for the calculation. Time series methods use either existing data collected from weather buoys or hindcast data to make the accessibility calculations. An advantage of a time series method is that where data is available for a specific site they allow for a detailed analysis and are backed up by real world data. However, real world wave bouy data is rarely available. Hindcast data is more readily available, but could over or under estimate real world conditions. Where there is not a significant amount of available data, statistical methods can be used. Statistical methods used include the Weibull method, where a probability distribution of wave heights is developed for a desired site. This is based on empirical methods to determine shape factors to generate a suitable Weibull distribution [10]. The other most common statistical method used is the Markov chain, this method is considered to be more accurate than the Weibull method but is also more complex, requires more input data and increases the complexity of the calculations [11]. Statistical methods are advantageous where there is limited data for a site, they can generate probabilistic models of wave height occurrences and in some cases can be modified to incorporate variations such as climate change. The definitions of accessibility used are consistent across different methods, the prime difference is how the data is collected or generated. Table 1 shows a summary of methods and sources used across existing studies.

Table 1. Summary of accessibility studies.

No.	Refs.	Authors	Method	Parameters Incl.	
				Hs	*u*
1	[8]	van Bussel & Bierbooms	Time Series	✓	✓
2	[12]	Silva & Estanqueiro	Time Series	✓	✓
3	[13]	O'Connor, Lewis et al.	Time Series	✓	✗
4	[14]	Browell, Zitrou et al.	Time Series	✓	✓
5	[11]	Martini, Guanche et al.	Time Series	✓	✓
6	[15]	Feuchtwang & Infield	Statistical (Weibull)	✓	✗
7	[16]	Walker, McCall et al.	Statistical (Weibull)	✓	✗
8	[17]	Scheu, Matha et al.	Statistical (Markov)	✓	✓
9	[18]	Paterson, Thies et al.	Statistical (Markov)	✓	✓
10	[19]	Seyr & Muskulus	Statistical (Langevin)	✓	✓
11	[20]	Rinaldi, Thies et al.	Statistical (Markov)	✓	✓

Martini and Guanche used a time series method and have applied set theory to create a mathematical definition of accessibility and completed a study of the North Sea using hindcast data [11]. There have also been time series accessibility studies on specific sites in Portugal, the Irish West Coast and the Netherlands using similar methodologies [8,12,13]. Analysis of FINO1 bouy data in the North Sea off the coast of Germany has also been completed to assess weather windows and waiting times to complete maintenance activities at that location [14].

A statistical method proposed by Feuchtang and Infield uses a closed form probabilistic method of calculating accessibility that only requires limited data about a site to perform quick calculations [15]. Walker and van Nieuwkoop-McCall also used a probabilistic method applying Weibull probability distributions to calculate weather windows with a case study on the Devonshire coastline in England [16]. Scheu and Matha have used Markov simulations to generate wave time series data to simulate conditions at a wind farm and model operational aspects including accessibility [17]. Paterson and Thies used a Markov switching autoregressive model to generate stochastic wind speed and wave height time series to calculate accessibility and weather windows [18]. Langevin models are another method that can be used to simulate environmental conditions at a site and generate wind and weather time series data when there is not enough available. A Langevin model was used to generate data in the North Sea which was then validated against hindcast and bouy data. It was found that the data produced by the Langevin method had good agreement with the time series data and the calculations required less input data than a Markov chain method [19]. Rinaldi et al. modelled O&M strategies to compare a fixed bottom wind farm with a floating wind farm, however that study considered that the two farms were at the same site with the same meteorological conditions for input [20].

The primary objective of this study is to develop an understanding of the relative accessibility of the floating sites in comparison to typical fixed bottom sites, this takes into consideration that floating wind sites are going to be developed in deeper waters, farther from shore with harsher meteorological conditions than a typical fixed bottom site. The secondary objective is to understand how accessibility is affected by type of access system, duration of maintenance activity and season.

The study used a time series method, collected hindcast wave data and developed code in MATLAB to complete the calculations. To perform the comparison, assessment sites in Scottish waters were selected. Scotland is home to the World's first floating wind farm (Hywind) with a second farm recently becoming operational at Kincardine off the coast of Aberdeen. Improving the understanding of accessibility of future sites for development will be an important factor in the success of floating wind in Scotland and the rest of the World.

The Scotwind leasing plan has been launched to identify sites suitable for development in Scottish waters. The plan will grant property rights for commercial scale offshore wind farms [21]. Large parts of the Scotwind leasing plan are in water with a depth greater than 70 m, making it likely that floating foundations will be the most economical solution [22]. In early 2022 plans were announced for the development of 10 floating wind farms across the Scotwind sites [4]. The case study looks at the predicted accessibility of the proposed Scotwind sites and compares them to the existing Moray East fixed bottom offshore wind farm site [23].

2. Methods

The accessibility of a given site can be influenced by a number of different factors, these include:

- Significant wave height (H_S),
- Wave period,
- Wind speed (u),
- Distance to port,
- Daylight hours,
- Visibility,
- Vessel capabilities,
- Other weather conditions, i.e., fog, lighting, etc.

Significant wave height limits accessibility as all vessels have maximum wave heights in which they can travel to a site and limits as to when they can safely transfer crew from the vessel to the turbine. Studies have been completed to attempt to model how different wave conditions effect vessel motion and the ability for a CTV to push on to a fender and safely transfer crew [24,25]. Wave height, peak period and direction will all have an influence on vessel motion and the ability to make transfers and will therefore effect accessibility. Wind speed is usually not significant in terms on its effects on vessel motion, but it will limit helicopter operations, lifting operations and make conditions difficult for technicians to work safely [24].

The distance to port of a site will obviously determine the travel time for technicians setting out to complete work activities, sites farther from shore will require longer weather windows to allow time to safely travel to the turbine, complete maintenance and return to shore. Daylight hours will also have an effect on accessibility as some operations will not be able to be safely completed at night so activities will be limited to daytime. In the same way, visibility will limit accessibility, as factors such as fog or heavy rain could make some operations unsafe. Other weather conditions such as lightning could also limit accessibility for safety reasons. Finally, vessel capabilities have an effect on many of these factors. Larger vessels with more advanced access systems such as walk to work gangways will be able to travel longer distances, operate in larger wave heights and transfer crew in more challenging conditions.

This study only considers the significant wave height (H_S) and the vessel crew transfer limit. This was done for simplicity and also as significant wave height is one of the most important factors determining accessibility and is used in operations and maintenance contracts to determine when maintenance contractors should be able to carry out work. Using Hs only allows for a high-level comparison between potential floating wind sites and an existing fixed bottom site. Existing studies have shown that for most sites wind speed generally correlates well with wave height [8,12]. Where wave heights are high enough to limit access wind speeds are likely to be high enough to prevent operations such as hoisting with a crane. Again, for this reason wave heights were considered as the most important factor for inclusion.

Waves can be characterized by wave period, significant wave height, direction and zero crossing period, however, H_S has become the industry standard for measuring the limits of access systems. The study also only considers the access conditions at the wind farm site. It does not include the travel routes of vessels or the possibility of tow to shore maintenance for floating wind turbines.

Approachability and accessibility have been defined mathematically by Martini and Guanche and their definitions were used as the basis for the calculations in this study [11]. Definitions of both terms are included in Box 1. Calculations are performed using some time series wave or wind data.

Figure 1 shows a time series plot of typical H_S data. The H_S limit has been set as 1.5 m. The wave heights are below the limit in the time periods a, b and c. These would constitute weather windows. If the weather window required was set as 3 time periods. Then, only window c would count towards the accessibility calculation. At all other time periods the H_S is above the limit so the weather window would be closed and there would be no access to that location. Typical weather window durations are based on the types of maintenance activities that may be required to operate an offshore wind farm. For this study it was assumed that the limit applies for the duration of any maintenance activity. The procedure for this work is outlined in Figure 2.

The wave data collected were ERA5 reanalysis data, which is produced by the European Centre for Medium Range Weather Forecasts (ECMWF). ERA5 uses historical real world weather data (i.e., satellite and weather buoy data) combined with advanced modelling to generate detailed weather data sets that can be used in climatological studies [26]. It has a spatial resolution of 10 to 30 km and the point closest to the centre of each site was used (Table A1, Appendix A). Data were collected for a single point within each site. The data has an hourly resolution and spans from 1 January 1990 to 31 December 2019. Data were downloaded from the ESOX LAUTEC website and was used as is, without any further processing [27]. As the data is based on historical information the potential for variation in future climatic conditions should be kept in consideration.

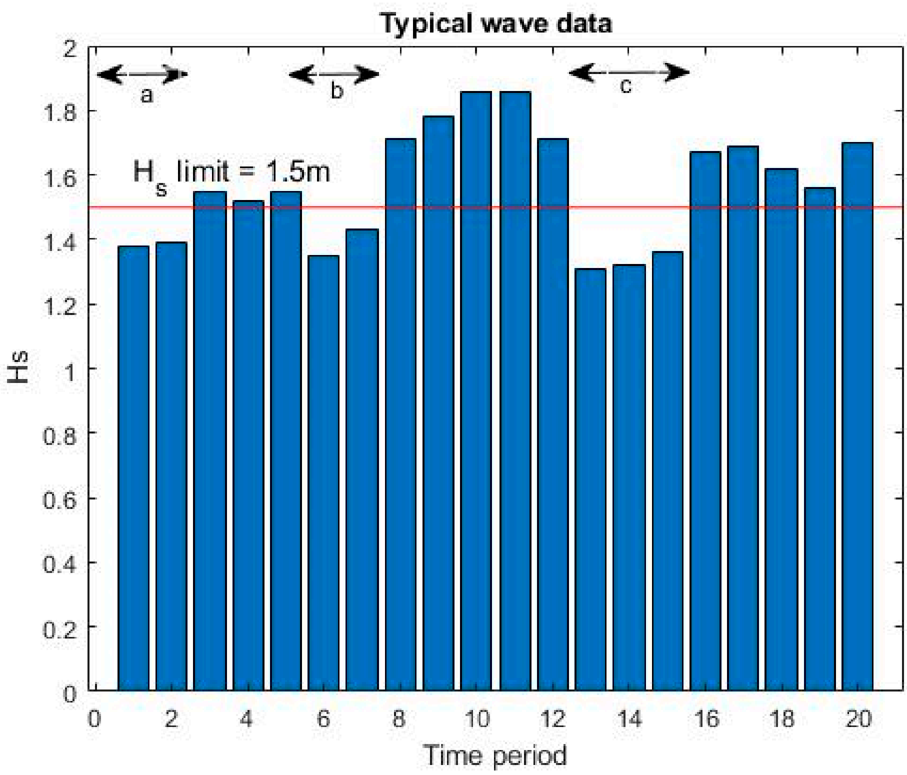


Figure 1. Weather window example.

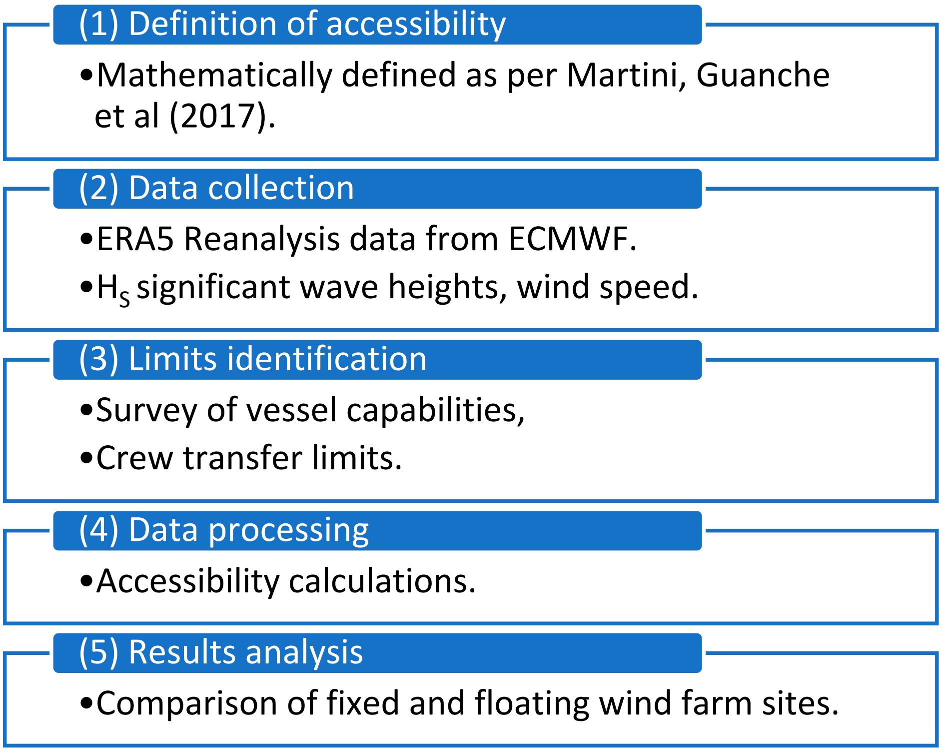


Figure 2. Summary of the research process [11].

Following data collection, the vessel crew transfer limits were identified. Transfer limits are determined by the vessel type and the access system which technicians use to cross from a vessel to a wind turbine. Near-shore wind farms are commonly serviced by medium sized CTVs (Crew Transfer Vessels) [9]. CTVs are typically monohulls or catamarans that can operate in wave heights up to around 1.5 m [9]. The crew transfer process involves the CTV pushing up against a fender to create friction against the turbine structure, allowing technicians to transfer to a ladder.

As wind farms move further offshore larger service operation vessels (SOVs) are used to reduce the travel time and improve the comfort of technicians. SOVs can operate as O&M bases with accommodation for technicians and spare parts stores onboard and are often used for offshore wind farms with travel distances from port greater than 50 km [9]. The SOVs wave height transfer limit will depend on the access system with which the technicians transfer from the vessel to the wind turbine. These include advanced 'Walk to work systems', i.e., Ampelmann which allow for work in larger wave heights. These are motion compensated gangways that can increase the crew transfer limit up to as much as 4.5 m [9]. The Hs limits for vessels used in this study limits are included in Table 2.

Table 2. Vessel wave height limits.

No.	Access System	Max H_S (m)
1	CTV (Catamaran)	1.5
2	SWATH CTV	2
3	SOV with access system	3.5
4	SOV with advanced access system	4.5

In the case of floating wind turbines, the access may be further complicated by the relative motion of the turbine, however, this is beyond the scope of this study.

Once we know the limiting wave heights that allow access, we need to know the time duration that access is needed. The weather window length will be determined by the time needed to complete the maintenance activity. Repair times can be anything from a few hours for minor repairs up to around 12 h or more for major repairs or annual services [28,29]. Typical weather window durations are shown in Table 3.

Table 3. Weather windows required for repairs.

No.	Weather Window (hrs)	Category
1	2 to 6	Minor repair
2	7 to 24	Medium repair
3	24+	Major repair

MATLAB code was developed to complete calculations for accessibility based on the significant wave height limit and the required weather window and the mathematical definitions defined earlier [11].

The MATLAB code takes as an input the wave height time series data in an excel sheet format for each of the sites where calculations were completed. On running the code the user then is requested to input the desired Hs limit for the calculation in metres, the weather window limit in hours and the regions for which calculations are to be completed.

An array is then generated that holds the time series of wave heights for each selected zone for the full 30-year period of data. A logical check is then done on the array to find all time instances where the actual wave height was less than the limit set for the calculation. This returns a logical array containing the full time series which include a 1 to indicate the wave height was less than the set limit at that instance or a 0 to indicate the wave height was greater than the limit. So weather windows will be indicated by groups of 1s in the time series.

The code then runs a loop over the array to find the start and end points of all-weather windows. The code can then calculate the lengths of all the weather windows over the entire time period. An array is generated that records all of the weather windows by their length in hours.

For the accessibility calculation then all weather windows of the required length or longer are summed and incorporated into the accessibility calculation. So if the window length was set as 12 h. It will sum the time included in all weather windows that were 12 h or longer. This sum divided by the total time will return the percentage accessibility.

Where:

$$Accessibility = \frac{\Sigma\, time\ in\ weather\ windows\ of\ sufficient\ length}{total\ time}$$

The case study was then run using data for the proposed Scotwind sites. Figure 3 shows a map of the sites. There are 15 locations situated across 4 regions, North, Northeast, West and East. There are already significant offshore developments in the Northeast and East regions, including two floating windfarms (Hywind & Kincardine). There are no offshore windfarms yet developed in the West or North regions. Moray East was selected as a comparison fixed bottom site. Moray East is a 950 MW windfarm located 22 km from shore in water depths of up to 54 m, it is located adjacent to the NE4 Scotwind site [30].

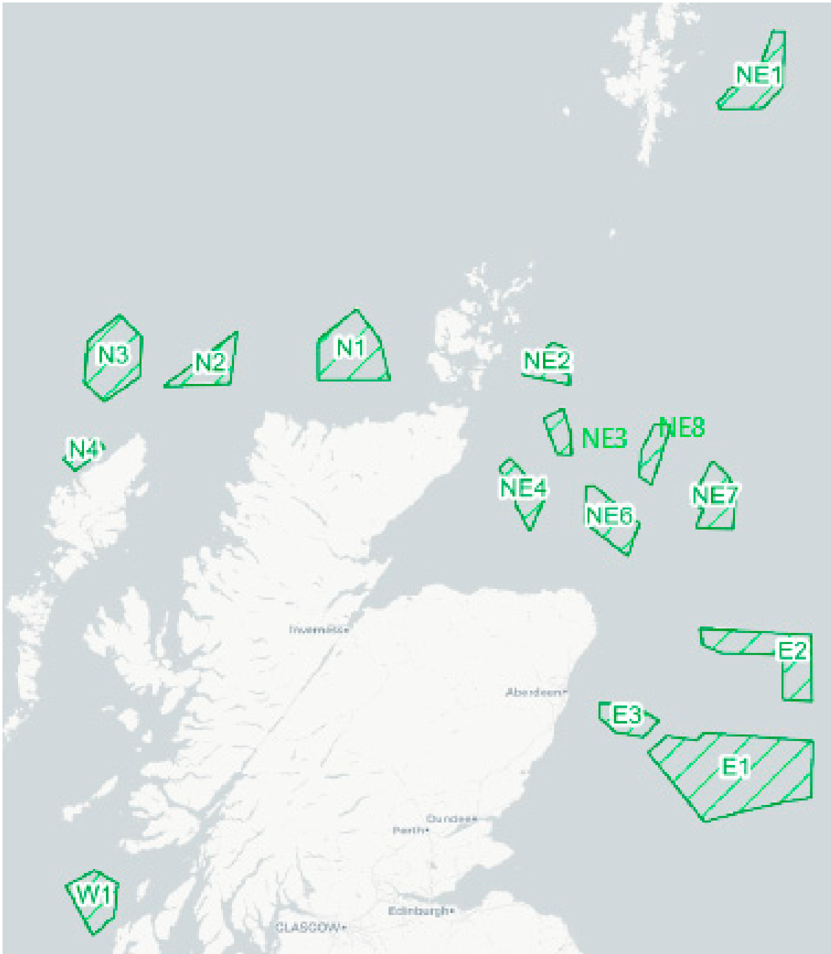


Figure 3. Map of proposed Scotwind sites [31].

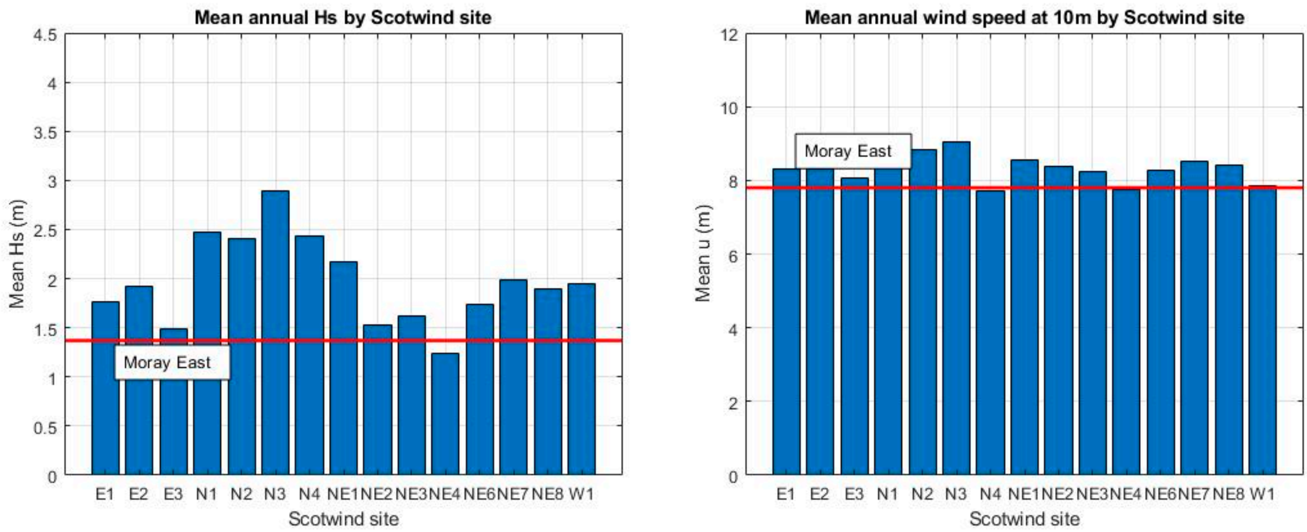
The majority of the Scotwind sites are in deep-water. Only the N4 site (62%) and W1 site (73%) have significant areas less than 50 m in depth. The remaining sites are almost all over 50 m depth, with much of the North and Northeast region over 70 m in depth [22].

Calculations were run for a full range of wave height limits and weather windows across all sites and the benchmark site at Moray East. To check the results, some dummy data that would give an expected output was run and showed the expected results. The results were also in line with other accessibility values available in the literature [8].

3. Results

Figure 4a,b show the variation in H_S and wind speed throughout the case study sites, the Moray East benchmark is indicated by a red line. The case study sites (excluding NE4) all have larger wave heights than Moray East. Figure 4a shows that N1 to N4 sites experiences significantly higher wave heights than other sites, however Figure 4b shows that the mean wind speeds are similar across all the sites.

Figure 5a shows H_S for the winter months (December to February). The wave heights are up to 25% higher in the winter months compared to the annual average.



(**a**) (**b**)

Figure 4. (**a**) Mean annual Hs across Scotwind sites (**b**) Mean annual wind speeds across Scotwind sites.

Figure 5b,c show the annual accessibility and winter accessibility for a minor repair using a CTV. All Scotwind sites (except NE4) have a mean annual accessibility below 0.6, dropping to less than 0.35 in the winter.

Figure 5d–f show the annual, winter and summer accessibility when the required weather window is increased to 24 h, i.e., a major repair. There is a large drop in accessibility in the winter when a longer weather window is required. The North region is almost entirely inaccessible under these conditions.

The grouped bar plots in Figure 6a,b show the variation of accessibility with H_S limit. Significant improvements in accessibility are seen once the H_S limit is increased to 3 m. Note that these results are the annual average, so winter will have lower accessibility and summer higher, given the same H_S limit.

Figure 6c shows the sensitivity of average annual accessibility to H_S for sites in each Scotwind region for a 6 h weather window. An Hs limit of at least 4 m is needed for all sites to achieve an accessibility of 0.8. However, at the Moray East site a limit of approximately 2 m will achieve the same target.

Figure 6d,e show the sensitivity of accessibility to H_s limit for the summer and winter seasons only. In the winter months, even with an H_S limit of 4.5 m the N1 site does not reach an accessibility of 0.8. For longer weather windows the accessibility will only decrease. In summer only an Hs limit of 2 m is enough to achieve 0.8 accessibility for the N1 site.

Figure 6f shows the sensitivity of accessibility to the weather window for a set H_S limit of 2 m. It shows there is a significant drop off in accessibility as the required weather window increases. In all Scotwind sites the accessibility drops below 0.

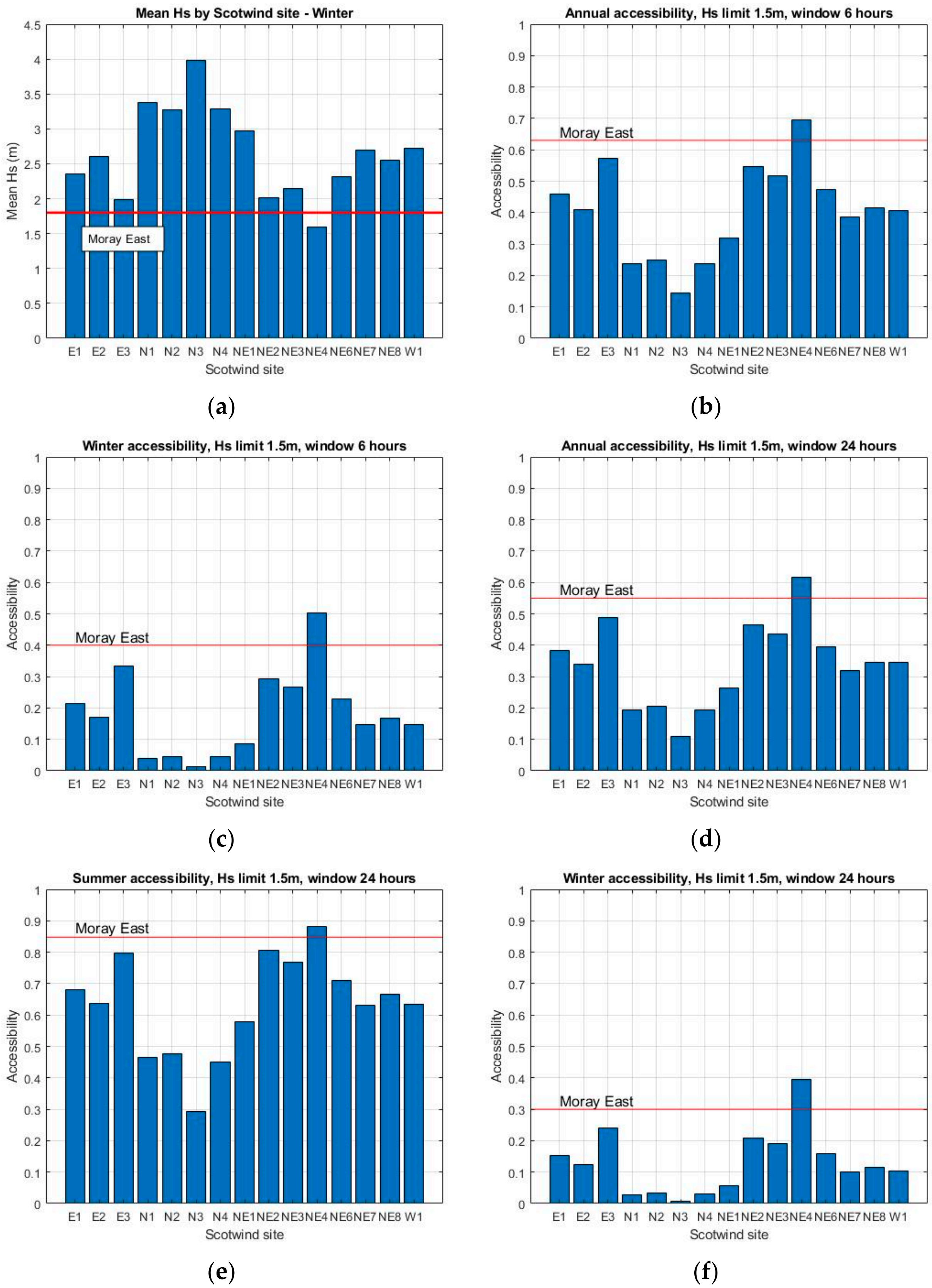
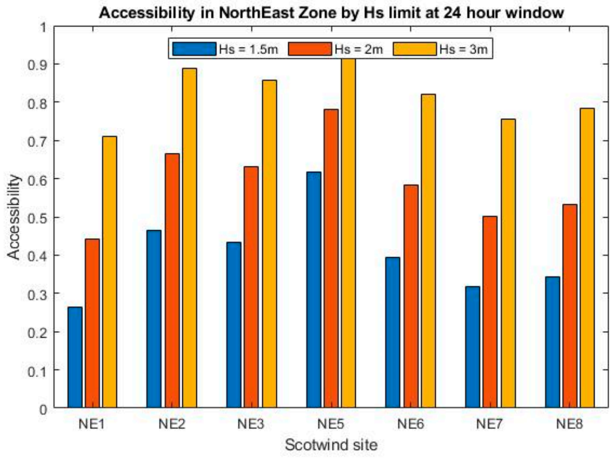
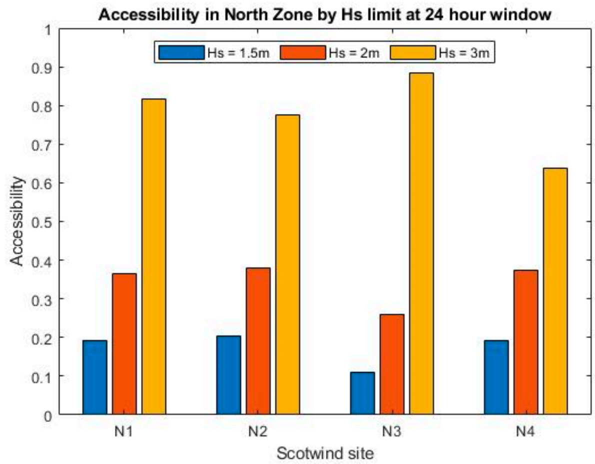


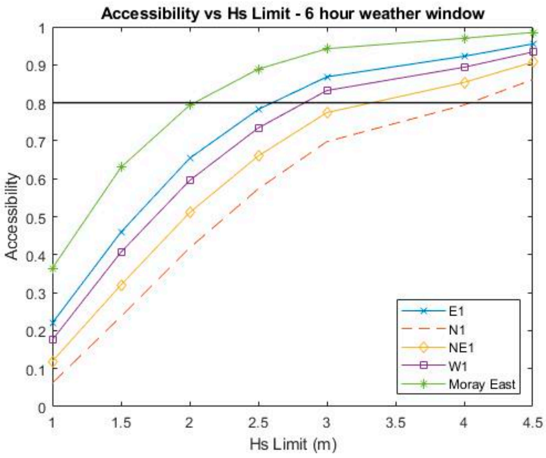
Figure 5. (**a**) mean significant wave heights in winter, (**b**) annual accessibility—H_S limit of 1.5 m and 6 h weather window, (**c**) winter accessibility—H_S limit of 1.5 m and 6 h weather window, (**d**) annual accessibility—H_S limit of 1.5 m and 24 h weather window, (**e**) summer accessibility—H_S limit of 1.5 m and 24 h weather window, (**f**) winter accessibility—H_S limit of 1.5 m and 24 h weather window.



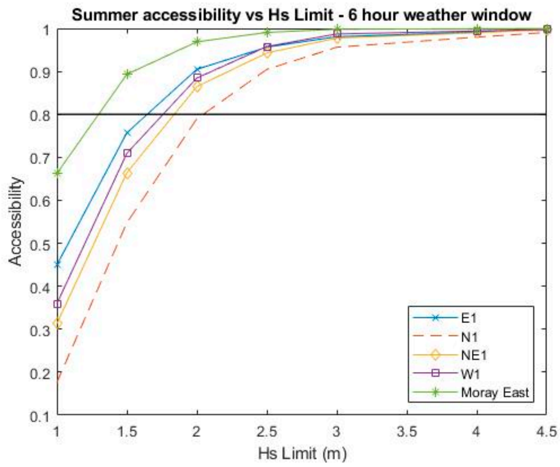
(**a**)



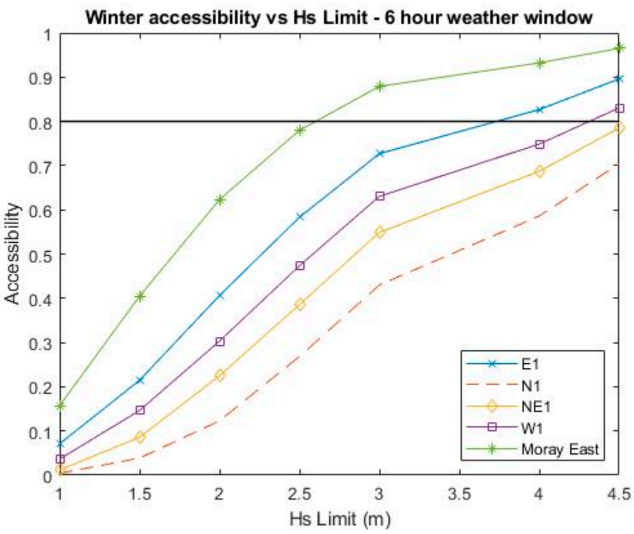
(**b**)



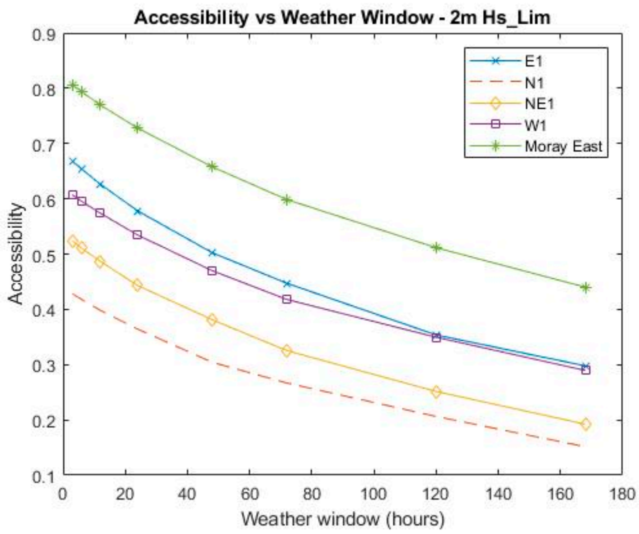
(**c**)



(**d**)



(**e**)



(**f**)

Figure 6. (**a**) accessibility of NE zone sensitivity to H_S limit, (**b**) accessibility of North zone sensitivity to H_S limit, (**c**) sensitivity of accessibility to Hs limit, (**d**) sensitivity of accessibility to Hs limit in summer, (**e**) sensitivity of accessibility to Hs limit in winter, (**f**) sensitivity of accessibility to weather window.

6 once the required weather window is greater than 24 h, whereas in Moray East it remains above 0.7

4. Discussion

This study has applied a methodology to calculate accessibility of wind farm sites using hindcast data and completed a case study to compare the accessibility of potential floating wind farm sites with existing fixed bottom wind farm sites.

The results indicate that many of the Scotwind floating wind farm sites will have much lower accessibility than existing fixed bottom sites. This is driven by the larger wave heights at the floating sites. Of the 15 floating wind sites potentially to be developed as part of Scotwind, only one (NE4) had higher accessibility than the reference fixed bottom wind site. The most exposed sites N1 to N4, had annual accessibilities of less than 0.25 when using a traditional CTV. In winter accessibility drops further, with values below 0.1 for some sites. This indicates that O&M at floating wind sites is potentially going to be extremely challenging, and there will be almost no access during winter months.

It is likely that vessels with larger wave height limits will be required to operate and maintain floating wind sites. Where H_S limits can be increased, we can see very large jumps in accessibility. For example, in the N3 region an increase of H_S from 1.5 m to 3 m saw accessibility increase from around 10% to 90%. The increase in accessibility with H_S is not a linear relationship and a relatively small increase in transfer limit can see a large increase in accessibility. The sensitivity analysis demonstrates that for medium repairs, requiring a six-hour window, an H_S limit of around 2 m will achieve 80% accessibility even in the North region during the summer, whereas in the winter even an H_S limit of 4 m is not enough to achieve 80%.

There is a large amount of regional variation in the results, highlighting that some floating sites will be easier to operate than others. The case study showed that the North-eastern and Eastern sites have higher accessibility levels than the Northern sites and are not much lower than the benchmark site. This is due to the more sheltered wave conditions experienced on the East coast compared to the Northern sites which are subjected to a large Atlantic fetch.

5. Conclusions

This study highlights that accessibility will be a challenging factor in the operation and maintenance of floating wind farm sites. The Scotwind case study indicates that many of the floating wind sites that will be developed in the future will have very low accessibility conditions if traditional CTVs are used.

O&M access strategies will need to develop on from what may have been effective for fixed bottom sites. The fleet of O&M and installation support vessels will also need to continue to develop, with a requirement for vessels with operating limits of 3 m and over becoming much more common.

However, the study also shows that some floating wind sites in more sheltered waters will be only slightly less accessible than comparable fixed bottom sites. This might indicate that the first sites that should be developed for floating wind should be those with higher accessibility such as NE4, E3 and others in the Northeast region. The North region should perhaps be given a longer timescale for development so that as the industry matures, and more advanced vessels become available then development in those areas can begin.

Further work in this area would be valuable in assisting developers in planning the development of the floating wind farm sites. It would be of value to increase the accuracy of the study by introducing additional constraints such as limits on wind speeds, wave period, floating turbine motion, daylight hours, and travel time.

Author Contributions: Conceptualization, B.J., J.C. and D.R.; methodology, D.R.; formal analysis, D.R.; writing—original draft preparation, D.R.; writing—review and editing, B.J. and J.C.; supervision, B.J., J.C. and D.M. All authors have read and agreed to the published version of the manuscript.

Funding: The authors would like to acknowledge EPSRC for funding this work through the Wind and Marine Energy Systems Centre for Doctoral Training under the grant number EP/S023801/1. For the purpose of open access, the author(s) has applied a Creative Commons Attribution (CC BY) licence to any Author Accepted Manuscript (AAM) version arising from this submission.

Data Availability Statement: Data used for this study are available at https://esox.lautec.com/map/ (accessed on 2 July 2021).

Acknowledgments: The project was also made possible by EPSRC funding to the Wind and Marine Energy CDT at the University of Strathclyde.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Reference site coordinates.

Region	Latitude	Longitude
E1	56.75	−0.5
E2	57.25	0.25
E3	57	−1.5
N1	59	−4.25
N2	58.75	−5.5
N3	59	−6.5
N4	58.5	−6.75
NE1	60.25	−0.25
NE2	58.75	2.25
NE3	58.5	−2.25
NE5	58	−2.75
NE6	58	−1.5
NE7	58.25	−0.5
NE8	58.5	−1.25
W1	56	−6.5
Moray East	58.25	−2.75

References

1. Global Wind Energy Coucil. *Global Wind Report 2021*; Global Wind Energy Coucil: Brussels, Belgium, 2021.
2. HM Government. *The Ten Point Plan for a Green Industrial Revolution*; HM Government: London, UK, 2020.
3. The Carbon Trust. *Floating WInd Joint Industry Project—Phase III Summary Report*; The Carbon Trust: London, UK, 2021.
4. Crown Estate Scotland. ScotWind Offshore Wind Leasing Delivers Major Boost to Scotland's Net Zero Aspirations. Available online: https://www.crownestatescotland.com/news/scotwind-offshore-wind-leasing-delivers-major-boost-to-scotlands-net-zero-aspirations (accessed on 20 January 2022).
5. RenewableUK. RenewableUK Wind Energy Projects. Available online: https://www.renewableuk.com/page/UKWEDSearch (accessed on 9 May 2022).
6. Scottish Government. *Sectoral Marine Plan for Offshore Wind Energy*; Scottish Government: Edinburgh, UK, 2018.
7. Hannon, M.; Topham, E.; Dixon, J.; McMillan, D.; Collu, M. *Offshore Wind, Ready to Float? Global and UK Trends in the Floating Offshore Wind Market*; University of Strathclyde: Glasgow, UK, 2019.
8. van Bussel, G.J.W.; Bierbooms, W.A.A.M. The DOWEC Offshore Reference Windfarm: Analysis of Transportation for Operation and Maintenance. *Wind. Eng.* **2003**, *27*, 381–391. [CrossRef]
9. Hu, B.; Yung, C. *Offshore Access Report*; TNO: Petten, The Netherlands, 2020.
10. Stallard, T.; Dhedin, J.-F.; Saviot, S.; Noguera, C. Procedures for Estimating Site Accessibility and Appraisal of Implications of Site Accessibility. EQUIMAR. 2010. Available online: https://www.wiki.ed.ac.uk/download/attachments/9142387/EquiMar-Del7-4-1+-+Del7-4-2.pdf?version=1 (accessed on 20 January 2022).
11. Martini, M.; Guanche, R.; Losada, I.J.; Vidal, C. Accessibility assessment for operation and maintenance of offshore wind farms in the North Sea: Accessibility offshore North Sea. *Wind Energy* **2017**, *20*, 637–656. [CrossRef]
12. Silva, N.; Estanqueiro, A. Impact of Weather Conditions on the Windows of Opportunity for Operation of Offshore Wind Farms in Portugal. *Wind. Eng.* **2013**, *37*, 257–268. [CrossRef]

13. O'Connor, M.; Lewis, T.; Dalton, G. Weather window analysis of Irish west coast wave data with relevance to operations & maintenance of marine renewables. *Renew. Energy* **2013**, *52*, 57–66. [CrossRef]
14. Browell, J.; Zitrou, A.; Walls, L.; Bedford, T.; Infield, D. Analysis of wind and wave data to assess maintenance access to offshore wind farms. In Proceedings of the European Safety and Reliability Association Conference, Amsterdam, The Netherlands, 29 September–2 October 2013; pp. 743–750.
15. Feuchtwang, J.; Infield, D. Offshore wind turbine maintenance access: A closed-form probabilistic method for calculating delays caused by sea-state. *Wind Energy* **2013**, *16*, 1049–1066. [CrossRef]
16. Walker, R.T.; van Nieuwkoop-McCall, J.; Johanning, L.; Parkinson, R.J. Calculating weather windows: Application to transit, installation and the implications on deployment success. *Ocean. Eng.* **2013**, *68*, 88–101. [CrossRef]
17. Scheu, M.N.; Matha, D.; Muskulus, M. Validation of a markov-based weather model for simulation of O&M for offshore wind farms. In Proceedings of the 22nd International Offshore and Polar Engineering Conference, ISOPE-2012, Rhodes, Greece, 17–22 June 2012; pp. 463–468.
18. Paterson, J.; Thies, P.R.; Sueur, R.; Lonchampt, J.; D'Amico, F. Assessing marine operations with a Markov-switching autoregressive metocean model. *Proc. Inst. Mech. Eng. Part M J. Eng. Marit. Environ.* **2020**, *234*, 785–802. [CrossRef]
19. Seyr, H.; Muskulus, M. Using a Langevin model for the simulation of environmental conditions in an offshore wind farm. *J. Phys. Conf. Ser.* **2018**, *1104*, 012023. [CrossRef]
20. Rinaldi, G.; Thies, P.; Johanning, L. Improvements in the O&M modelling of floating offshore wind farms. In Proceedings of the 4th International Conference on Renewable Energies Offshore (RENEW 2020), Lisbon, Portugal, 12–15 October 2020.
21. Crown Estate Scotland. *ScotWind Leasing: Seabed Leasing for New Offshore Wind Farms*; Crown Estate Scotland: Edinburgh, UK, 2020.
22. Gray, A. *Initial Predictions for Offshore Wind Farms in the ScotWind Leasing Round*; Catapult ORE: Glasgow, UK, 2021.
23. Wu, M. Numerical analysis of docking operation between service vessels and offshore wind turbines. *Ocean. Eng.* **2014**, *91*, 379–388. [CrossRef]
24. González, D.F.; Lemmerhirt, M.; Abdel-Maksoud, M.; König, M.; Düster, A. Numerical and Experimental Investigation Regarding the Landing Manoeuvre of a Catamaran Vessel at an Offshore Wind Turbine in Waves. In Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, St. John's, NL, Canada, 31 May–5 June 2015; Volume 7. Ocean Engineering, V007T06A045. [CrossRef]
25. Konig, M.; Gonzalez, D.F.; Abdel-Maksoud, M.; Duster, A. Numerical investigation of the landing manoeuvre of a crew transfer vessel to an offshore wind turbine. *Ships Offshore Struct.* **2017**, *12*, S115–S133. [CrossRef]
26. Hersbach, H.; Bell, B.; Berrisford, P.; Hirahara, S.; Horányi, A.; Muñoz-Sabater, J.; Nicolas, J.; Peubey, C.; Radu, R.; Schepers, D.; et al. The ERA5 global reanalysis. *Q. J. R. Meteorol. Soc.* **2020**, *146*, 1999–2049. [CrossRef]
27. Lautec Esox. Available online: https://esox.lautec.com/map/ (accessed on 2 July 2021).
28. Dinwoodie, I.; Endrerud, O.-E.V.; Hofmann, M.; Martin, R.; Sperstad, I.B. Reference Cases for Verification of Operation and Maintenance Simulation Models for Offshore Wind Farms. *Wind. Eng.* **2015**, *39*, 1–14. [CrossRef]
29. Carroll, J.; McDonald, A.S.; McMillan, D. Failure rate, repair time and unscheduled O&M cost analysis of offshore wind turbines. *Wind Energy* **2016**, *19*, 1107–1119.
30. Moray East Offshore Windfarm. Available online: https://www.morayeast.com/project (accessed on 17 July 2021).
31. Marine Scotland Maps NPI. Available online: https://marinescotland.atkinsgeospatial.com/NMPI/Default.aspx (accessed on 20 July 2021).