Impact of weather conditions on the windows of opportunity for operation of offshore wind farms in Portugal

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Abstract – The deployment of offshore wind parks face several challenges. Among them are the difficulties introduced by the atmospheric and sea conditions in accessing those wind parks. A *window of opportunity* is a timeframe when weather and sea conditions are acceptable and enable to perform specific tasks in the installation and operation/maintenance of the offshore wind park. This study identifies typical time periods of windows of opportunity to access three offshore Portuguese maritime regions. The accessibility conditions also take into account the system type transportation method for local access, namely, rubber boat, boat with OAS or helicopter.

1. Introduction

In recent years there has been a growing awareness and environmental education in society. In fact, the concerns regarding the environment, particularly climate change have been very present in people lives. The most relevant evidence was the Kyoto Protocol (1997) or more recently the Copenhagen Summit (2009) on which were appointed and settled political/economical issues for the environmental benefit of the European Union. The evidence that endogenous production of energy (renewable) reduces the external dependence of imported fuels has significantly grown in society, particularly during the most recent years when the wind energy production has featured an expressive increase [1].

Currently, one of the most promising wind development areas in Portugal are the offshore wind parks [2]. However, there are several obstacles and challenges for the deployment of these wind farms. The “expertise” transition from land to the marine environment will need to deal with a harsher environment for operations, higher costs and also with the accessing impact for visiting the wind farm according to the weather and oceanic patterns.

The construction and maintenance operations should only be conducted in safe weather conditions: dependent on the wind speed, sea swell and visibility [3]. This dependence should not be neglected since a low profitability of the wind farm can occur when the strategy to manage the wind farm for repairing or installing materials is not appropriate.

The availability of a wind farm, defined as the percentage of time when there are technical conditions for the production of electricity, is a function of the accessibility to the wind park [4]. Figure 1 shows the relation between the availability of the wind park and its accessibility conditions. An increase of the distance to shore implies a decrease of the availability due to lower accessibility conditions to the wind farm [5].

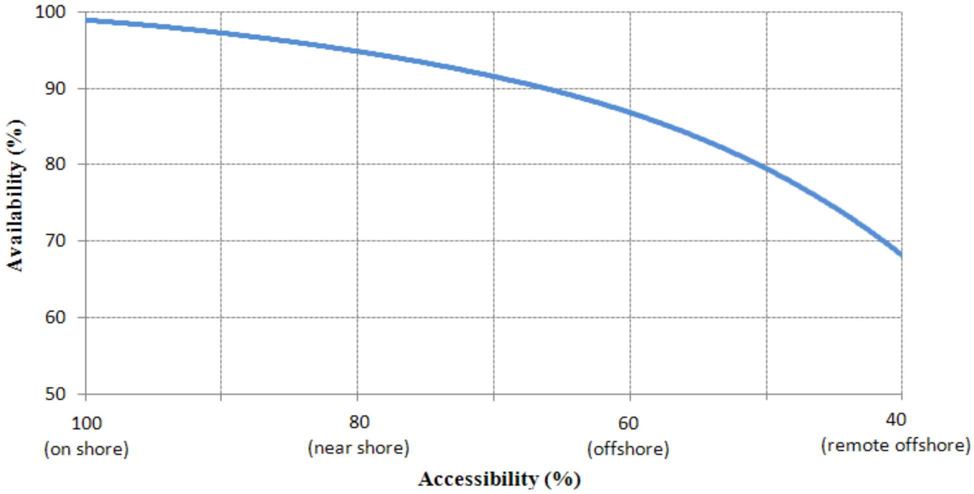


Fig. 1. - Graphical representation of the availability of a wind farm as a function of the accessibility by boat (adapted from [5]).

2. Methodology

2.1. Data

Three cases studies for Continental Portugal were chosen to illustrate the developed methodology. Figure 2 depicts each of the three sites and Table 1 their respective coordinates.

Fig. 2. - Graphical representation of the three case studies around the western coastal regions of Continental Portugal.

Table 1: Site locations for the cases studies.

Site	Distance to the coast (Km)	Depth (m)	Polar Coordinates	
			Longitude	Latitude
1	2	30	-8.9º	41.8º
2	9	38	-8.8º	41.2º
3	5	38	-9.4º	39.2º

The sea and atmospheric data used in this study was generated and supplied by the Danish company ConWx ApS. This company is dedicated to the prediction of weather and sea conditions using numerical models (IRIE and WaveWatch III v.3.14) [6]. Simulated hourly data was provided for the three sites (table 1), covering an almost uninterruptable period of 10 years, ranging from 03 January 2000 to 31 December 2009. The wave data covers the period between 03 January 2000 and 03 January 2009. The simulated parameters available were:

- Significant wave height
- Waves period
- Waves direction
- Wind speed at 10 meters
- Wind speed at 100 meters
- Wind direction

The simulated wind data was compared with the Offshore Wind Atlas developed by LNEG [7] while the wave data was compared with the Portuguese Wave Atlas– *ONDATLAS* [8]. On both cases there's an underestimation of the data provided by the ConWx ApS company. Table II and III show the correction factors used on both cases.

Table 2: Average wind speeds obtained with both models and the correction factor.

Site	Wind speed at 100 meters (m/s)		
	IRIE Model	Offshore Wind Atlas	Correction Factor
1	5.73	7.68	1.34
2	6.43	7.39	1.15
3	6.51	7.53	1.16

Table 3: Significant wave height obtained with both models and the correction factor.

Site	Significant wave height (m)		
	WaveWatch III	ONDATLAS	Correction Factors
1	1.16	2.01	1.73
2	1.24	2.00	1.61
3	1.35	2.13	1.58

Statistical methods are commonly presented in literature as the best tools for analyzing the behavior of wind and waves via their probabilistic behavior, using a probability distribution function. The most suitable distribution function to describe both wind speed [9] and significant wave height [10] is the Weibull distribution. The distribution of windows of opportunity can also be represented by a Weibull distribution according to[11]. Equation (1) shows the Weibull distribution function and equation (2) its cumulative form

$$f(x)=\begin{cases}\frac{k}{A}\left(\frac{x}{A}\right)^{k-1}\cdot\exp\left[-\left(\frac{x}{A}\right)^{k}\right], x\geq 0\\ 0, x<0\end{cases} \quad (1)$$

$$F(x)=1-\exp\left[\left(-\frac{x}{A}\right)^{k}\right] \quad (2)$$

The parameters *A* and *k* on both equations (1) and (2) represent, respectively, the scale factor (same unit than variable x) and the shape factor (non-dimensionless).

An exceedance probability *P*(*x*) can also be obtained for the length of the windows of opportunity by applying the following equation:

$$P(x)=1-F(x) \quad (3)$$

2.2 Windows of opportunity determination

As mentioned above due to adverse weather conditions an offshore wind farm may be inaccessible during a certain period of time or even if the accessibility is guaranteed its length may not allow performing specific tasks. However the accessibility in the wind park does not only depend on the weather and sea conditions, but also on the type of access system. [12].

Typically the access to wind turbines in an offshore wind farm can be accomplished through a simple rubber boat, although the use of a helicopter or boats prepared with offshore access system (OAS) is sometimes necessary. The access system types are also dependent on meteorological and oceanic conditions which are presented in Table IV [13].

Table IV: Limit values for visiting offshore wind farms by access system type.

Access system	Maximum significant wave height (m)	Maximum wind speed (m/s)
Rubber boat	1.5	10.0
Boat with OAS	2.5	12.0
Helicopter	-	20.0

It is important to mention that the main activities concerned with the construction/maintenance/operation of the wind parks have a security criteria based on wind speed. Table V shows the maximum wind speeds allowed for the most frequent work tasks performed in offshore wind farms [11, 14].

Table V. – Limit values for task performance.

Maximum wind speed (m/s)	Task
5.0	Climbing met masts
7.0	Inspection of the tower and blades
12.0	Climbing to the rotor
17.0	Working inside the nacelle

In this work, the assessment of the windows of opportunity starts by defining a maximum wind speed V_{max} and a maximum significant wave height Hs_{max} according to the values presented in tables IV and V. If the wind speed and the significant wave height at a certain time are bellow V_{max} and Hs_{max} then there is a window of opportunity. Otherwise, the weather conditions are adverse, not allowing the access to the offshore area. If the length of the window of opportunity ($T_{window\ of\ opportunity}$) is lower than the time required to perform a task (T_{need}) then the task cannot be performed. In fact, the task shall only be performed when $T_{window\ of\ opportunity}$ is greater or equal than T_{need}. Figure 3 depicts on a diagram the processes related to the determination of an adequate window of opportunity for a specific task (table V).

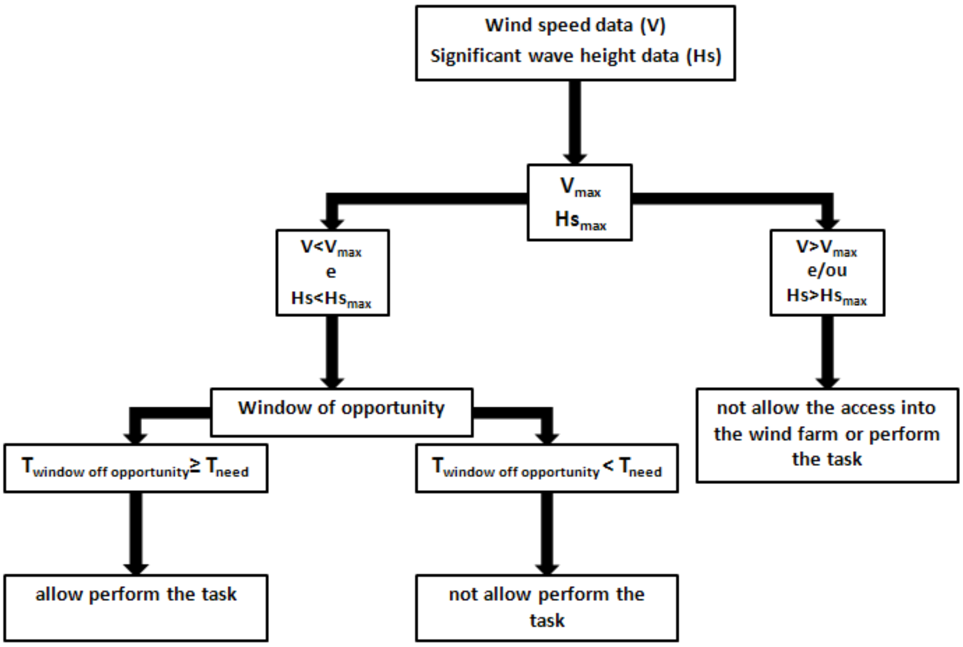


Fig. 3: Flow diagram to inspect a window of opportunity.

For the Portuguese coastal areas, and taking into account the wind and ocean variability in these areas, the maximum values V_{max} and Hs_{max} for each of the three regions under analysis can be taken as V_{max}=12m/s and Hs_{max}=2.5m for any season. A simulation scenario is displayed if Figure 4, considering all July months from the 10 year data period and transportation access by boat with OAS capacity. It shows the climatological wind of opportunity for a summer period where the abscissa represents hours from 00h UTC day 1. The green line corresponds to the typical period of window of opportunity and the red one the waiting time (periods where the weather or sea conditions don't allow the access to the offshore wind farm).

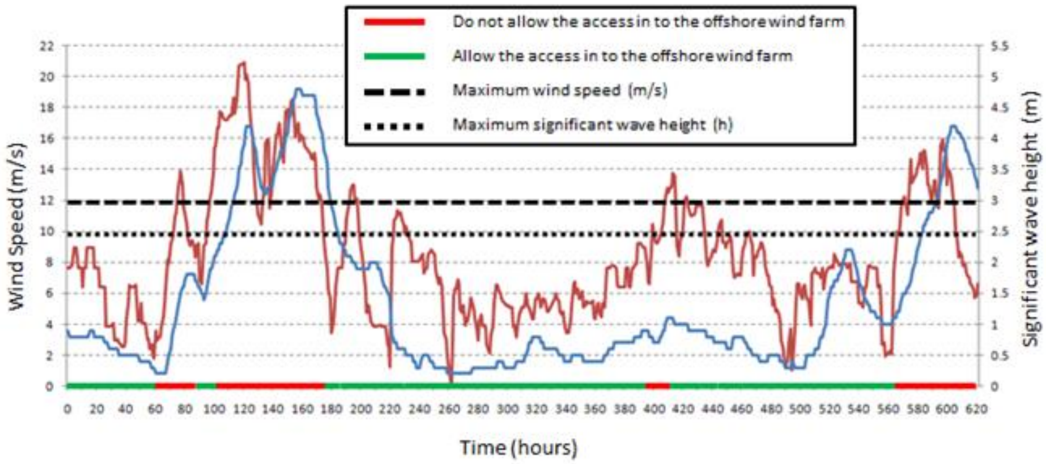


Fig. 4: Mean representation of windows of opportunity for a summer period (10 years of simulated data). The three study areas are considered.

3. Results

For each of the three study sites, a climatological scenario was produced for the average spring, summer, autumn and winter seasons. Since, in Portugal, floating offshore wind turbines are envisaged in the near future and site 2 is a natural candidate for prototype testing due to the existing and grid and mooring infrastructures, the results hereafter will be presented for this site.

The graph depicted in figure 5 shows the accessibility (%) for site 2 throughout the one-year period under analysis by access system type. In table VI the representative statistics are included.

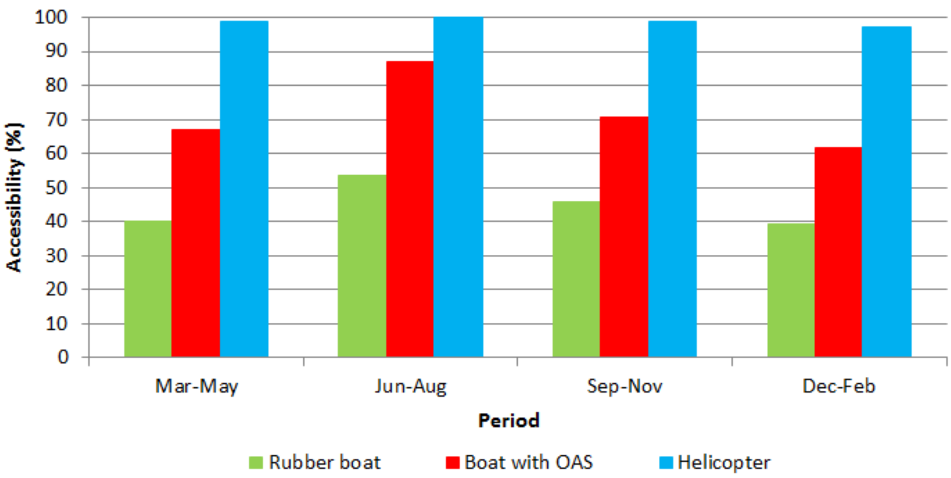
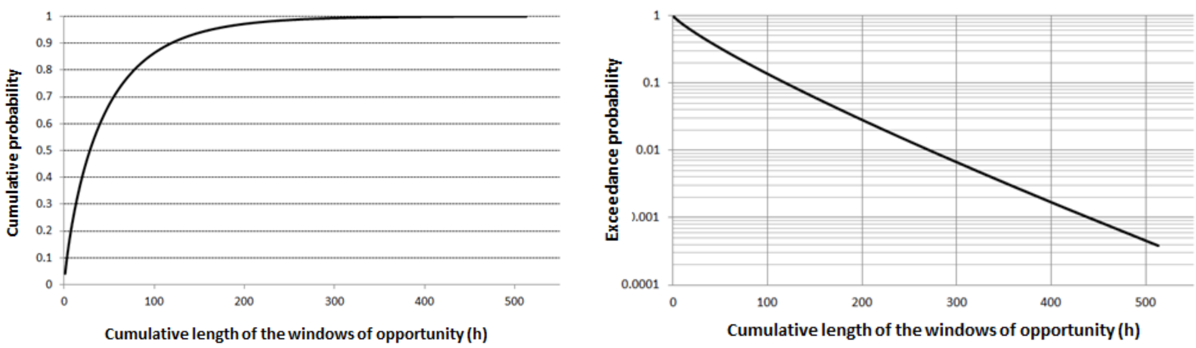


Fig. 5: Accessibility throughout the analyzed period by type of access (Site 2).

Table 6: Statistics of the windows of opportunity (Site 2).

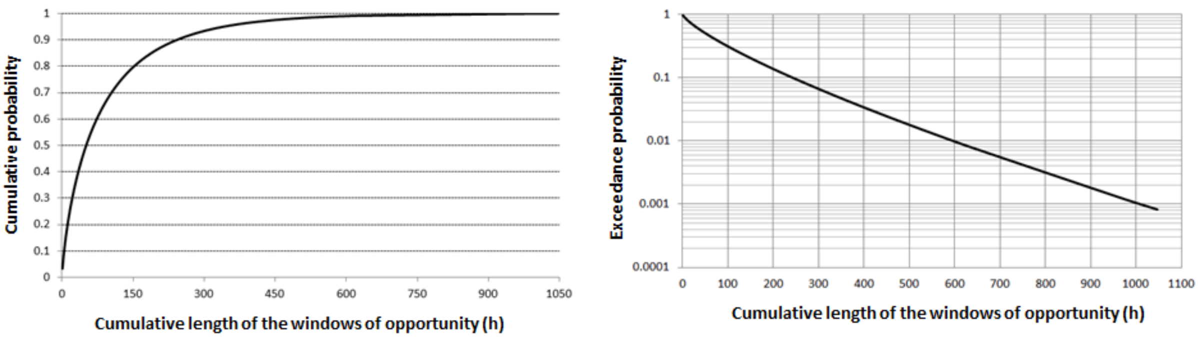
		Length of the windows of opportunity	
Access system		Hours	Days
Rubber boat	Average	49	2
	Maximum	513	21
	Minimum	1	0
Boat with OAS	Average	97	4
	Maximum	1047	44
	Minimum	1	0
Helicopter	Average	467	19
	Maximum	4579	190
	Minimum	1	0

The cumulative probability density function and the probability of exceedance for the length of the windows of opportunity are depicted in figures 6 to 8 according to each access system type.



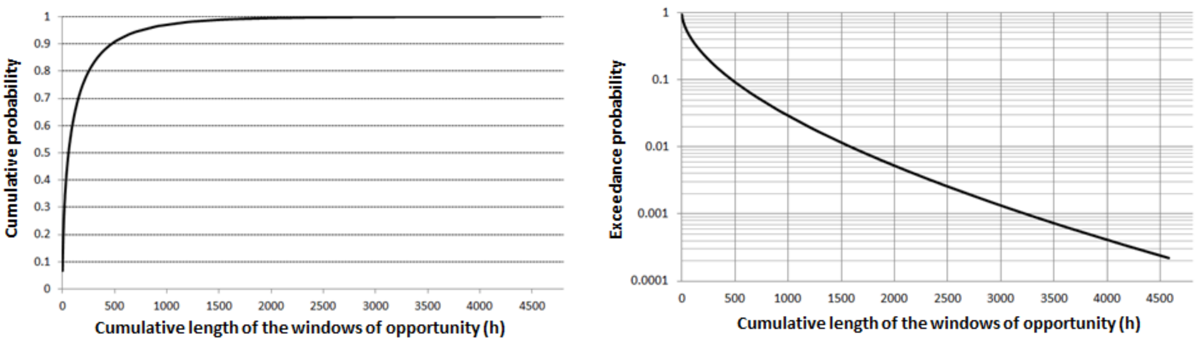
(a) (b)

Fig. 6: Graphs of (a) Cumulative probability and (b) Exceedance probability of the length of the windows of opportunity using a rubber boat as an access system type (Site 2).



(a) (b)

Fig. 7: Graphs of (a) Cumulative probability and (b) Exceedance probability of the length of the windows of opportunity using a boat with OAS as an access system type (Site 2).



(a) (b)

Fig. 8: Graphs of (a) Cumulative probability and (b) Exceedance probability of the length of the windows of opportunity using a helicopter as an access system type (Site 2).

The following tables distinguish the performance probability of the most important the construction and maintenance tasks to perform in offshore wind farms.

Table 7: Probability of accomplishment of offshore wind farms' tasks having a rubber boat as access system (Site 2).

	Condition			
Task	V_{max}	Hs_{max}	Height (m)	Probab. (%)
Climbing met masts	5.0	1.5	10	29.4
			100	22.4
Tower and blade inspection	7.0		10	39.4
			100	33.5
Climbing to the rotor	12.0		10	45.2
			100	44.9
Working inside the nacelle	17.0		10	46.1
			100	45.4

Table 8: Probability of accomplishment of offshore wind farms' tasks having a boat with OAS as access system (Site 2).

	Condition			
Task	V_{max}	Hs_{max}	Height (m)	Probab. (%)
Climbing met masts	5.0	2.5	10	37.3
			100	28.4
Tower and blade inspection	7.0		10	53.2
			100	44.1
Climbing to the rotor	12.0		10	72.1
			100	69.1
Working inside the nacelle	17.0		10	75.6
			100	72.5

Table 9: Probability of accomplishment of offshore wind farms' tasks having a helicopter as access system (Site 2).

	Condition			
Task	V_{max}	Hs_{max}	Height (m)	Probab. (%)
Climbing met masts	5.0	-	10	41.2
			100	31.3
Tower and blade inspection	7.0		10	60.8
			100	49.7
Climbing to the rotor	12.0		10	92.9
			100	84.6
Working inside the nacelle	17.0		10	98.3
			100	99.2

4. Conclusion

In the present study, a methodology to evaluate the length of the windows of opportunity for accessing offshore wind locations in Portugal was characterized. Three sites were studied. In this paper, only the results from site ID 2 were analyzed due to its relevance for testing innovative prototypes. According to the simulated results, it was found that the most favorable periods for accessing the site is the summer period with an availability between 80-90% when using boats with OAS technology, while the lowest accessibility was found for the winter season with an average ~60% availability for the same boat technology.

When a helicopter is used, no seasonal variation was identified and therefore the accessibility is close to 100% throughout the year. The length of the windows of opportunity, when comparing rubber boats with other access system types, increases in about 23 days for boats with OAS and in about 169 days for the helicopter case. As an example, one can consider 100 hours as the necessary length of the opportunity to access the offshore wind park. From Figures 6, 7 and 8 one concludes that the exceedance probability is 16% for a rubber boat, 31% for a boat with OAS and 39% for a helicopter.

The results obtained for site 2 are very promising for accessing an offshore system for maintenance, testing and resistance purposes. For other sites, namely, site ID 1 and site ID 3, the results obtained are very similar to the ones illustrated in this paper. Overall, Portugal appears to have adequate conditions for offshore site maintenance strategies, with acceptable sizes of the windows of opportunity which is an important factor in favor of the offshore wind farm deployment on the western coastal regions.

5. Acknowledgements

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