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

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Motivation

•Offhore wind resource is huge;

•the development of offshore wind projects has grown significantly in recent years;

But…

•There are several obstacles and chalenges for the deployment of offshore wind farms;

- difficult environment for operation and maintenance
- higher costs
- particular wind and sea conditions to access WT

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Objective

Characterize the wind and maritime swell behavior in west coastal regions on Portugal to:

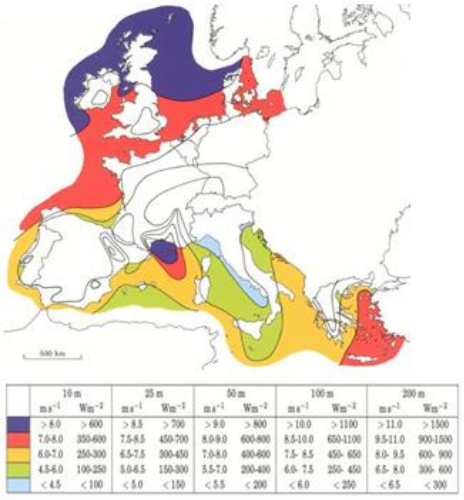
- Identify the extreme values;
- Identify average return period;
- Identify the windows of opportunity;

This leads to the management of installation, operation and maintenance of the offshore wind parks.

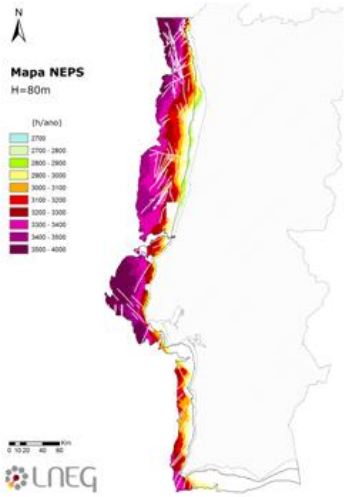
Introduction

Constrains to offshore wind farm developments:

- More difficult/ expensive installation
- Transmissions losses for the coast
- Installation barriers (depth , protected areas,…)
- Local Accessibility:
    - Wind speed
    - Significant wave height
    - Visibility



	10 m		25 m		50 m		100 m		200 m	
	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}
	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300



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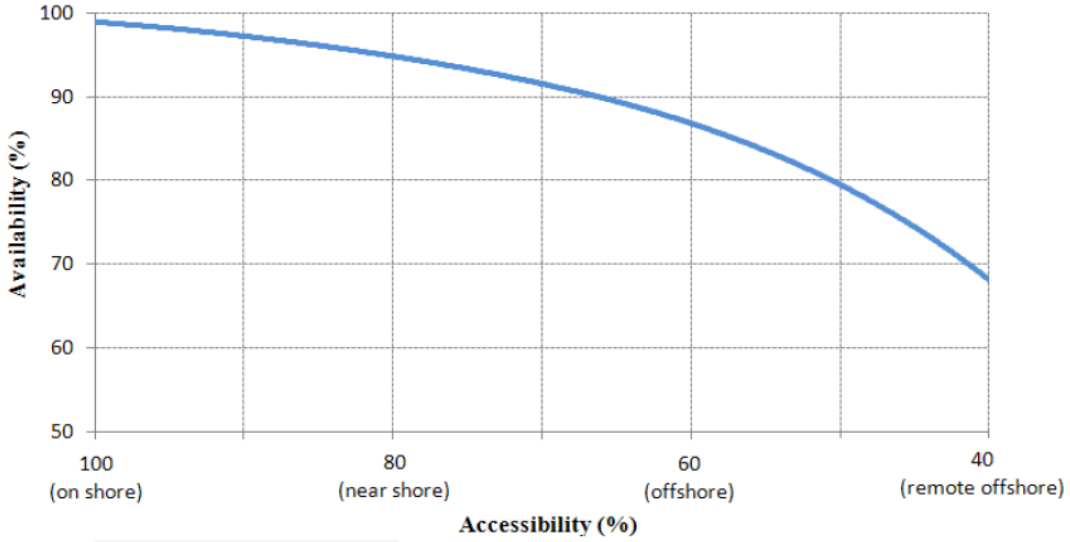
Introduction

Availability: the percentage of time when there are technical conditions for the production of electricity.

Accessibility: the percentage of time that wind farm can be accessed, depending on:

- Weather and sea conditions
- Type of access system



Methodology

Statistical methodologies were used to analyze the behavior of wind and maritime swell.

- Probability Density Function of Weibull Distribution:

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

A = scale parameter
k = shape parameter

- Cumulative Distribution Function of the Weibull Distribution :

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

- Exceedance Probability:

$$P(x) = 1 - F(x)$$

Methodology

Extreme Values and **Return Period** determination:

- Probability Density Function of Gumbel Distribution :

$$f(x) = \exp\left\{-\exp\left(-\frac{(x-\mu)}{\beta}\right)\right\} \cdot \exp\left(\frac{-(x-\mu)}{\beta}\right) \cdot \frac{1}{\beta}$$

μ = location parameter
β = scale parameter

com $\mu > 0$ e $-\infty < \beta < +\infty$.

- Cumulative Distribution Function of the Gumbel Distribution:

$$F(x) = \exp\left\{-\exp\left(-\frac{(x-\mu)}{\beta}\right)\right\}$$

- Return Period:

$$R = \frac{1}{P(x)} = \frac{1}{1-F(x)} \quad \text{or} \quad v = \mu - \beta \cdot \ln\left[-\ln\left(1-\frac{1}{R}\right)\right]$$

R = return period
μ e β Gumbel distribution parameters

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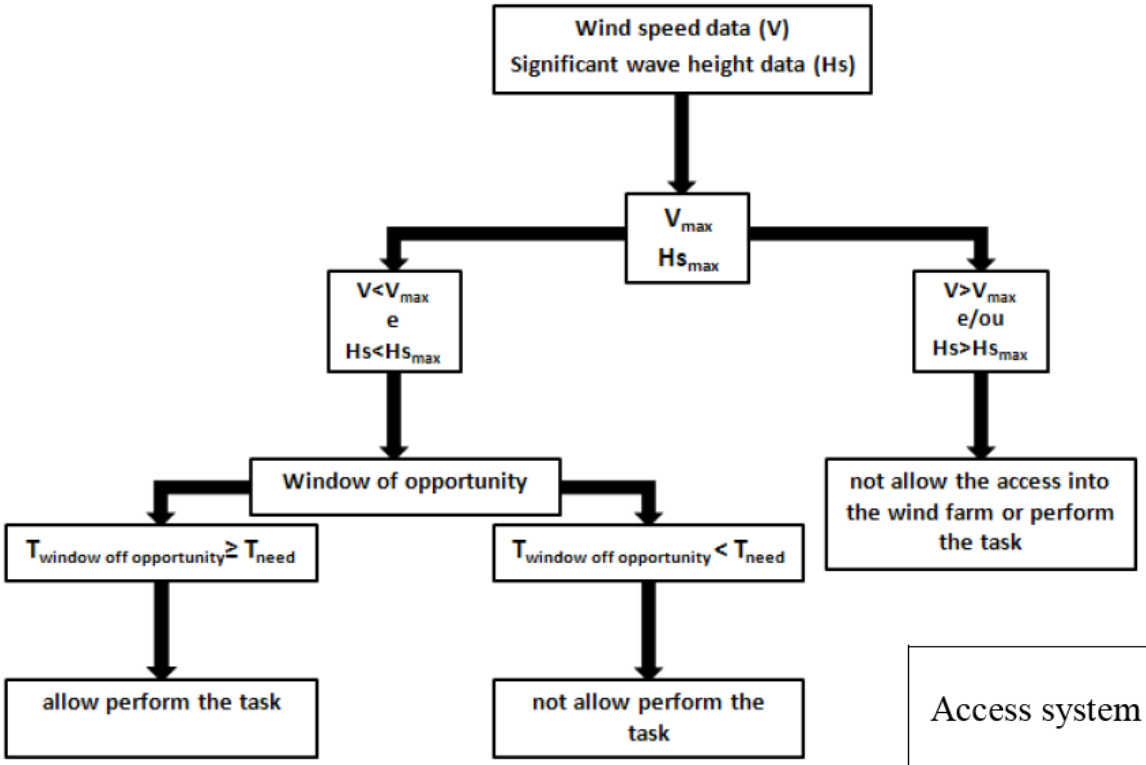
Methodology

Window of Opportunity determination:



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

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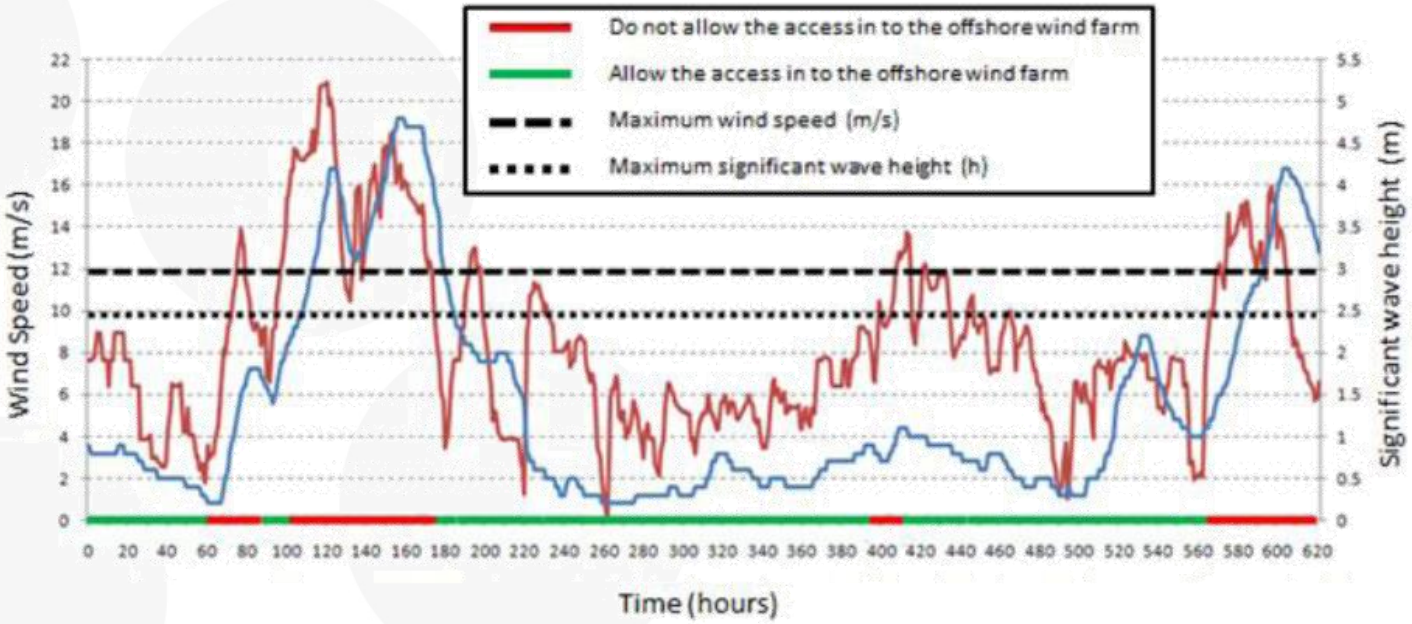
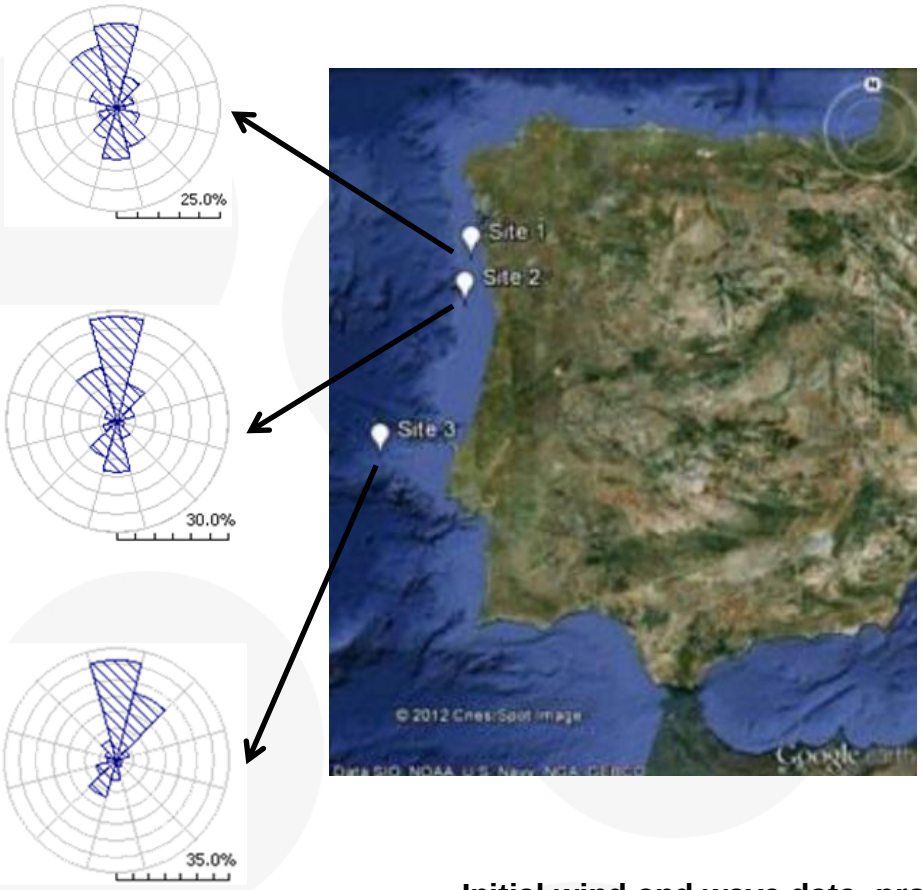
Methodology

Window of Opportunity determination:



Atmospheric flow and sea conditions



Site 1

	Hs (m)	V_{10m} (m/s)	V_{100m} (m/s)
Average	2.01	5.81	7.88
Maximum	12.1	22.5	30.8

Site 2

	Hs (m)	V_{10m} (m/s)	V_{100m} (m/s)
Average	2.00	6.36	7.61
Maximum	11.2	23.2	29.7

Site 3

	Hs (m)	V_{10m} (m/s)	V100m (m/s)
Average	2.14	7.14	7.67
Maximum	11.2	25.1	28.5

Initial wind and wave data: provided by ConWx ApS company

Applied a correction factor on data based on:

Portuguese Offshore Wind Atlas;

Portuguese Wave Atlas (ONDATLAS)

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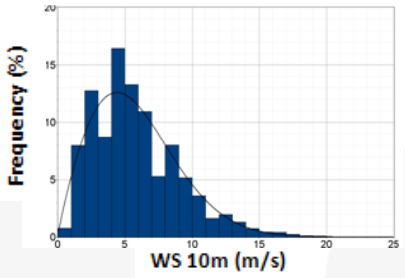
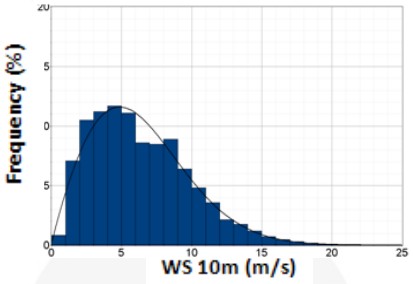
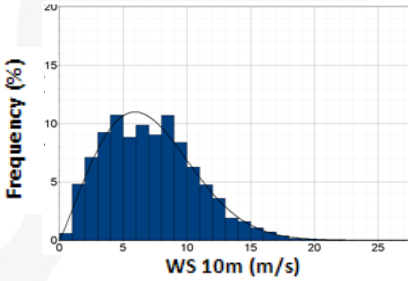
Atmospheric flow and sea conditions

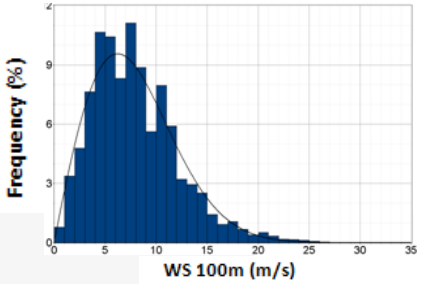
Wind Speed (10 m)

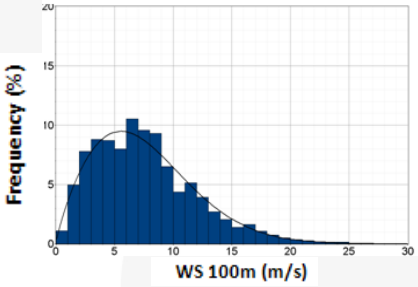


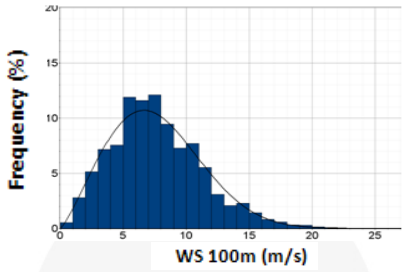




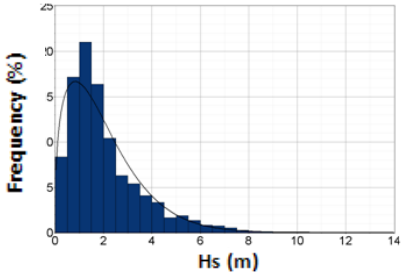
Wind Speed (100 m)

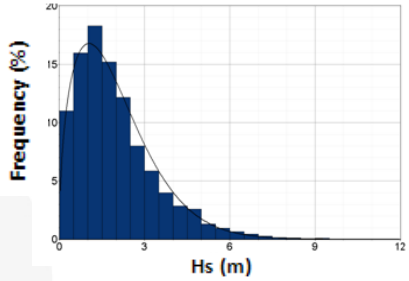


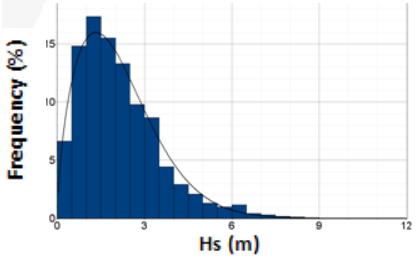




Significant Wave height



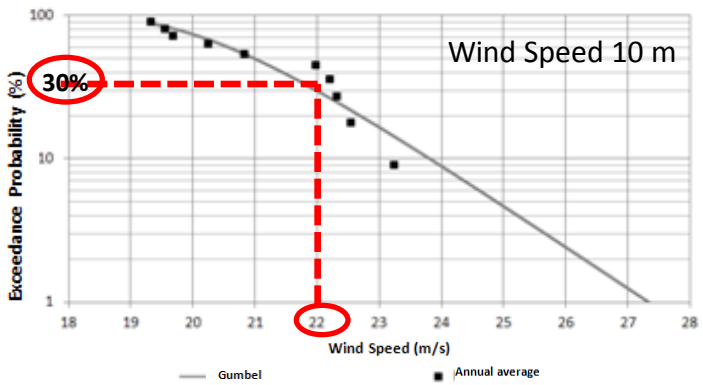




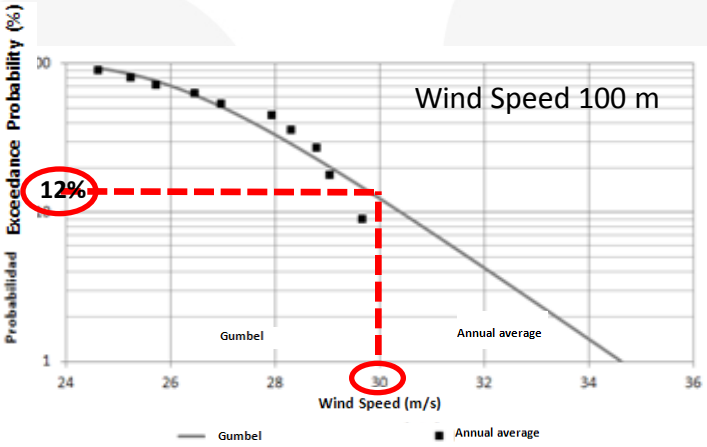
Extreme phenomena

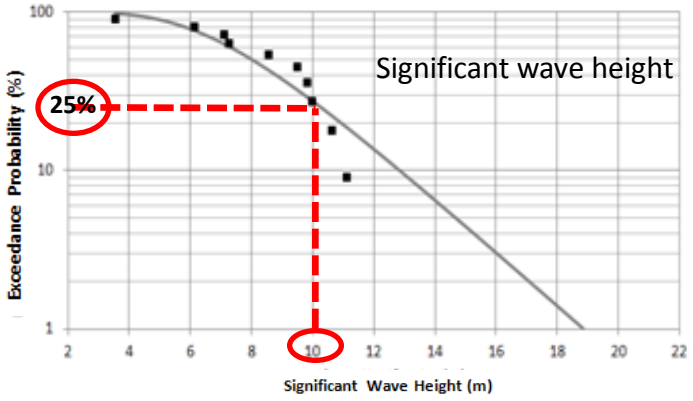
Site 2: (natural candidate for prototype testing of floating WT - existing grid and mooring infrastructures)

Probability of Exceedance



	Gumbel distribution parameters		
	β	μ	r^2
Wind Speed 10 m	1.50 (m/s)	20.4 (m/s)	0.900
Wind Speed 100 m	1.90 (m/s)	26.4 (m/s)	0.936
Significant wave height	2.56 (m)	7.09 (m)	0.846

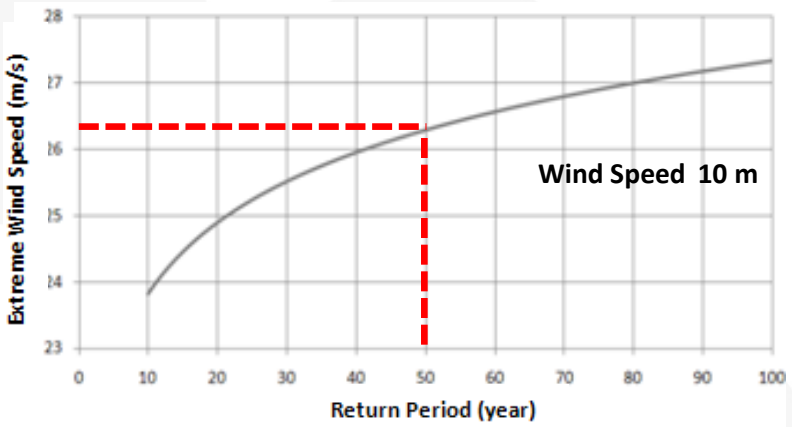


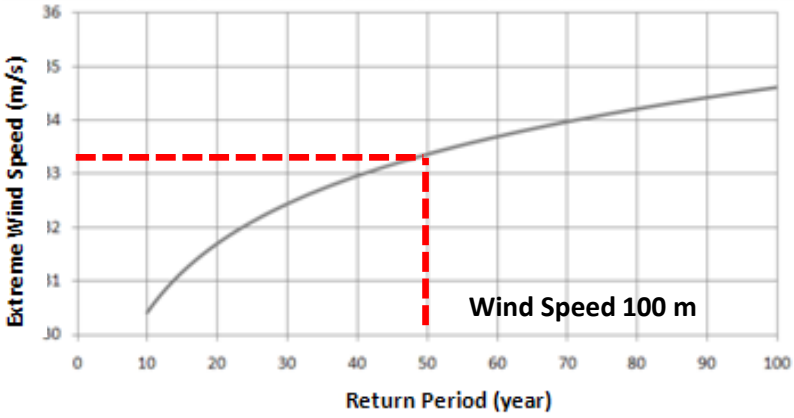


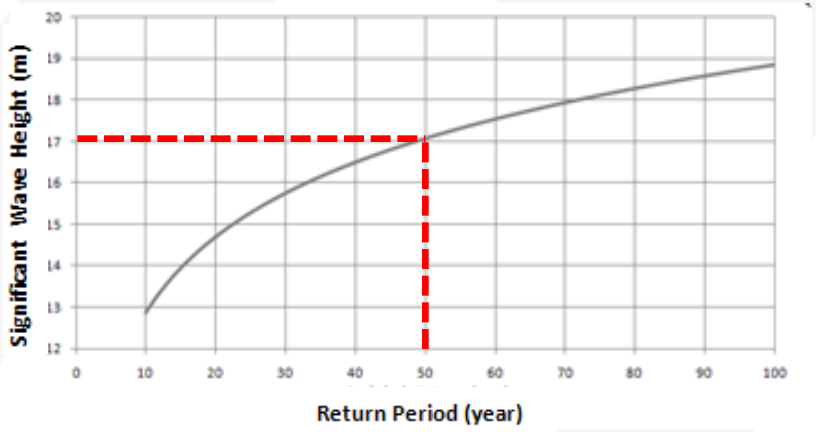
Return Period

Site 2:

The occurrence of extreme wind speed values and the corresponding return period is also important to consider

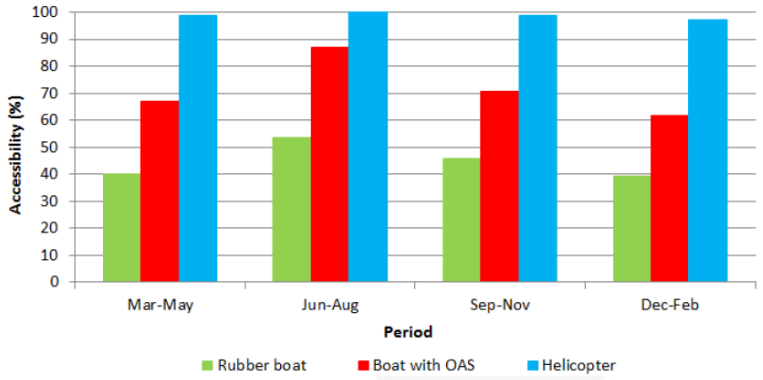






Window of opportunity

Site 2



Access system		Length of the windows of opportunity: Hours	Length of the windows of opportunity: 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

+50%

+80%

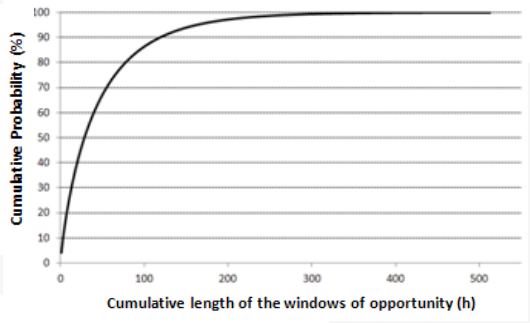
	Condition		Accessibility (%)				
Access System	Hs_{max} (m)	WS_{max} (m/s)	Total	Spring	Summer	Autumn	Winter
Rubber Boat	1.5	10.0	45.1	40.2	53.5	45.9	39.4
Boat with OAS	2.5	12.0	72.1	67.2	86.8	70.5	61.7
Helicopter	-	20.0	98.8	98.6	99.9	98.6	97.3

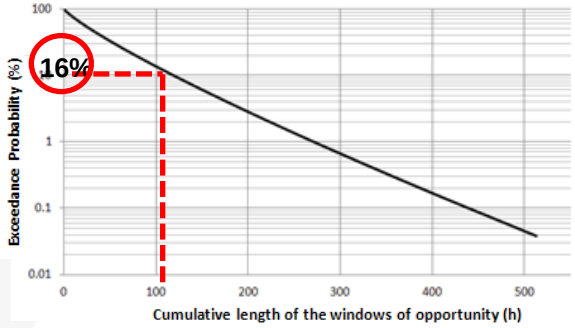
MORE favorable period

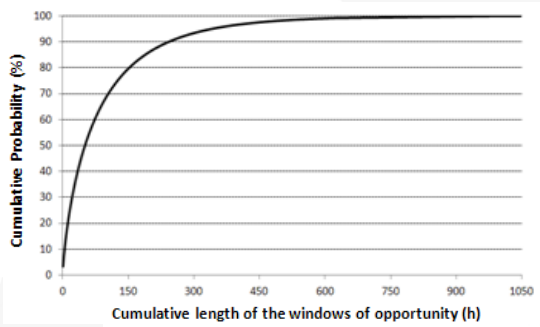
LESS favorable period

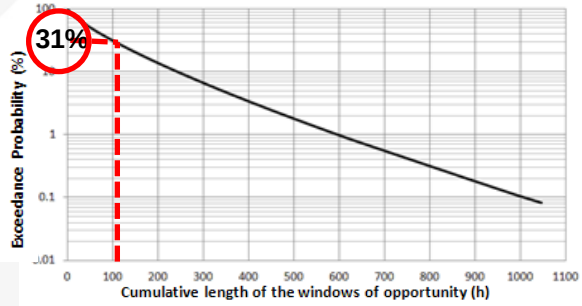
Window of opportunity

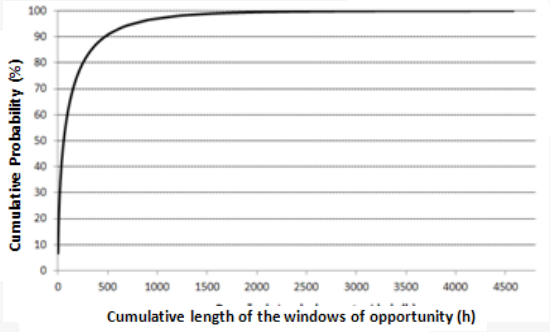
Example: If the time needed to perform a certain task is 100 hours…

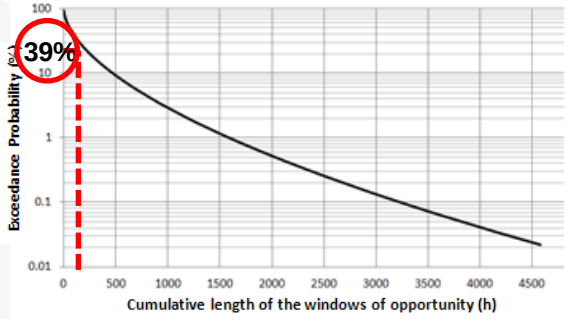












Window of opportunity

	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

	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

	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

Conclusions

- The most favorable periods for accessing the site is the summer period : 80-90% availability when using boats with OAS technology.
- The lowest accessibility was found for the winter season with an average ~60% availability for the same boat technology type.
- When a helicopter is used, no seasonal variation was identified and the accessibility is almost close to 100% all over the year.
- The length of the windows of opportunity, when comparing rubber boats with other access system types, increases 23 days for boats with OAS and 169 days for the helicopter case.

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Conclusions

• Portugal has adequate conditions for offshore site maintenance strategies, with reasonable sizes of windows of opportunity.

• For the installation of wind turbines, there is a large number of windows of opportunity, but they are relatively short, therefore the installation of offshore wind parks must be carefully planned.

• This is an important factor in favor of the offshore wind farm deployments on the country.

Thank You

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