Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m

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Definitions & Abbreviations

CEREMA	Centre d’Études sur les risques, l’environnement, la mobilité et l’aménagement
DLC	Design Load Cases
DTU	Technical University of Denmark
ECS	Extreme Current State

EHWL	Extreme High Water Level
ELWL	Extreme Low Water Level
ESS	Extreme Sea State
EWLR	Extreme Water Level Range
EWM	Extreme Wind Model
GdF	Golfe de Fos
GoM	Gulf of Maine
HAT	Highest Astronomical Tide
HSE	Health and Safety Executive
IEC	International Electrotechnical Commission
LAT	Lowest Astronomical Tide
LSM	Least Square Method
NERACOOS	Northeast Regional Association of Coastal and Ocean Observing Systems
MSL	Mean Sea Level
NM	Nautic Mile
NOAA	National Oceanic and Atmospheric Administration
NORSOK	Norwegian petroleum industry Standards
NREL	National Renewable Energy Laboratory
NTM	Normal Turbulence Model
WMO	World Meteorological Organisation
WoB	West of Barra

Symbols

u	Wind Speed
u_{10}	Mean wind speed with averaging period of 10 minutes
u_{1hour}	Mean wind speed with averaging period of 1 hour
v_{ref}	50-years return period 10-minutes wind speed
I_{ref}	Reference Turbulence Intensity
z_0	Height
z	Height
Z_{hub}	Hub Height
H	Height
δ	Weibull location parameter
A	Weibull shape parameter
k	Weibull scale parameter
H_s	Significant wave height

$H_{s_{50years}}$	50 year Return Period Significant Wave Height
T_p	Wave peak period
$T_{p_{max,50years}}$	Maximum 50 year peak period
$T_{p_{min,50years}}$	Minimum 50 year peak period
$T_{max,50years}$	Maximum 50 year water temperature
$T_{min,50years}$	Minimum 50 year water temperature
T_a	Air temperature
T_s	Sea surface temperature
T_f	Sea water freezing point
v_c	Mean surface current speed
$v_{c,wind}$	Current speed induced by wind
$v_{c,tide}$	Current speed induced by tides

Executive Summary

The LIFES50+ is an EU-funded project as part of the Horizon2020 Framework. The project aims at optimizing four floater concepts for a 10MW wind turbine, and at water depths deeper than 50 m. The four concepts are: a Semi-submersible by Olav Olsen, a Tension Leg Platform (TLP) by Iberdrola, a Semi-submersible by Nautilus, and a floater concept by Ideol. The latter does not follow in any of the classical floater types used in the Oil&Gas industry (i.e. Spar, Semi-submersible and TLP), and consists of a floating ring-shaped concrete hollow caisson.

This report, together with the LIFES50+ Deliverable 1.1, "Oceanographic and meteorological conditions for the design", forms the design basis for the design of the four concepts.

Three generic sites have been defined for the design of the four concepts, representative of mild (Site A), moderate (Site B) and severe (Site C) conditions. The site conditions for the three sites are partly based on the publicly available information from three areas: Golfe de Fos area (France) for the Site A, Gulf of Maine area (USA) for the Site B, West of Barra (Scotland) for the Site C.

The site conditions for the three sites are provided in the LIFES50+ Deliverable 1.1, "Oceanographic and meteorological conditions for the design". Appendix A includes the background information on how the environmental parameters have been selected.

This report gives the criteria, the parameters (e.g. environmental conditions) and the Design Load Cases (DLCs) for the analysis of the four concepts at the three sites. The four concept developers have agreed to design according to the DNV-OS-J103:2013-06 "Design of floating wind turbine structures" and the related standards, e.g. DNV-OS-J101 and DNV-OS-E301. In addition, also IEC standards are considered, e.g. in the definition of the wind environmental conditions according to IEC61400-1. It is strongly advised not to deviate from the requirements of the governing standards (DNV-OS-J103), if not explicitly mentioned in the design basis. In particular, in order to ensure a fair evaluation of the four concepts, it is important that the safety class and the evaluation of the concept redundancy are consistent with the governing standards. Some assumptions and simplifications have been made in the design basis, the most important ones are:

- Only a selected number of DLCs is considered for the analysis of the four concepts. These DLCs are considered the most relevant for the design of floating wind turbine structures, and some selected sensitivity studies will be carried out to justify this assumption; however, additional analysis and considerations would be needed for a commercial project.
- It is assumed that the project consists of a single unit. If a commercial wind farm would be developed, additional considerations might influence the analysis and the cost, e.g. evaluation of the shallowest position at the site, different orientations of the station keeping system, park turbulence, etc.
- The fatigue analysis is based on a simplified approach and it is considered only for one generic site. The local wave and wind conditions at the three sites are not used for the fatigue analysis.
- In case the local wind distributions are used to calculate the Levelized Cost Of Energy (LCOE), it should be noted that the impact of the different wind distribution is not reflected in

the design (e.g. the benefits of an higher average wind speed will be visible in the power production but not in the cost of the wind turbine).

- Assumptions on the site conditions were taken in LIFES50+ D1.1, e.g. turbulence intensity is according to IEC Class C; extreme wind conditions were limited to be within IEC Class I, simplified soil conditions are used.

Contents

1 Objective

The EU commission granted the Horizon2020 project to the LIFES50+ consortium for the qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50 m.

For this purpose, three generic sites have been defined for the design, representative of mild (Site A), moderate (Site B) and severe (Site C) conditions. The site conditions for the three sites are partly based on the publicly available information from three areas: Golfe de Fos area (France) for the Site A, Gulf of Maine area (USA) for the Site B, West of Barra (Scotland) for the Site C.

The project includes the design and evaluation of four different floater concepts: a Semi-submersible concept by Olav Olsen, a Tension Leg Platform (TLP) by Iberdrola, a Semi-submersible by Nautilus, and a floater concept by Ideol. The latter does not follow in any of the classical floater types used in the Oil&Gas industry (i.e. Spar, Semi-submersible and TLP), and consists of a floating ring-shaped concrete hollow caisson.

This report, together with the LIFES50+ Deliverable 1.1, “Oceanographic and meteorological conditions for the design”, forms the design basis for the design of the four concepts.

The site conditions for the three sites are provided in the LIFES50+ Deliverable 1.1, “Oceanographic and meteorological conditions for the design”. Appendix A includes the background information on how the environmental parameters have been selected.

This report gives the criteria, the parameters (e.g. environmental conditions) and the Design Load Cases (DLCs) for the analysis of the four concepts at the three sites.

It is strongly advised to not deviate from the requirements of the governing standards (DNV-OS-J103), if not explicitly mentioned in the design basis.

2 Project Description

The project consists of three generic representative locations. These sites are described below and more information are available in Annex A. It is assumed that the project consists of a single unit. If a commercial wind farm would be developed, additional considerations will be needed, e.g. evaluation of the shallowest position at the site, different orientations of the station keeping system, park turbulence, etc.

2.1 Site A: Moderate environmental conditions

Site A is considered to be the site with the mildest environmental conditions, reflecting Mediterranean site conditions.

The main parameters regarding site A are given below:

Parameter	Value
Number of wind turbines	1, 5, and 50
Distance from shore	Approximately 30 to 50 km
Water depth	70 m
Water level range (absolute)	1.48 m

Table 1: Main parameters for Site A (Moderate environmental conditions)

2.2 Site B: Medium environmental conditions

Site B is considered to be a medium severe site with average sea state conditions and medium extreme wind speeds.

The main parameters regarding site B are given below:

Parameter	Value
Number of wind turbines	1, 5, and 50
Distance from shore	9 km
Water depth	130 m
Water level range (absolute)	5.12 m

Table 2: Main parameters for Site B (medium severe environmental conditions)

For the present analysis, one wind turbine at a water depth of 130 m is selected. Regarding wind farm, the details will be provided in the update and shallowest water depth will be used for the integrated loads.

2.3 Site C: Severe environmental conditions

Site C is detected as the harshest site with the most extreme wave heights and wind speeds of all three locations.

The main parameters regarding the reference site are given below:

Parameter	Value
Number of wind turbines	1, 5, and 50
Distance from shore	19 km
Water depth	100 m
Water level range (absolute)	6.64 m

Table 3: Severe parameters for Site C (severe environmental conditions)

3 Standards and Regulations

The main standards used for the design of the complete floating wind turbine system are listed in Table 4. Further, national technical requirements may also be applicable and shall be considered in case of a commercial project.

Document No.	Title
DNV-SE-0073:2014-12	Type and component certification of wind turbines according to IEC 61400-22
DNV-OS-J103:2013-06	Design of floating wind turbine structures
DNV-OS-J101:2014-05	Design of offshore wind turbine structures
IEC 61400-3:2009	Wind turbines – Part 3: Design requirements for offshore wind turbines
DNV-OS-E301:2013-10	Position mooring
DNV-RP-C205:2014-04	Environmental conditions and environmental loads
IEC 61400-1:2005	Wind turbines – Part 1: Design requirements

Table 4: Design Standards and Regulations

4 Definitions, abbreviations, and symbols

In the following sections, the definitions, abbreviations, and symbols used for the design are specified.

4.1 General

ALS	Accidental Limit State (please refer to DNV-OS-J101, [1], Section 2.4)
FLS	Fatigue Limit State (please refer to DNV-OS-J101, [1], Section 7.10)
ULS	Ultimate Limit State (please refer to DNV-OS-J101, [1], Section 7.1)
γ_F	Partial load factor
γ_M	Partial material factor

4.2 Wind conditions

NWP	Normal wind profile
NTM	Normal turbulence model
ETM	Extreme turbulence model
EOG	Extreme operating gust
ECD	Extreme coherent gust with direction change
EDC	Extreme direction change
EWS	Extreme wind shear

For explanations of these models, please refer to DNV-OS-J101, [1], Section 3.2.3.

4.3 Water levels

MSL	Mean sea level, it is termed as the average of LAT and HAT (please refer to DNV-OS-J103, [2], Section 3.2.1)
LAT	Lowest astronomical tide, it is the lowest water level that can be predicted to occur under any combination of astronomical conditions (please refer to DNV-OS-J103, [2], Section 3.2.1)
HAT	Highest astronomical tide, it is the highest water level that can be predicted to occur under any combination of astronomical conditions (please refer to DNV-OS-J103, [2], Section 3.2.1)
LDSWL	Lowest design water level
HDSWL	Highest design water level

The hub height of the wind turbine is specified with respect to the mean sea level (MSL).

4.4 Sea states

NSS	Normal sea state (please refer to DNV-OS-J101, [1], Section 3.3.4.2)
ESS	Extreme sea state (please refer to DNV-OS-J101, [1], Section 3.3.4.6)
SSS	Severe sea state (please refer to DNV-OS-J101, [1], Section 3.3.4.4)
H_s	Significant wave height (please refer to DNV-OS-J101, [1], Section 3.3.1)
T_p	Peak period (please refer to DNV-OS-J101, [1], Section 3.3.1)
H_{NWH}	Normal wave height (please refer to DNV-OS-J101, [1], Section 3.3.4.3)
H_{SWH}	Severe wave height (please refer to DNV-OS-J101, [1], Section 3.3.4.5)
H_{EWH}	Extreme wave height (please refer to DNV-OS-J101, [1], Section 3.3.4.7)
$\mathrm{H}_{\mathrm{RWH}}$	Reduced wave height (please refer to DNV-OS-J101, [1], Section 3.3.4.8)
NCM	Normal current model (please refer to DNV-OS-J101, [1], Section 3.4)
ECM	Extreme current model (please refer to DNV-OS-J101, [1], Section 3.4)

5 Coordinate system and units

5.1 Coordinate system

5.1.1 Wind turbine coordinate system

The coordinate axis system in which loads and centres of gravity are expressed is a rotating coordinate system, parallel to the rotating axis system situated at the nacelle. In Figure 1, the support structure coordinate system has its origin between mudline and tower top at the intersection with the support system axis and does not rotate with the nacelle. The tower top coordinate system in Figure 2 has its origin at the intersection of the tower axis and the upper edge of the yaw bearing and rotates with the nacelle. The orientation corresponds to the support structure coordinate system.

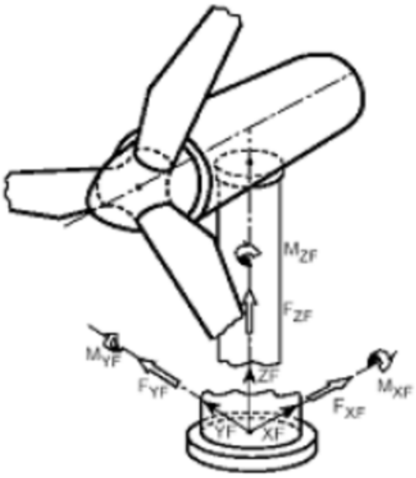


Figure 1: Local rotating axis system at the tower bottom, from GL2012 – Offshore Guideline

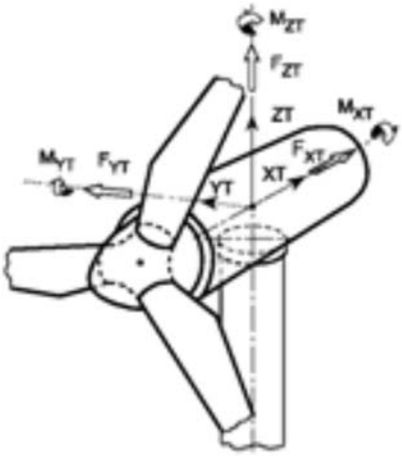


Figure 2: Local rotating axis system at the nacelle, from GL2012 – Offshore Guideline

5.1.2 Environmental conditions coordinate system

The coordinate system followed for the waves, current, and wind is shown in Figure 3. Reference is taken from North (0°), increasing clockwise. For example, a wind direction of α_{Wind}=0° indicates a wind direction coming from North. A wind direction of α_{Wind}=30° and a wave direction of α_{Wave}=60° indicate a wind-wave misalignment of β= 30°.

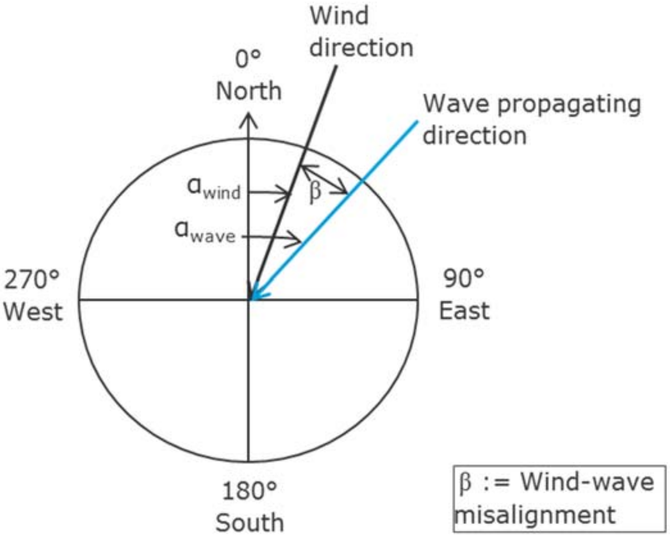
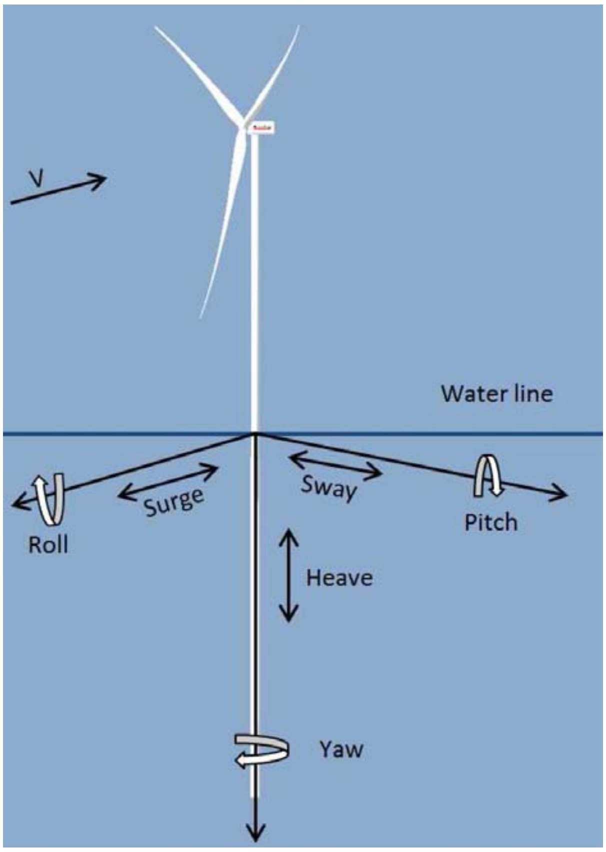


Figure 3: Direction of environmental impact

5.1.3 Rigid body-motion modes

The rigid-body motion modes are defined in **Error! Reference source not found.**.



Surge	Translation along the longitudinal axis (main wind direction)
Sway	Translation along the lateral axis (transversal to the main wind direction
Heave	Translation along the vertical axis
Roll	Rotation about the longitudinal axis
Pitch	Rotation about the lateral axis
Yaw	Rotation about the vertical axis

Figure 4: Definition of rigid-body motion modes [2]

5.2 Units and sign convention

The units followed for all the sub-systems shall be consistent – in SI system. The sign convention followed for the directional sector for wind, waves and current are shown in Section 5.1.2.

Wind direction of 0° is defined as coming from North. This applies to waves, currents, and other environmental forces, as well.

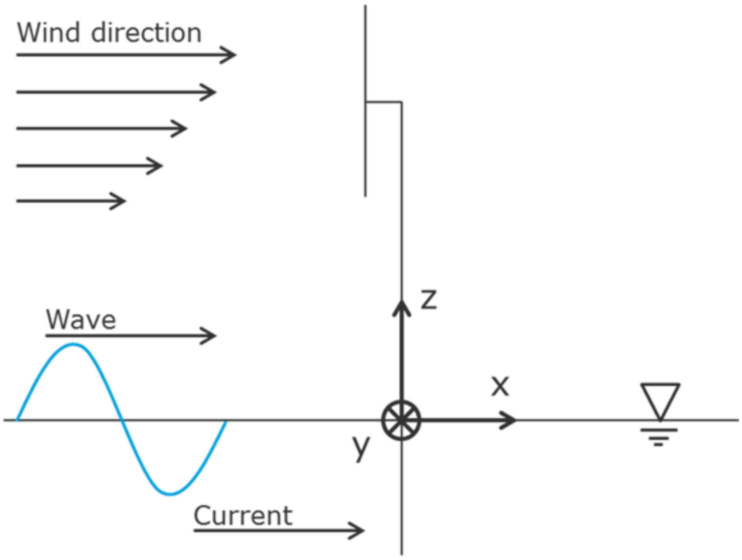


Figure 5: Sign convention in a global coordinate system

6 Design

6.1 Design criteria

6.1.1 Safety class

Three safety classes are defined in DNV-OS-J103, see reference [2]. *Low safety class* is used for structures, whose failures imply low risk of human injury, minor environmental consequences, minor economic consequences and negligible risk to human life. *Normal safety class* is used for structures, whose failures imply some risk for human injury, some environmental pollution or significant economic consequences. *High safety class* is used for structures, whose failures imply large possibilities for human injuries or fatalities, for significant environmental pollution or major societal losses, or very large economic consequences. For floating wind turbine structures, which are unmanned during severe environmental loading conditions, the consequences of failure are mainly of an economic nature.

The different safety classes applicable for different parts of the floating units and their station-keeping systems are reflected in terms of different requirements for load factors (see **6.1.4**). The requirements for material factors remain unchanged regardless of which safety class is applicable for a particular wind farm or structure in question.

The safety class shall be chosen according to [2], Section 2. Normal safety class shall be used for the design of unmanned platforms. In case other design criteria are considered, the safety class shall be chosen accordingly.

6.1.2 Mooring line redundancy

Redundancy considerations are an important part of the station keeping design and form part of the basis for selection of the appropriate safety class. For station keeping systems without redundancy, the design of the various components of the station keeping system shall be carried out to a safety class which is at least one safety class higher than the one specified in [2][8], Section 2.1.3. This implies that station keeping systems without redundancy shall be designed to a higher safety class.

Redundancy of the station keeping system shall be considered according to [2], Section 8. The redundancy of the system shall be demonstrated during the analysis.

6.1.3 Design Life

The design life describes the period of time over which the structure in question is designed for to provide an acceptable minimum level of safety. In order to sustain the harsh offshore environment, adequate inspection and maintenance have to be carried out. This applies to the entire wind farm including substation and submerged power cable, and station keeping system. The design life shall be agreed upon for all concepts to obtain comparable results for the fatigue analysis.

The life time is assumed to be 25 years, in accordance to D2.1 [3].

6.1.4 Partial Safety Factors

6.1.4.1 Partial load factors

Partial load factors γ_F reflect the uncertainty of the loads and their probability of occurrence (e.g. normal, extreme and abnormal loads). The partial safety factors for loads are independent of the materials used. Partial load factors shall be applied according to the table below and [1], Section 5.

Load factors γ_F for the ULS and the ALS							
Load factor set	*Limit state*	*Load categories*					
		G	Q	E			D
				Safety Class			
				Low	*Normal*	*High*	
(a)	ULS	1.25	1.25	0.7(*)			1.0
(b)	ULS	1.0	1.0	1.20	1.35	1.55	1.0
(c)	ULS for abnormal wind load cases	1.0	1.0	1.1			1.0
(d)	ALS	1.0	1.0	0.9	1.0	1.15	1.0

Load categories are:
G = permanent load
Q = variable functional load, normally relevant only for design against ship impacts and for local design of platforms
E = environmental load
D = deformation load
For description of load categories, see OS-J101, Sec.4 "Loads and load effects".

(*) When environmental loads are to be combined with functional loads from ship impacts, the environmental load factor shall be increased from 0.7 to 1.0 to reflect that ship impacts are correlated with the wave conditions.

Table 5: Partial safety factors for loads γ_F [1]

For fatigue loading the structure shall be able to resist expected fatigue loads, which may occur during temporary and operational design conditions. Whenever significant cyclic loads may occur in other phases, e.g. during manufacturing and transportation, such cyclic loads shall be included in the fatigue load estimates. The load factor γ_F in the FLS is 1.0 for all load categories.

6.1.4.2 Partial material factors

Partial safety factors for materials γ_M take into account the dependence on the type of material, the processing, component geometry and, if applicable, the influence of the manufacturing process on the strength.

Partial safety factors for material for steel structures shall be applied according to [1], Section 7. For other materials, e.g. concrete, the material factors for concrete and reinforcements shall be used accordingly, see [1], Section 8. Please note that material factors for station keeping systems depend on the material and the system. The offshore standards references [4] to [7] supply further information.

6.2 RNA and tower

RNA and tower are reported in the tables below, further information can be found in [8].

Parameter		Value
Rated power	kW	10000 (DTU 10MW RWT – IEC Class IA)
Rotor diameter	m	178.3
Hub height (w.r.t MSL)	m	119.0
Power regulation	-	Variable speed, collective pitch
Rated rotor speed	rpm	9.6
Rotor speed range	rpm	6.0 to 9.6
Rated wind speed	m/s	11.4
Cut in wind speed	m/s	4.0
Cut out wind speed	m/s	25.0

Other parameters, reference [8]		
Rotor mass	kg	227,962
Nacelle mass	kg	446,036
Tower mass	kg	628,442
CoM_{tower}, along tower from ground	m	47.6

Table 6: Main parameter for RNA and tower

For simulation of DLC		
Yaw error (normal and extreme)	deg	8° (normal), 20° (extreme)
For FLS		
Life time of the turbine	years	25

Table 7: DLC Information

6.3 Substructure

The following sections describe the concept designs. The information available has been somewhat limited and will be updated during the design phase of the concepts. A general concept sketch is presented below.

6.3.1 Ideol

The concept is a semi-submersible / barge platform with moon pool, which is made of concrete.

Acceptable range of periods for which the floater is designed (surge, heave, pitch)	*To be defined during the design*
Description on station keeping / static stability principle	*Mooring systems with steel cable, chain or synthetic lines are routinely proposed depending on actual site and operator specifications.* *Static stability is ensured by classical hydrostatic analyses. These analyses do consider damaged-compartment cases.*
If any floater controller is present in the floater	*No*
Redundancy on mooring lines and safety class	*Prefers to design redundant mooring system.*
Main material for the hull	*Reinforced concrete*
Anchor type	*Site-dependent. Driven piles, drag embedment or suction anchors can be used.*

Table 8: General information of Ideol - to be updated

Figure 6: Ideol concept sketch

6.3.2 Nautilus

Nautilus is a semi-steel structure with four columns as floaters. It is designed for water depth of 50 to 250 m.

Acceptable range of periods for which the floater is designed (surge, heave, pitch)	*To be defined during the design*
Description on station keeping / static stability principle	*Catenary moorings, water ballast*
If any floater controller is present in the floater	*To be defined during the design*
Redundancy on mooring lines and safety class	*To be defined during the design*

Table 9: General information of Nautilus - to be updated

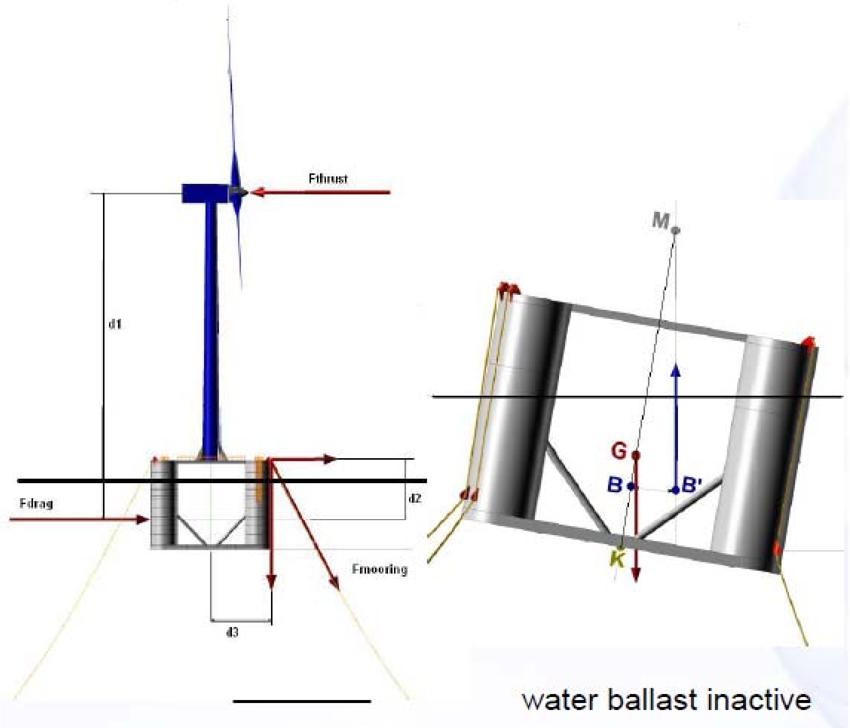


Figure 7: Nautilus concept sketch

6.3.3 Olav Olsen

The OO Star-Semi concept is a semi-submersible concept with 3 columns, a center shaft (turbine tower), star pontoon, and heave plates for improved hydrodynamic stability. The concept is assumed to be suitable for shallow water application. Mooring system consists of 3 mooring lines.

Acceptable range of periods for which the floater is designed (surge, heave, pitch)	*To be defined during the design*
Description on station keeping / static stability principle	*Mooring lines, ballasting*
If any floater controller is present in the floater	*To be defined during the design*
Redundancy on mooring lines and safety class	*To be defined during the design*

Table 10: General information of Olav Olsen - to be updated

Figure 8: Olav Olsen concept sketch

6.3.4 Iberdrola IC

The TLPWIND® concept consists of a central cylindrical column and four pontoons symmetrically distributed (perpendicular, 90°) on its bottom. In the top of the central column, a conical frustum allows a smooth transition between the main cylinder diameter and the offshore wind turbine tower diameter.

Acceptable range of periods for which the floater is designed (surge, heave, pitch)	*To be defined during the design*
Description on station keeping / static stability principle	*Station keeping is achieved through pre-tensioned tendons. The tendons could be manufactured of steel or synthetic material depending on the specific conditions of the site and available supply chain.*
If any floater controller is present in the floater	*No*
Redundancy on mooring lines and safety class	*To be defined during the design*

Table 11: General information of Iberdrola IC

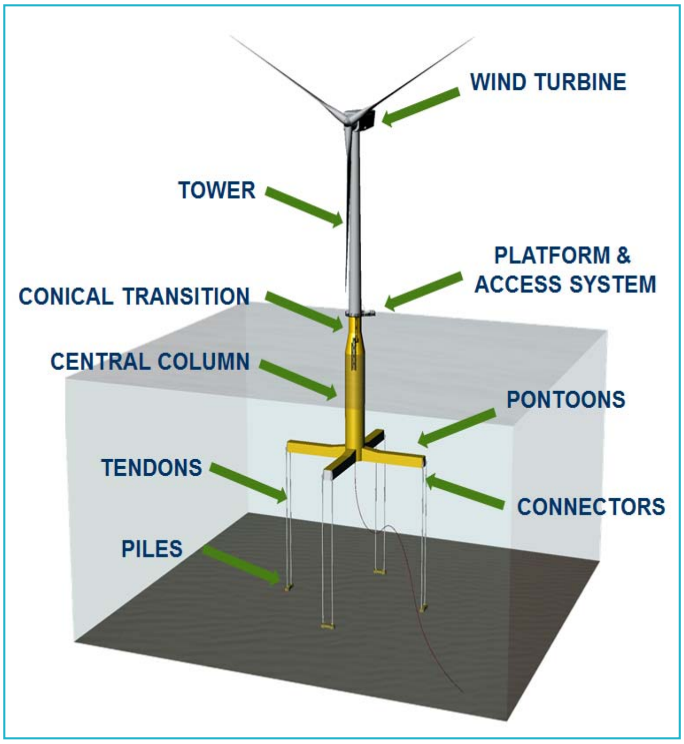


Figure 9: Iberdrola IC concept sketch

6.4 Tolerances and operational limits

Here, the tolerances and operational limits considered for the design are specified:

To be defined by the WTG manufacturer and floater concept developers.

Operational limits (assumptions):

Inclination of tilt: 10 degree in operational conditions. No limits in idling conditions have been set for this project.

Max. acceleration: Maximal acceleration to nacelle is usually defined by the wind turbine manufacture. For this project no limit has been set to the max acceleration of the nacelle.

Clearances: Shall be considered during the design and the analysis according to the requirements in the relevant standards:

- IEC61400-1, [9], Section 7.6.5, for tower clearance (blades and tower)

- DNV-OS-J103, [2], Section 7, item 1.2.3 for blade tip clearance from water
- DNV-OS-J103, [2], Section 7, item 1.6.4 for air gap for the deck. If this air gap is too low, slamming loads need to be accounted for

6.5 Overall damping

The damping of offshore wind turbines significantly influences the turbine response and the dynamic loading.

The damping contributions from structural, hydrodynamic and aerodynamic shall be adequately explained and motivated. This section includes the damping that will be applied in the analysis and the methods used to model it.

6.5.1 Structural damping

The structural damping of the blade has been defined in ”Description of the DTU 10 MW Reference Wind Turbine”, reference [8].

In general, for steel a material damping of the floater of $0.2\% \leq D_{steel} \leq 0.3\%$ of D_{crit} can be assumed.

Damping regarding the RNA and tower can be found in the following tables.

Mode	Natural frequency [Hz]	Logarithmic Damping [%]
1st flap mode	0.61	3.0
1st edge mode	0.93	3.0
2nd flap mode	1.74	8.4
2nd flap mode	2.76	8.9
3rd flap mode	3.57	17.0
1st torsion mode	5.69	20.8
4th flap mode	6.11	26.4
3rd edge mode	6.66	5.0

Table 12: Natural frequency and damping for the isolated blade [8]

The structural damping of the tower is as follows:

Mode	Natural frequency [Hz]	Logarithmic Damping [%]
1st Tower side-side mode	0.25	1.9
1st Tower fore-aft mode	0.25	1.9
1st fix-free mode	0.50	3.1
1st asymmetric flap with yaw	0.55	2.3
1st asymmetric flapt with tilt	0.59	2.8
1st collective flap mode	0.63	3.1
1st asymmetric edge 1	0.92	2.9
1st asymmetric edge 2	0.94	3.0
2nd asymmetric flap with yaw	1.38	4.8
2nd asymmetric flap with tilt	1.55	6.1

Table 13: Natural frequendy and damping of the whole turbine [8]

6.5.2 Aerodynamic damping

The aerodynamic damping consists mostly of the controller behaviour during power production for surge and pitch and shall be accounted for during the simulations.

If a simplified model of the aerodynamics is used then the effect of the aerodynamic damping shall be properly accounted for.

6.5.3 Hydrodynamic damping

The hydrodynamic damping implementation is described can be found in D4.4, see also Section 8. There, the methods and codes for the analysis are presented for the four concepts.

For commercial projects, assumptions for hydrodynamic damping shall be assessed in model tests or on prototypes.

6.5.4 Other damping contributions

At the moment no other damping contribution is being considered for the design. Other contributions shall be justified during the design phase.

7 Site Conditions

The environmental conditions are presented in `Annex A`. In the present Design Basis, contents have been extracted and are presented in the following sections.

7.1 Wind climate – general

The wind speeds are provided for 10 min mean. Conversion to 1 hour and 3 hours mean values should be done according to the standards, e.g. [10], section §2.3.11, or [11].

Parameter		**Unit**	**Site A**	**Site B**	**Site C**
Operational conditions	Mean air density	kg/m^3	1.225	1.225	1.225
	Annual average wind speed, $V_{ave,hub}$	m/s	11.0	10.46	11.74
	Weibull scale parameter, A	m/s	9	6.214	9.089
	Weibull shape parameter, k	-	1.6	1.701	2.096
	Wind shear exponent	-	0.14	0.14	0.14[1]
	Mean free turbulence intensity at 15 m/s, I_{15}	-	12% (Turbulence class C)		
	Standard deviation of turbulence intensity	%	4.07	4.9	5.23
Extreme conditions	Air density at extreme wind	kg/m^3			
	10 min. mean reference wind speed (50 years return period) at hub height, V_{ref}	m/s	37.0	44.0	50.0[2]
	2 sec. gust wind speed (50 years return period) at hub height	m/s	52.0	62.7	75.3
	Extreme wind shear exponent	-	0.11	0.11	0.12

Table 14: Wind climate – basic data

7.1.1 Probability distribution

For the wind speed probability, standard Weibull distribution with the corresponding scale and shape parameters provided in Table 14 will be used.

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[1] For Site C, logarithmic profile is selected, see Annex A

[2] The extreme wind speed at Site C as been reduced to 50m/s to be within IEC Class I. Higher extreme speeds at the reference sites are expected, see Annex A.

7.1.2 Wind rose

Wind rose for a site can be found in Annex A.

7.1.3 Wind spectrum

Kaimal spectrum as described in Section 3.2.4.3 of reference [1] is used for the turbulence modelling. Further recommendations on how/when to use different wind spectra are given in DNV-RP-C205 [10].

7.2 Wind climate – Turbulence

Different turbulence levels shall be defined for the design of a commercial offshore wind farm project, see Sections 7.2.1 - 7.2.4.

For this project, a simplified approach has been used and only one turbulence level has been used for all the conditions at all the sites. For the three sites, the turbulence has been defined as IEC class C, ref.[9], for all the DLCs, see Table 15.

The turbulence level is defined for 10-minutes time series. For longer time series the turbulence level shall be properly adjusted, e.g. see eq. 18 in IEC 61400-3, ref. [10][11]. In particular, it shall be ensured that the energy content and the max 10-minutes-mean are maintained in the longer time series.

7.2.1 Characteristic turbulence

The characteristic turbulence intensities for NTM and ETM will be used according to IEC 61400-1, ref.[9], Sections 6.3.1.3 and 6.3.2.3, respectively.

The turbulence class has been defined to be IEC wind turbulence class C in [12].

Wind speed [m/s]	NTM [%]	ETM [%]
2	0.426	0.980
3	0.314	0.678
4	0.258	0.527
5	0.224	0.436
6	0.202	0.376
7	0.186	0.332
8	0.174	0.300
9	0.165	0.275
10	0.157	0.255
11	0.151	0.238
12	0.146	0.224
13	0.142	0.213
14	0.138	0.203
15	0.135	0.194
16	0.132	0.187
17	0.130	0.180
18	0.127	0.174
19	0.125	0.169
20	0.124	0.164
21	0.122	0.160
22	0.121	0.156
23	0.119	0.152
24	0.118	0.149
25	0.117	0.146
26	0.116	0.143
27	0.115	0.141
28	0.114	0.138
29	0.113	0.136
30	0.112	0.134
31	0.112	0.132
32	0.111	0.130

Table 15: Turbulence intensity for NTM and ETM for Class C

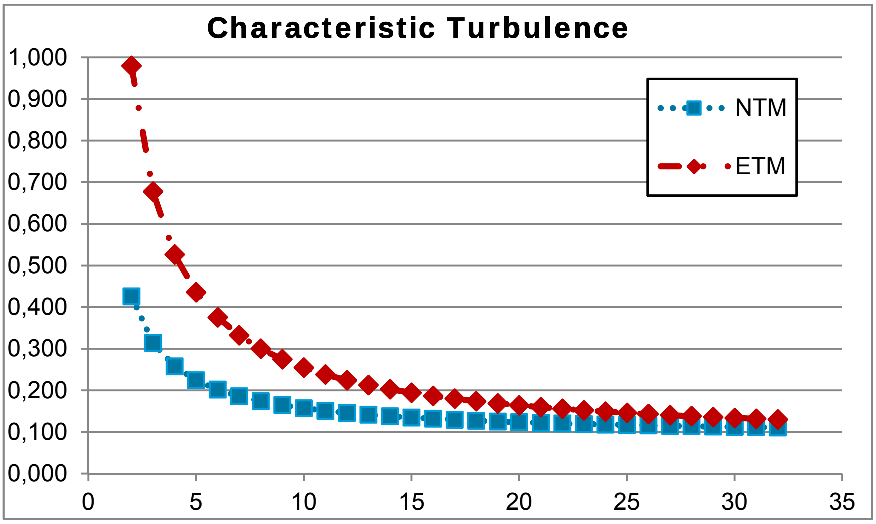

Figure 10: Normal and extreme turbulence

7.2.2 Effective turbulence

If an offshore wind farm is considered, a combination of both characteristic turbulence and wind turbine wake induced turbulence needs to be included. For that, effective turbulence intensities are calculated as per Section 11 of IEC 61400-1.Ed.3, ref.[9], including the Amendment:2010 by considering the number of neighbouring wind turbines (including the distance to the turbine under consideration) and is weighted with respect to material Wohler slopes. These are used for FLS.

For this project it has been decided to use a simplified approach and the NTM values in Table 15 will be used for FLS analysis.

7.2.3 NTM for ULS DLCs

For ULS DLCs such as DLC 1.1, the NTM can be set to characteristic ambient turbulence inside the offshore wind farm as defined in equation D.4 of reference [9] including Amendment:2010.

For this project it has been decided to use a simplified approach and the NTM values in Table 15 will be used.

7.2.4 Extreme turbulence

In the case of DLC 1.3, the maximum centre wake ($\widehat{\sigma_T}$) as given in Annex D of reference [9] including Amendment:2010 is used. Please see Section 7.2.1 for characteristic extreme turbulence information.

For this project it has been decided to use a simplified approach and the ETM values in Table 15 will be used.

7.3 Deterministic wind conditions

Deterministic wind conditions were not defined in Annex A for the three sites.

Therefore it is recommended that the deterministic wind conditions shall be defined according to [9], Section 6.3.2, with the following additional considerations:

- For EDC, ECD and EWS, in addition to the periods of the events defined in [9], the relevant natural periods of the structure shall be considered.
- The period and amplitude of the EOG has to be calculated as per [2], depending on the periods of the structure for the four concepts, see Section 3 §2.2.10 of [2] for further guidance.

7.4 Water levels

The water levels shall be unique for each site. The values to be used shall be taken from water level statistics as a basis for representation of the long term and short term water level conditions.

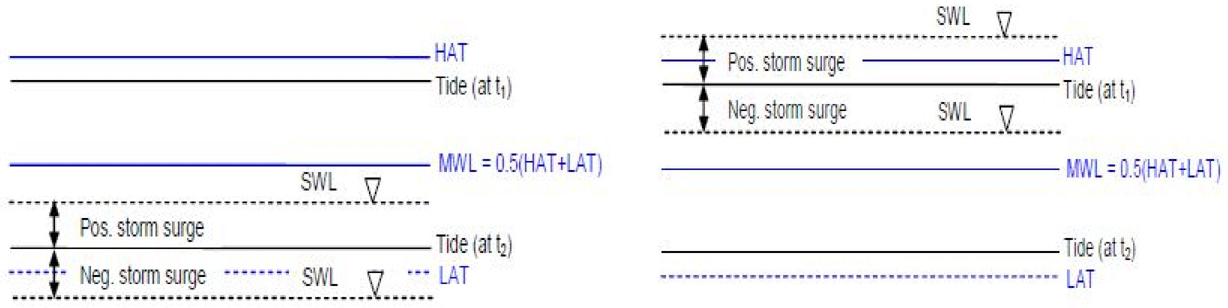

Figure 11: Definition of water levels

Water level variation considered in the analysis is given in Table 16, according to the values in [1].

Parameter			Site A	Site B	Site C
Highest design water level	m	HSWL = HDWL	1.13	4.32	4.16
Highest astronomical tide	m	HAT	Tidal range small	3.22	3.16
Mean sea level	m	MSL		1.62	2.32
Lowest astronomical tide	m	LAT		0.00	-1.48
Lowest design water level	m	LSWL = LDWL	-0.35	-0.80	-2.48

Table 16: Water levels for all sites

The water depths are presented in the following. For commercial project the range for each water depth shall be taken into consideration.

			Site A	Site B	Site C
Water depth	m	d	70	130	100

Table 17: Water depths for all sites

7.5 Wave climate

The wave climate is represented by the significant wave height H_s and the spectral peak period T_p.

Here, a brief description about the general wave climate based on measurements is provided. The wave rose and contour plots of H_s vs. T_p is provided. The wind/wave misalignment with frequency of occurrence is reported in Table 18, according to [1].

The sea states are defined in the next sections, based on the values reported in Annex A.

7.5.1 Normal sea state (NSS)

The NSS parameters to be considered for the fatigue analysis (DLC 1.2) are given in the table below. Since only one fatigue assessment will be performed, the data are not directly correlated to one of the three sites. Instead the data are taken from [13], where the fatigue methodology for this project is described.

V_{hub} [m/s]	H_s [m]	T_p [s]	P [-]
5	1.38	5	3.45%
5	1.38	7	6.89%
5	1.38	11	3.45%
7.1	1.67	5	5.99%
7.1	1.67	8	11.98%
7.1	1.67	11	5.99%
10.3	2.2	5	6.41%
10.3	2.2	8	12.83%
10.3	2.2	11	6.41%
13.9	3.04	7	5.12%
13.9	3.04	9.5	10.24%
13.9	3.04	12	5.12%
17.9	4.29	7.5	2.90%
17.9	4.29	10	5.81%
17.9	4.29	13	2.90%
22.1	6.2	10	0.94%
22.1	6.2	12.5	1.88%
22.1	6.2	15	0.94%
25	8.31	10	0.19%
25	8.31	12	0.37%
25	8.31	14	0.19%

Table 18: Wind speed (V_{hub}) – wave (H_s,T_p) – correlation, from [13]. Values to be used for fatigue analysis (DLC 1.2)

For the other DLCs with NSS, the site specific data in Annex A should be used.

7.5.2 Severe sea state (SSS)

In the case of severe sea state, it is assumed to use the parameters corresponding to extreme sea state as given in Table 19.

7.5.3 Extreme sea state (ESS)

The ESS parameters considered are given below:

			Site A	Site B	Site C
50-yr sign. Wave height	[m]	$H_{s50,3h}$	7.50	10.9	15.6
50-yr sign. Peak period range	[s]	$T_{p50,3h\,\min} - T_{p50,3h\,\max}$	8.0 – 11.0	9 - 16	12 - 18
1-yr sign. Wave height	[m]	$H_{s1,3h}$	4	7.7	11.5
1-yr sign. Peak period	[s]	$T_{p1,3h}$	6.0 – 11.0	9 - 16	12 - 18

Table 19: Design waves for 50 and 1-year return periods

7.6 Current climate

The modelling of current shall be performed according to DNV-OS-J101, [1]. A reference to vortex-induced vibrations and vortex-induced motions is made to RP-C205,[10]. If no measured data is available, the variation in current velocity with depth may be considered as:

$$v(z) = v_{tide}(z) + v_{wind}(z)$$

where

$$v_{tide}(z) = v_{tide0}\left(\frac{h+z}{h}\right)^{1/7}$$

for $z \leq 0$ and

$$v_{wind}(z) = v_{wind0}\left(\frac{h_0+z}{h_0}\right)$$

For $-h_0 \leq z \leq 0$
In which

$v(z)$ = total current velocity at level z
z = vertical coordinate from still water level, positive upwards
$v_{tide}(.)$ = tidal current at still water level
$v_{wind}(.)$ = wind-generated current at still water level
h = water depth from still water level (taken as positive)
h_0 = reference depth for wind-generated current; $h_0 = 50$ m

7.7 Soil conditions

For the soil condition on the seabed, some assumptions will have to be made based on the available information reported in Appendix A. The soil conditions at the site will directly influence the choice of the anchors.

7.8 Other conditions

Here, the following other conditions are described:

			Site A	**Site B**[3]	**Site C**
Air temperature	$T_{max,50air}$	°C	31	-	15
	$T_{min,50air}$	°C	8	-	6
Air density	ρ_{air}	kg/m³	1.225	1.225	1.225 [9]
Water temperature	$T_{max,50water}$	°C	5	-	19
	$T_{min,50water}$	°C	30	-	3
Water density	ρ_{water}	kg/m³	From standard EOS with salinity of 38 psu or approximate with 1029 kg/m3	-	1025-1028
Marine Growth	Thickness	mm	+2 to -40m: 100 Below 40m: 50	-	Ref. [9]
	Density	kg/m³	1325 ([9], 6.7.4)	-	-
Ice			-	Yes	Not expected
Earthquake			-	-	
Lightning			-	-	IEC 61000-24
Weather windows and weather downtimes			No information available	No information available	No information available
Tropical storm / hurricane			None	No information available	No information available

Table 20: Other conditions – main data

8 Load Calculation

The load analysis for the integrated structure has to fulfill the requirements in the standards for the specific environmental conditions at site.

8.1 Coupled analysis

DNV-OS-J103, reference [2], requires that the loads are calculated through coupled analysis and that the model is verified against model tests.

During the LIFES50+ project, the main focus has been put on ensuring a comparable approach between the four concepts, as explained in [2]. This is in order to have a fair comparison between the four concepts.

The numerical models used for the analysis of the four concepts are described in LIFES50+ deliverable D4.4, see [14]. It is concluded that the numerical models used by the four concept developers are comparable in terms of accuracy of the analysis and validation of the models.

8.1.1 Hydrodynamic model

The wave theory and the hydrodynamic model for the analysis are described in [14] for the four concepts. The numerical models used by the four concept developers are considered fairly comparable in terms of theoretical accuracy.

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[3] Please refer to [1] "Definition of the target locations business cases" for further information

The validation and calibration of the hydrodynamic models shall be a part of the design verification of a commercial project.

8.1.2 Aerodynamic model

All the four concept developers use a similar approach (BEM model) for the calculation of the aerodynamic loads, as presented in [13].

8.2 Fatigue analysis (FLS)

Fatigue load analysis will be carried out through a simplified approach described in a technical memo from Ideol [13].

The following assumptions are made for the FLS analysis:

- Only one fatigue analysis per concept is performed, and it will be considered for all the three sites.
- Only loads during normal production are considered (DLC 1.2). This approach is considered sufficient for a preliminary assessment of the concept. Idling, start-up and shutdown cases should be included for the assessment of the final design.
- The wind turbulence is assumed according class C and the wind distribution is according the Site B in Table 14.
- NSS and scatter diagram of significant wave height vs. mean wind speed is considered according to the data from [13], reported in Table 18.
- Other environmental conditions and parameters (e.g. water depth, soil conditions, etc.) are according to Site B.

In [13] also the following hypotheses are made on the environment directions:

- Only aligned wind/wave conditions are considered.
- The prevailing wave direction is considered 100% of the time as the base case.
- In order to help optimise the most critical items, 2 additional directions around the prevailing wave direction would be considered, each 90 degree off the prevailing direction, with 25% probability each.

The cases to be considered are summarized in the table below, from [13].

Case	Probability	Wave direction	Wind direction	Current direction
Basic	100%	0 deg	0 deg	0 deg
Optimised fatigue	50%	0 deg	0 deg	0 deg
	25%	90 deg	90 deg	90 deg
	25%	270 deg	270 deg	270 deg

Table 21 Wave directions to be considered, from Error! Reference source not found.**[13].**

Furthermore, during the analysis, the following should be taken into account:

- A wind speed interval of 2 m/s (or lower) should be considered in the setup of DLC 1.1.
- Three periods should be associated to each wave height.
- At least a total of 3 hours simulations per wind speed should be used.
- In [13] it is required that the simulation length should be at least of 1 hour. A shorter simulation length may be used if it is shown to be conservative with a sensitivity study.

This approach is considered valid for a conceptual evaluation of the four concepts.

The following aspects should be assessed in sensitivity studies by the four concept developers, in order to prove that the fatigue assessment is equally conservative for all the designs under evaluation:

- Relative importance of the misalignment in the analysis and orientation of the wind turbine with respect to the platform. The influence of this parameter may be dependent on the concept type. It should be shown with a sensitivity analysis whether the approach in [13] is conservative for the specific design, i.e. if the aligned conditions are the most conservative for the design in fatigue. If any of the concepts will show that the approach in [13] is not conservative for some parts of the system, it is recommended that a proper contingency factor should be applied to take into account this uncertainty. The contingency factor should be agreed with the other project participants.

Note: It is considered a fair assumption that all the concept developers select independently the orientation of their platform, without further sensitivity analysis.

8.3 Ultimate loads (ULS)

For the conceptual evaluation of the four concepts, the ultimate loads should be simulated as per the design load cases in Table 22. The environmental conditions in the table should be according to the values in the previous sections of the report. The PLF are defined according to [2], Section 6.1.4.1 and the statistical method followed for post-processing the results is described in [1].

Tendons shall be designed against slack in the ULS, according to [1] Section 8, §3.3. When temporary tendon tension loss is permitted in the ULS according to, tendon dynamic analyses shall be conducted to evaluate the effect of the tension loss on the complete tendon system and its supporting structures.

8.4 Serviceability Limit State (SLS) and Accidental Limit State Fatigue loads (ALS)

Serviceability limits described in [2] (or defined by the floater designer) should be evaluated during the load analysis. The results from DLC 1.1 should be used for the evaluation and a load factor of 1.0 may be used.

DNV-OS-J103, [2], defines a number of ALS load cases in Section 4, §7.1.1 to §7.1.4.

For this project it is considered sufficient to consider the case of mooring failure.

These load cases are described in `Table 23` and are only valid for the concepts having a redundant station keeping system, to carry out a qualification of the redundancy of the station keeping system. For this purpose, characteristic environmental loads defined as 1-year (or larger) loads can be assumed in conjunction with load factors for the ALS in the relevant safety class. The analysis of the mooring fault should include both a transient load case (including the transient response following the mooring line failure) and a DLC in damage conditions (after the failure).

[2] does not explicitly define the ALS load cases. A recommendation is reported in Table 23 and some clarifications are given below.

For the transient load cases:

- The length of the simulations can be reduced in order to include the transient event (similarly to fault case DLC2.3)
- The environmental conditions should be according to the 1-year return period. Analysis according to the governing DLCs in ULS conditions would be recommended
- Both, the idling and operational conditions shall be considered for the wind turbine
- At least three seeds per case shall be used

For the post-failure conditions:

- The length of the simulation should be of 3 hours
- The environmental conditions should be at least according the 1-year return period
- At least three seeds should be used

8.5 Load cases

8.5.1 Reduced load case table

Design Situation	DLC	Wind Condition	Marine Condition				Other Conditions:	Type of Analysis	PSF
			Waves	**Wind & wave directionality**	**Sea Currents**	**Water Level**			
1) Power Production:	1.1	NTM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[AH_s \mid V_{hub}]$	COD, UNI	NCM	MSL		U	N (1.25)
	1.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	MIS, MUL	NA	NWLR or ≥ MSL		F	* *
	1.4	ECD $V_{hub} = V_r - 2\ m/s$, V_r, $V_r + 2\ m/s$	NSS $H_s = E[AH_s \mid V_{hub}]$	MIS, wind direction change	NCM	MSL		U	N
	1.6	NTM $V_{in} < V_{hub} < V_{out}$	SSS $H_s = H_{s,SSS}$	COD, UNI	NCM	NWLR		U	N
2) Power Production + occurrence of fault:	2.3a	EOG $V_{hub} = V_r \pm 2\ m/s$, and V_{out}	NSS $H_s = E[AH_s \mid V_{hub}]$	COD, UNI	NCM	MSL	External or internal electrical fault including loss of electrical network	U	A
6) Parked (standing still or idling):	6.1	Turbulent - EWM $V_{hub} = V_{ref}$	ESS $H_s = H_{s,50}$	MIS, MUL	ECM $U = U_{50}$	EWLR		U	N
	6.2	Turbulent - EWM $V_{hub} = V_{ref}$	ESS $H_s = H_{s,50}$	MIS, MUL	ECM $U = U_{50}$	EWLR	Loss of electrical network Yaw misalignment of ±180 deg	U	A

Table 22: Reduced load case table

Design Situation	**DLC**	**Wind Condition**	**Marine Condition**				**Other Conditions:**
			Waves	**Wind & wave directionality**	**Sea Currents**	**Water Level**	
9) Transient mooring line failure:	9.1 (Production)	NTM V_{rated}, V_{out}	NSS $H_s = E[AH_s \mid V_{hub}]$	COD, UNI	1 year value (or higher return periods)	1 year WL (or higher return periods)	One mooring line failed just before or after the start of the simulation.
	9.2 (Parked)	ETM V_{ref}	ESS $H_s = H_{s,50}$ *(1 year value may also be used)*	COD, UNI	1 year value (or higher return periods)	1 year WL (or higher return periods)	One mooring line failed and the floater reached its equilibrium position.
10) Mooring failure (damaged condition):	10.1 (Parked)	ETM V_{ref}	ESS $H_s = H_{s,50}$ *(1 year value may also be used)*	COD, UNI	1 year value (or higher return periods)	1 year WL (or higher return periods)	One mooring line failed and the floater reached its equilibrium position.

Table 23: Load cases for ALS, only relevant for concepts having a redundant station keeping system.

8.5.2 Load case descriptions

For the certification of a commercial offshore wind farm project, the complete list of DLCs according to [1] shall be used.

During LIFES50+ project, a subset of DLCs has been selected for a first evaluation of the feasibility of the concepts. These DLCs are presented in Table 22, with the additional ALS cases in Table 23.

For normal production cases (DLC 1.1 and 1.2), the following should be applied:

- According to the standards, the simulations should be at least 3 hours for ULS analysis. This could be avoided showing with sensitivity analysis that the extreme loads are not governed by this DLC. Lower lengths can be used for fatigue analysis (1 hr or lower, depending on sensitivity) and power performance
- A wind speed bin of 2 m/s is recommended for the analysis. For DLC 1.2, the width of the bin according to Table 21 can be used.
- At least 3 seeds per wind speeds should be used

For the DLCs dealing with deterministic gusts (DLC 1.4 and 2.3), the gust periods and amplitudes shall be calculated according to Section 7.3. The sensitivity of the specific platform design to the gust periods shall be considered in the analysis as described in [2], Section 3, §2.2.9 to 2.2.11:

- For ECD (DLC 1.4), the amplitude of the gust may be considered as defined in IEC-61400-1, [6]. In addition to the period prescribed in IEC-61400-1, the most relevant platform periods shall be considered, e.g. yaw periods for platforms with relatively high frequency yaw response and law yaw damping.

- For EOG (DLC 2.3), the same considerations above apply. In addition, also the amplitude of the gust has to be calculated depending on the gust period, see equation in DNV-OS-J103, [2], Section 3, §2.2.10. This DLC also includes a grid failure. The timing of the grid failure has to be changed with respect to the start of the gust, in order to include in the analysis the most conservative case.

For DLC 1.6, a limited number of wind speeds may be selected depending on the wind turbine operational parameters, e.g. cut-out, rated and two wind speeds depending on the WT operation and concept periods. At least 3 seeds per wind speed shall be considered. The simulation length should be 3 hours.

For DLC 6.1 and 6.2 the same external conditions can be used for the setup of both idling cases, with the exception of the wind direction and the safety factor. At least 3 seeds per wind speed shall be considered. The simulation length should be 3-hours.

For the evaluation of DLC 6.2 a sensitivity analysis can be carried out before hand, to evaluate the most severe yaw error and reduce the number of simulations. The worst wind direction may be different for different components.

8.6 Sensitivity analysis to be run

For the certification of a commercial offshore wind farm project, the full list of DLC table, according to [2]. Possible deviations shall be motivated with analysis and sensitivity studies.

Sensitivity studies can be used to:

- Ensure that the right combination of stochastic parameters and external conditions is considered for the given return period

- Justify assumptions and simplifications in the analysis, showing that the selected methodology is conservative for the design
- Extend the validity of the preliminary analysis to later stage of the design

A list of sensitivity analysis is reported in the next section. These analyses are meant to be performed in combination with the subset of DLCs in Table 22 and Table 23.

Sensitivity analysis shall also be performed when assumptions are made during the design that cannot be justified with other argumentations, e.g. when simplifications in the model are used.

8.6.1 Sensitivity analysis for ULS

The effect of the following parameters shall be considered

- Misalignment (if not assessed in the DLCs setup)
- Wave peak period/height (depending on the concept)
- Swell (if relevant)
- Mooring line orientation, with respect to wave direction
- Wind direction, with respect to the platform orientation
- Water depth (if not included in the DLCs setup)
- Gusts and periods, e.g. evaluation of EOG in DLC 2.3
- Currents (if not included in the DLC setup)
- Ice, marine growth or any other factor relevant for the site under investigation but not included in the DLC setup

8.6.2 Sensitivity analysis for FLS

The effect of the following parameters shall be considered

- Misalignment
- Wind direction, with respect to the platform orientation
- Ice, marine growth or any other factor relevant for the site under investigation but not included in the DLC setup.

9 Transportation, Installation, and Commissioning methodology/ plans

Transportation, installation and commissioning methodology/ plans regarding the wind turbine and the floater system will be considered in a later stage of the project and should be described before the concept evaluation phase.

10 Operation and maintenance plans

Operation and maintenance for the concepts will be considered in a later stage of the project and should be described before the concept evaluation phase.

11 References

[1] DNV-OS-J101:2014-05, Design of Offshore Wind Turbine Structures

[2] DNV-OS-J103:2013-06, Design of Floating Wind Turbine Structures

[3] LIFES50+ Deliverable 2.1, General considerations for evaluation procedures

[4] DNVGL-OS-E301:2015-07, Position Mooring

[5] DNVGL-OS-E302:2015-07, Offshore Mooring Chain

[6] DNVGL-OS-E303:2015-07, Offshore Fibre Ropes

[7] DNVGL-OS-E304:2015-07, Offshore Mooring Steel Wire Ropes

[8] Description of the DTU 10 MW Reference Wind Turbine, DTU Wind Energy Report-I-0092, July 2013

[9] IEC 61400-1:2005, Wind turbines – Part 1: Design Requirements, incl. Amendment:2010

[10] DNV-RP-C205:2014-04, Environmental Conditions and Environmental Loads

[11] IEC 61400-3:2009, Wind turbines – Part 3: Design Requirements for Offshore Wind Turbines

[12] LIFES50+ Deliverable 1.1, Oceanographic and meteorological conditions for the design

[13] Ideol report M01-2015-08-14-TCH, LIFEs50+ Fatigue analysis method proposal

[14] LIFES50+ D4.4, Overview of the numerical models used in the consortium and their qualification

Annex A BACKGROUND INFORMATION ON SITE CONDITIONS

Objective

This appendix includes the background information from “LIFES50+ Deliverable 1.1, Oceanographic and meteorological conditions for the design” used for the Design Basis.

A-1 Site A: Moderate environmental conditions

This section is not a site assessment. Instead, the objective here is to provide realistic design parameters for the reduced set of design load cases presented in the design basis, for the design and evaluation of innovative floating wind turbine concepts. Environmental parameters at Site A are to allow the evaluation of innovative concepts for floating offshore wind turbine platforms when deployed in areas with good wind resource and relatively benign storm wind and waves.

Site A could be quite generic to comply with the objectives of LIFES50+, but in order to ensure realism and coherency between the different environmental parameters in the design load cases, site-specific met-ocean data is taken from a real area. For Site A, this area is some 30 km offshore, south of Fos sur Mer, in the Département des bouches du Rhône, France. More details on this site and its selection procedure can be found in LIFES50+ Deliverable D1.1: Meteorological and Oceanographic Conditions for the Design [A1]. Figure 12, reproduced from that report, shows the approximate location of the area considered.

A-1.1 Data and information sources

The data and information sources available to this study of environmental parameters for Site A have been presented in LIFES50+ Deliverable D1.1 [A1] . A number of valuable datasets have been obtained in the last weeks of this study, including buoy records and high resolution wave propagation model outputs in the area. These will be presented in detail in the relevant sections herein.

A-1.2 General met-ocean information

The information provided in this section completes that provided in D1.1 [A1]. Information provided in [A1] is not repeated here.

A-1.2.1 Wind

A-1.2.1.1 Average wind speed at hub height: 11 m/s

There are no *in situ* measurements of wind speed available within the area considered for Site A. Published reanalysis data and global and meso-scale modelling results are compiled in Table 24. Except for the study of the European Environment Agency [A2], all the studies indicate highly favourable conditions for wind energy projects in this part of Southern France, with annual average wind speeds at 120 m above 10 m/s.

However, global or mesoscale models have insufficient resolution to represent air motion over the complex topography in the area, and in general winds are less well modelled near coastlines. In addition at Site A the wind resource is dominated by the contribution of the Mistral, a local orographic wind descending over complex terrain in the Rhône valley and modified by strong thermal effects as it blows over the warm waters of the Golfe du Lion (e.g. [A3]). It is thus important to evaluate what information can be obtained from available wind observations in the vicinity.

The data obtained by CEREMA for the Candhis buoy deployed near Site A do not include wind measurements. The closest available records of wind measurements in the area are, onshore, those of the Marignane automatic weather station (WMO ID: 07650, 43°26'16"N, 5°12'58"E, elev. 32 m), and, offshore, those of the Lion buoy (WMO:61002, 42.0392N, 4.68283E, moored at 2300 m). Both are freely distributed online by Météo France. Figure 12 shows the location of these measurements relative to the location of Site A.

For Marignane AWS, 3-hourly records are available with excellent coverage from 1996 onward, while at Lion Buoy, hourly records are available with good coverage from 2002 onward. Figure 13 shows the monthly average values of the 10-minute mean wind speed from observations at Marignane AWS and Lion buoy, at 10 metres and extrapolated to hub height with the Normal Wind Profile (NWP) defined in Section A-1.3.1.1.1. The seasonal cycle at Lion buoy is very pronounced, with an amplitude almost half of the mean value, while at Marignane AWS monthly means are quite consistent throughout the year. Year to year variability is relatively small at both locations (Figure 14). A slight trend towards long-term decrease is apparent in the yearly means at Marignane, but this may simply reflect changes in surrounding terrain in this relatively urbanised area.

Source	Information available in study	Inferred wind at 120 m
ADEME (2014)	> 9 m/s at 50 m in this coastal area	> 10 m/s
Cosseron et al. [A3]	≈7 m/s at 10 m offshore in the area	≈ 10 m/s
EEA [A2]	≈8 m/s at 80 m in this coastal area	≈ 8.5 m/s
Arent et al. (2012)	≈11 m/s at 90 m offshore in this area	≈ 11.5 m/s
Troen and Petersen (1989)	> 9 m/s at 50 m in this coastal area	> 10 m/s

Estimates of average wind speed at Site A inferred from published results. The figures are read off low resolution maps and may have limited precision. The wind at hub height is extrapolated with the normal wind profile (see Section A-1.3.1.1.1). References not in the text: ADEME (2014): l'énergie éolienne (available from ademe.fr) ; Arent et al. (2012): report available at www.nrel.gov/docs/fy13osti/55049.pdf (last accessed 2015/11/02) ; Troen and Petersen (1989): European Wind Atlas, available at orbit.dtu.dk/files/112135732/European_Wind_Atlas.pdf (last accessed 2015/11/02).

Table 24: Average Wind Speed at Site A from Published Results

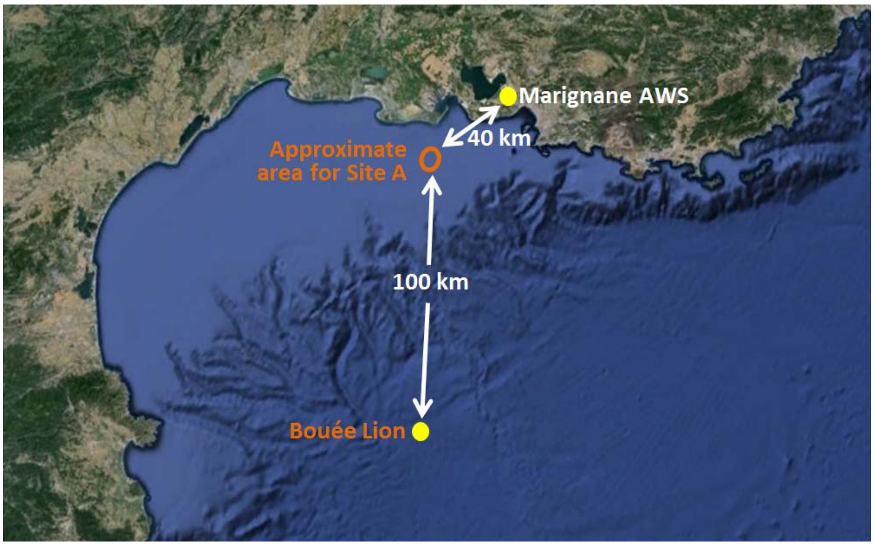
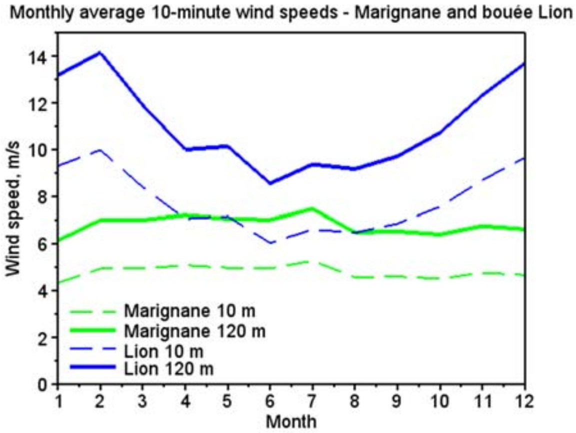


Figure 12: Location of Lion Buoy and Marignane Weather Station

The long-term average of the 10-minute mean wind speed at hub height, obtained correcting uneven sampling of the seasonal cycle, are, for Marignane: 4.82 m/s at 10 m and 6.82 m/s at 120 m above ground level, and for Lion buoy: 7.83 m/s at 10 m and 11.09 m/s at 120 m above sea level. It could be expected that the offshore buoy would have higher average wind speed. Nonetheless, the values at Marignane seem surprisingly low for an area generally seen as quite favourable for the development of wind projects, and is well below the range of estimates of published results in Table 24. There are apparent complications with the use of this record such as low resolution in velocity values. Information on the surrounding terrain and other specificities for this weather station should be checked before using its data. Until further information is available concerning the record of wind measurements at Marignane AWS, the data is not considered for the evaluation of average wind speed and wind speed distribution for Site A.

Lion buoy is 100 km south of Site A and average wind velocity there may be higher than at Site A. There is no *in situ* information to evaluate any possible differences. Reanalysis results presented in Table 24 differ, with MERRA reanalysis presented in [A3] suggested slightly lower average wind speed at Site A than near Lion buoy, while Blended Sea Winds presented in [A4] suggest the contrary. At any rate, the average wind speed estimated from the record there is within the range of the published results compiled in Table 24. As there is no information to quantify how much lower wind



Monthly average of 10-minute mean wind velocities recorded at Marignane (thin dashed green) and extrapolated to the hub height of 120 m above sea level (thick green) and from Lion buoy (thin dashed blue) and extrapolated to hub height (thick blue). Extrapolation to hub height is assuming the Normal Wind Profile (Section A-1.3.1.1.1).

Figure 13: Monthly Average Wind Speed at Hub Height, Marignane AWS and Lion buoy

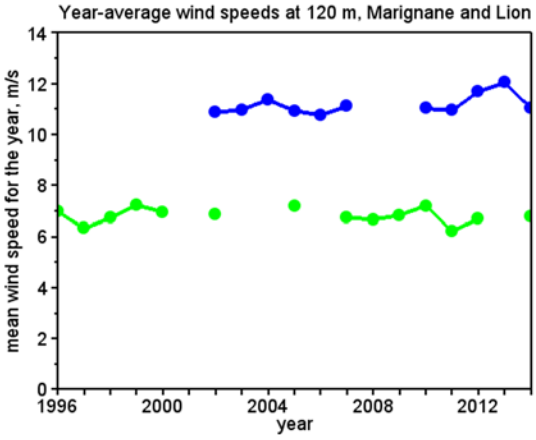
speed should be at Site A, it is proposed to use the Lion record to characterise the long-term average of the 10-minute mean wind speed value at hub height (120 m) for Site A as:

$$v_{\mathrm{ave}} = 11\ \mathrm{m/s} \tag{1}$$

In earlier discussions within LIFES50+ WP1, the view was expressed that for deployment scenarios in LIFES50+ it may be preferable to use values of v_{ave} lower than 10 m/s in order to stay within standard wind turbine classes. Manufacturers may lack interest in producing turbines outside of these classes due to limited market size. $v_{ave} = 10\ \mathrm{m/s}$ could be an acceptable approximation for Site A as well, although it is not what the best interpretation of available information would lead to.

In any case the distinction should be clearly made between

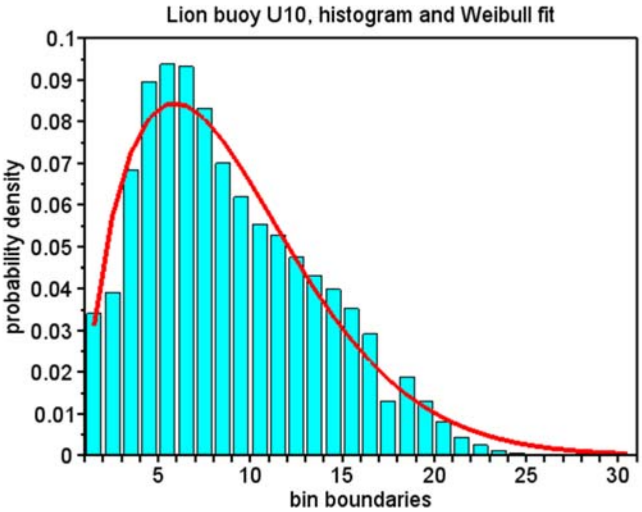
- v_{ave} as the expected value of the long-term average of the10-minute wind speed for a particular site, and
- the annual average wind speed for wind turbine *design according to classes*, which as per IEC61400-1:2005, Equation (9), is defined as $V_{\mathrm{ave}} = 0.2\, V_{\mathrm{ref}}$, where V_{ref} is 50, 42.5 and 37.5 m/s for wind turbine classes I, II and III respectively. This defines V_{ave} from V_{ref} which depends on extremes values and has no relevance to average values.



Yearly average of 10-minute mean recorded at Marignane (green) and Lion buoy (blue) extrapolated to 120 m above ground/sea level, for those years where the seasonal cycle is sufficiently sampled. Extrapolation to hub height is assuming the normal wind profile of Section A-1.3.1.1.1.

Figure 14: Interannual Variability in Wind Speed, Marignane AWS and Lion buoy

Site A is characterised by low extreme (see Section A-1.3.1.5) and high average 10-minute wind speed. This is excellent for the cost of energy but results in a large discrepancy between the actual average wind speed and V_{ave} as defined from V_{ref} in IEC61400-1:2005 Equation (9). With 50-year return level at hub height of 37 m/s, Site A would be Class III for the references wind speed, whereas the average wind speed is beyond that of Class I. The decision is made not to curtail to 10 m/s the excellent resource data at Site A, and propose deployment scenarios in LIFES50+ for Site A with $v_{\mathrm{ave}} = 11\ \mathrm{m/s}$.



Probability density function of 10-minute mean wind speed at 10 m in the record of measurements at Lion buoy. Uneven sampling of the seasonal cycle has been corrected by first obtaining monthly probability density functions. Best fitting Weibull is obtained for scale parameter of c = 9 and shape parameter k = 1.6.

Figure 15: Histogram and Weibull fit of Wind Speed at Lion Buoy

A-1.2.1.2 Wind speed distribution: Weibull c=9, k=1.6

Wind speed distribution is not directly used for design but is essential for the cost of energy calculations within LIFES50+/WP2. As discussed in the previous section, the best information available on the mean wind conditions at Site A is provided by the record of wind measured at the Lion buoy.

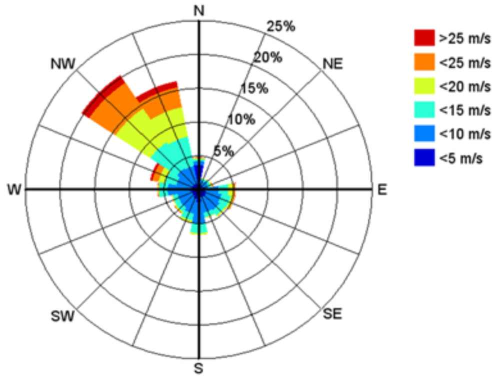
Figure 15 shows the probability density function of 10-minute mean wind speeds measured at the Lion buoy. In order to correct the effect of uneven sampling of the seasonal cycle, the monthly probability distributions were obtained first and combined to get the annual probabilities. The best fitting Weibull distribution has scale parameter $c = 9$ and shape parameter $k = 1.6$. It is apparent that the wind distribution at Site A is not very well fitted by a Weibull distribution, but not so much to justify the use of more complicated distributions such as bi-modal Weibull (e.g. [A5]). Although it is difficult to compare with much precision, no apparent disagreement is found with earlier reports on wind speed distribution from Bouin [A6] and Ruti et al. [A7].

A-1.2.1.3 Wind rose: NW and NNW prevailing

Figure 16 shows the wind rose from the Lion buoy record, with wind speeds extrapolated to their 120 m value with the normal wind profile (Section A-1.3.1.1.1). The prevailing NW and NNW pattern is very pronounced, with over 1/3 of all records within the NW and NNW sectors and nearly all wind over 20 m/s blowing from those sectors.

There are uncertainties as to how representative this would be of the wind conditions at Site A. Lion Buoy is in a location where rather than the Mistral, the Tramontane may be expected to be the prevailing wind. This is another orographic wind which shares some characteristics with the Mistral, but which could be expected to blow slightly more from the West.

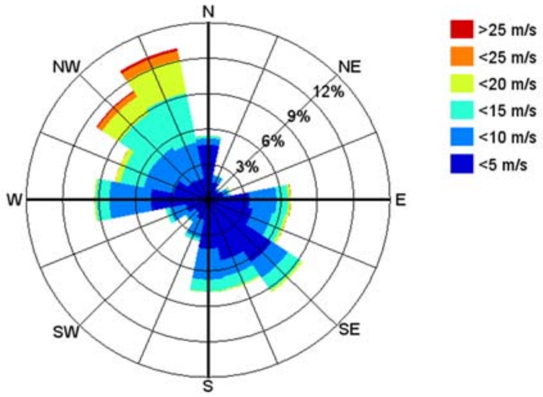
As mentioned earlier the wind speed record from the closer Marignane AWS should be used with caution until more information is obtained on this station, but it is still worth examining the wind direction data available there. Figure 17 shows the wind rose extrapolated to 120 m from the Marignane record. Although NW and NNW winds are still prevailing, this is less pronounced than at Lion buoy, with a non-negligible frequency of southeasterly winds. However, in episodes of wind speed over 20 m/s, the dominance of NW and NNW sectors is very marked there also.



Wind rose at 120 m, Lion buoy record corrected for uneven sampling of the seasonal cycle and extrapolated to 120 m with the normal wind profile (Section A-1.3.1.1.1).

Figure 16: Wind Rose at Lion Buoy

The wind rose at Site A can be expected to have characteristics in between those of Lion Buoy and Marignane AWS. However, as it is sufficient for the purpose of realistic deployment scenario for Site A, it is proposed to simply use the wind rose from Lion Buoy as data quality there can be expected to be higher.



Wind rose at 120 m above ground, Marignane AWS record corrected for uneven sampling of the seasonal cycle and extrapolated to 120 m with the normal wind profile (Section A-1.3.1.1.1).

Figure 17: Wind Rose at Marignane

A-1.3 Proposed load case parameters

A-1.3.1 Wind conditions

A-1.3.1.1 Wind profile

A-1.3.1.1.1 Normal Wind Profile (NWP): power law, exponent 0.14

No site-specific information on the profile mean wind speed at Site A is available at time of writing. For the profile of the (10-minute mean) wind speed during normal operating conditions, reference is made to IEC61400-3:2009/6.3, Equation (3) and the guidance note in DNV-OS-J101:2014-05/3.2.5.2. The Normal Wind Profile (NWP) is defined therein such that the 10-minute mean wind speed at height z above sea-level relates to the 10-minute mean wind speed at height h as follows:

$$U_{10\mathrm{min}}(z) = U_{10\mathrm{min}}(h) \times (z/h)^{0.14} \qquad \mathbf{(2)}$$

Equation **(2)** is the suggested NWP for Site A.

A-1.3.1.1.2 Extreme Wind Profile: power law, exponent 0.11

Parameters for load cases in extreme conditions for Site A including the recommended profile of the 10-minute mean wind speed for with a recurrence period of 50 years were presented in LIFES50+ deliverable D1.1 – Meteorological and Oceanographic Conditions for the Design [A1]. As per IEC61400-1/6.3.2.1 and IEC61400-3/6.3, for Site A the extreme 10-minute mean wind speed with return periods in excess of 50 years follows a power law profile with exponent of 0.11:

$$U_{10\mathrm{min,50years}}(z) = U_{10\mathrm{min,50\,years}}(h) \times \left(\frac{z}{h}\right)^{0.11} \qquad \mathbf{(3)}$$

It is worth mentioning that for the 50-year return level at Site A (37 m/s at the hub height of 120 m), the resulting profile is very similar to the Frøya profile recommended for extreme wind speeds in the North Sea in DNV-OS-J101:2014-05/3.2.3.3 or DNV-RP-C205/2.3.2.12. LIFES50+ D1.1 [A1] can be consulted for more details.

A-1.3.1.2 Normal turbulence model (NTM): IEC Class C

Following the discussions of consortium partners involved in this work package, until more site-specific information is available that indicate otherwise, the Normal Turbulence Model (NTM) for Site A is based on IEC61400-1:2005 Class C. This is a turbulence model initially conceived for onshore wind turbines, though the least turbulent of the three standards IEC classes, so presumably the most appropriate offshore. For the moment, ambient turbulence generated by other turbines in an offshore wind farm scenario is ignored. This may be revisited once layout options are decided upon.

As per IEC61400-1:2005/6.3.1.3 Equation (11), or DNV-OS-J101:2015-5/3.2.5.3, in NTM the representative value of the turbulence standard deviation σ_1 in IEC notation (or the characteristic standard deviation of wind speed $\sigma_{U,c}$ in DNV GL standards), defined as the 90th centile of probability distribution of the standard deviation of wind speed σ_U, conditioned on the 10-minute mean wind speed at hub height, is given by:

$$\sigma_{U,c} = I_{\mathrm{ref}}\left(0.75\, U_{\mathrm{hub,10\,min}} + b\,\right); \quad b = 5.6\ \mathrm{m/s} \qquad \mathbf{(4)}$$

where for Class C wind turbines, $I_{\mathrm{ref}} = 0.12$. I_{ref} is the mean value of the turbulence intensity for $U_{\mathrm{hub,10\,min}} = 15\ \mathrm{m/s}$.

It is noted here that recent design practice for offshore wind turbines usually avoids the use of onshore turbulence classes, except for the design of the rotor and nacelle assembly, and instead makes use of specific offshore turbulence characteristics (e.g. [A8], [A9]). This is usually less conservative than onshore Class C.

For southerly winds it seems reasonable to assume that turbulence characteristics at Site A will be similar to those reported for corresponding met-ocean conditions in other offshore locations. This may not be so for northerly winds, the main resource and perhaps main driver of turbine fatigue at Site A. The Mistral and Tramontane winds reach the Golfe du Lion after rapid descent of complex terrain that may be expected to generate energetic eddies. There is anecdotic evidence from sailing experience that wind is occasionally very gusty a considerable distance offshore Marseilles.

A-1.3.1.2.1 Turbulence information from gust factors at Site A: very limited

This section reports on the analysis of gust data onshore to obtain information on turbulence levels in northerly winds at Site A – with limited success. Neither mast nor remote sensing (Lidar or Sodar) measurements are available on Site A. 10 meter's wind measurements are 30-40 km away, and only hourly records are available so that turbulence intensity cannot be obtained directly.

Gust factors, the ratio of maximum gust speed over the mean wind speed over given time intervals, are related to turbulence intensity (e.g. [A10]), and various authors have developed theoretical and empirical relationships relating the two ([A11], [A12]). Unlike turbulence intensity, the ratio of the maximum 3-second gust to the 10-minute mean wind speed is often available in the record of Automatic Weather Stations (AWS) and buoys operated by national weather services and port authorities.

Publicly available records of observation from the Lion buoy, the nearest offshore buoy taking wind measurements, do not include gust factors. The Candhis buoy deployed closer to Site A do not have wind records. However, the record distributed online by Météo France of wind measurements at Marignane AWS (WMO ID: 07650, 43°26'16"N, 5°12'58"E, elev. 32 m, see Figure 19 for a map), near the coast some 40 km northeast of Site A, does include some gust information from 2004 onward, although it is rather sparse - 1525 records out of a total 56384 records since 1996. Starting September 2015 gust factors are well recorded and thus better information may be obtained in the next few months.

There are significant uncertainties associated with the use of the record of gust factors at Marignane AWS to inform on turbulence conditions at Site A, including the possibility of uneven sampling in the sparse record, the rate of decrease of turbulence with distance offshore (Site A is some 30 km offshore) and the possibility that gust factors at the Marignane AWS are dominated by local effects that differ from those on other parts of the coastline that would more strongly influence northerly winds reaching Site A. It is nonetheless worth investigating as it is the only potential source of information on turbulence in the area available at this point.

Figure 18 plots the reported 3-seconds gusts against concurrent 10-minute mean wind speed at 10 m above ground level at Marignane AWS. Only records with northerly winds (between 275° and 45°) are included – but these represent the bulk of the available data. Gust factors typically fall within the interval 1.25 to 1.7, although on rare occasions it is significantly higher, reaching values of 2 or more. The best fit (in the least square sense) is for an average gust factor of 1.45. It should be noted that this least square fit will give small weight to errors on low wind speed data points, so that this gust factor should be considered representative of the data only for wind speeds above some 5 m/s.

There are various ways to relate gust factors to turbulence intensity. It is possible to derive expressions starting from an assumption for the turbulence spectrum, but a widely used empirical expression ([A12], as reported in [A10]) is:

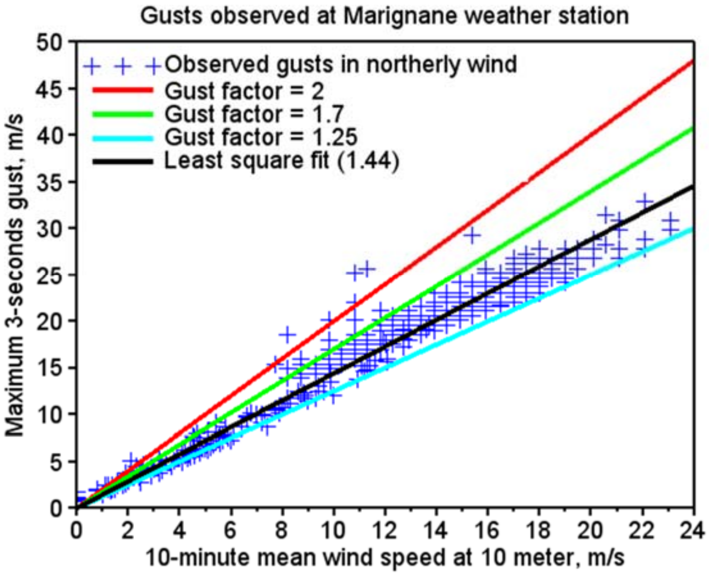
$$G(t) = 1 + 0.42 I_u \ln\left(\frac{3600}{t}\right) \quad \textbf{(5)}$$

where $\mathrm{I_u}$ is the longitudinal turbulence intensity, and $\mathrm{G(t)}$ is the gust factor for a gust duration of t seconds. Other similar relationships include that reported by Harstveit [A11] for gust durations of 2-5 seconds in exposed, inhomogeneous hilly terrain in Norway:

$$G(t) = 1 + \frac{I_u}{0.4 \pm 0.05} \quad \textbf{(6)}$$

For 3-seconds gusts, (5) becomes $I_u = 0.34\,(G-1)$. The gust factors usually reported at Marignane AWS then relate to turbulence intensities at 10 meter above ground between 8.5% to 24% for the commonly observed range of 1.25 to 1.7, with a best fit value of 15.3%. The range is very similar applying (6).

There are further uncertainties on what this implies for turbulence intensities at hub height (120 m). Onshore I_u is reported [A13] to decrease 10-30% between near surface measurements to 100 m. Reports for offshore turbulence suggesting more rapid decrease with height [A14]. Alternatively, gust factors can be converted to different heights with certain assumptions for wind and terrain characteristics. For example, applying Table 2.1.4.3.1 in [A15] converts the best fit gust factor of 1.45 to 1.34 at 100 m height, which in turn with Equation (5) converts to 12% turbulence intensity at 100 m height. Further decrease is expected to hub height.



Gust Factors (GF, the ratio of maximum 3-seconds mean wind speed to the 10-minute mean wind speed) recorded at Marignane weather station for northerly winds (direction between 275° and 45°), on the coast some 40 km northeast of Site A. Also indicated are the lines corresponding to $GF = 2$, 1.7, 1.25 and least square fit ($GF = 1.45$).

Figure 18: Gust Factors at Marignane Automatic Weather Station

Finally, how these inform the turbulence characteristics some 30 km offshore is subject to significant further uncertainties. Decrease in turbulence intensity offshore is reported for Vindeby data [A14], ranging for some 20% after a 30 km fetch for 10 m height values, to some 30% after the same fetch for the values at 50 m. Without any other information, one can only assume similar decrease in turbulence intensity for northerly winds reaching Site A. This last link in this increasingly weak chain of surmises would lead to turbulence intensities of less than 10% at Site A – again, as mentioned earlier, because of the method used for least square fitting of gust factor, this would may not apply to very low wind speeds.

In conclusion: turbulence information is near-inexistent for Site A. The gust factor data available in the area is sparse, distant, onshore and only available near the surface. Examination of this limited record, however, suggests that turbulence levels in the coastal area is not so high that northerly wind at hub height at Site A would have turbulence intensities above 10% even at low wind speeds.

A-1.3.1.3 Extreme Operating Gust (EOG): use resonance period duration

The Extreme Operating Gust (EOG) is to be used in Design Load Case (DLC) 2.3a in the reduced load case table provided in the design basis, in power production with occurrence of fault such as loss of electrical network.

IEC61400-3:2009/7.4.2 describes this DLC, while the velocity profile and time series of the EOG is specified in IEC61400-1:2005/6.3.2.2 or DNV-OS-J101/2014-05/3.2.5.5. However, these are focused on fixed offshore turbine applications and specify gust duration of 10.5 seconds. To account for the possibility of resonant response for a floating structure and mooring ensemble, which have longer eigen periods typically in the range of 10-100 seconds, following DNV-OS-J103/2.2.9-2.2.10 longer gusts with durations close to these eigen periods is recommended for the evaluation of LIFES50+ floating platform concepts at Site A.

A-1.3.1.4 Extreme coherent gust with direction change (ECD)

Extreme Coherent gust with Direction change (ECD) is used in DLC1.4 in the reduced load case table of this design basis, as a load case in power production. Reference is made to IEC61400:2005/6.3.2.1 and DNV-OS-J101:2014-05/3.2.5.8 for the specification of ECD. There is no site-specific information for Site A that would indicate a different specification for ECD than those in these standards.

A-1.3.1.5 Extreme wind speed (EWM) at hub height: 37 m/s

The table of reduced Design Load Cases (DLC) of this design basis uses the Extreme Wind speed Model (EWM) for the two load cases in parked mode, DLC 6.1 and 6.2. Both are to use the turbulent EWM (not to be confused with Extreme Turbulent Model ETM). As per IEC61400-1:2005/6.3.2.1 and DNV-OS-J101:2014-05/3.2.5.4, the turbulent EWM makes use of the 50-year return level of the 10-minute mean wind speed at hub height, which was specified in [A1] based on published results for the vicinity of Site A. Thus,

$$U_{\text{hub,EWM}} = U_{\text{hub,10 min,50 years}} = 37\ \text{m/s} \tag{7}$$

As discussed in Section A-1.3.1.1.2, the profile of 10-min mean wind speed during the 50-year storm is to follow a power law profile with exponent of 0.11. EWM represents turbulent wind speeds with a characteristic standard deviation which in the aforementioned standards sections is specified as from the 10-minute mean wind speed at hub height (here 120 m):

$$\sigma_{U,c,EWM} = 0.11\ U_{\text{10 min,hub,EWM}} = 4.1\ \text{m/s} \tag{8}$$

A-1.3.2 Wave conditions

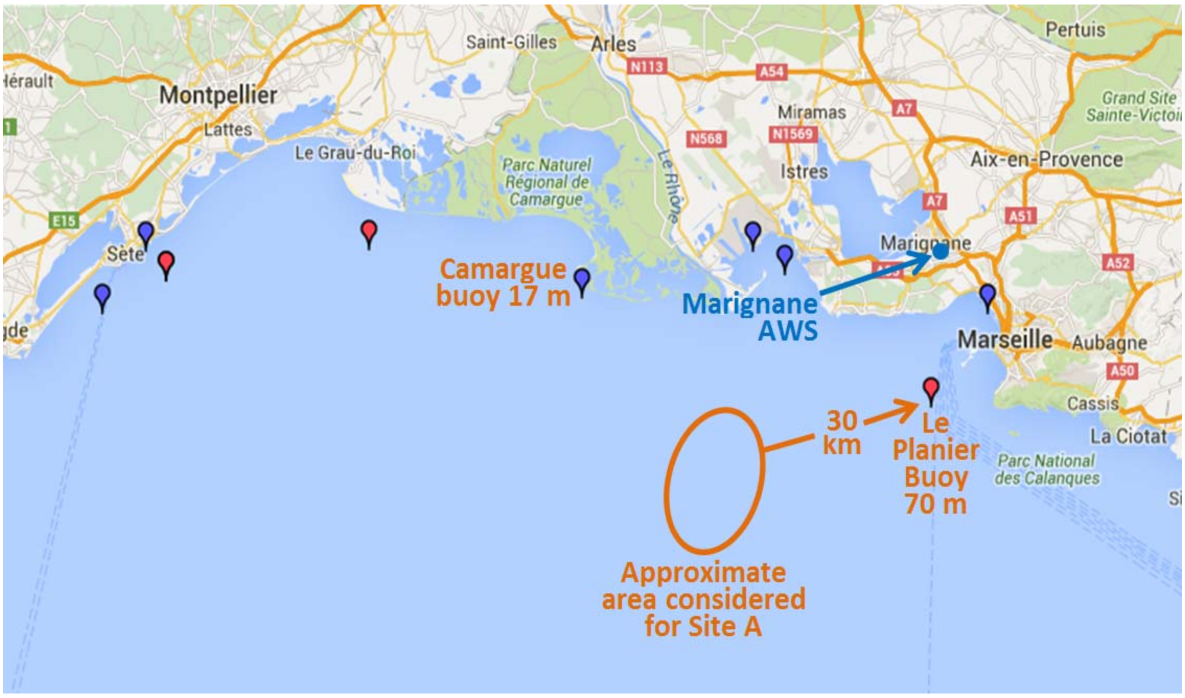
A-1.3.2.1 Normal sea-state (NSS)

Cerema – DTecEMF graciously provided this project with data from Candhis buoys deployed in the area. Because of a deployment depth similar to the depth set for the deployment scenario for site A (70 m), the observations from Le Planier Buoy (43°12.5'N, 5°13.8'E, depth: 70 m) are selected as the most representative of conditions in Site A. An hourly record of sea-states spanning the period from January 2011 to June 2015, with excellent temporal coverage, is available for this analysis. Figure 19 shows the location of the buoys together with approximate location of Site A.

A-1.3.2.1.1 Scatter diagram for all wind speeds

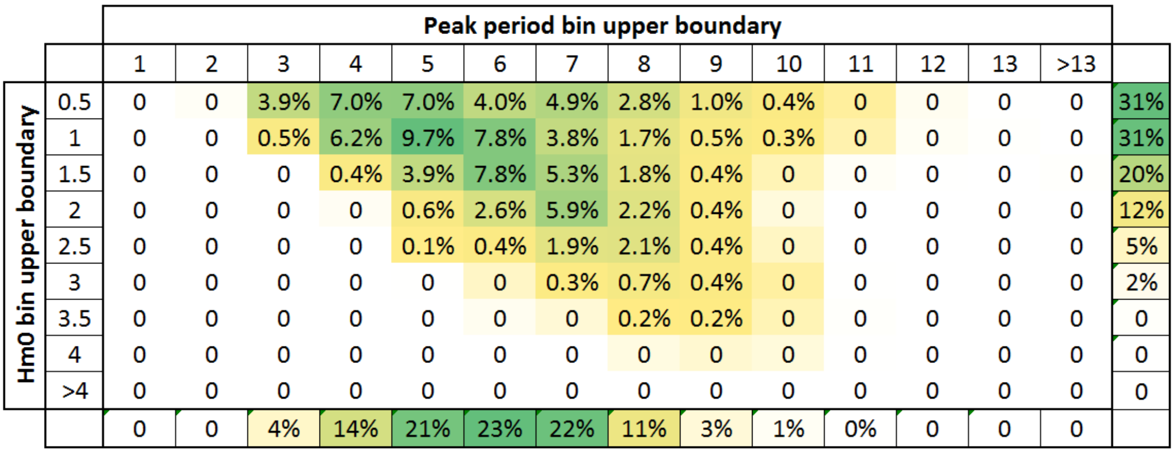
The joint probability distribution of spectral significant wave heights (H_{m0}) and peak periods (T_p) in the Le Planier buoy record is shown in Figure 20. To correct for uneven representation in the data record of different times of the year, the monthly statistics were calculated first and combined to obtain the yearly averaged values.

The most common sea-state has H_{m0} between 0.5 and 1 metre, and peak period between 4 and 5 seconds. H_{m0} is higher than 2 m only 7% of the time. The peak period is between 5 and 6 seconds 23% of the time and becomes longer for stormier seas, with the most common range being 8 to 9 seconds for seas with H_{m0} over 3.5 metres. These results are very similar to published results in the area including those made available by Cerema – DTecEMF on the Candhis website.



Approximate location of the area considered for Site A, Le Planier and Camargue Candhis buoy, and Marignane Automatic Weather Station. Also indicated are the depths of deployment of the buoys. Figure adapted from the map of Candhis buoy locations in the vicinity available from Cerema - DTecEMF.

Figure 19: Location of Candhis buoys and Marignane weather station



		Peak period bin upper boundary														
		1	2	3	4	5	6	7	8	9	10	11	12	13	>13	
Hm0 bin upper boundary	0.5	0	0	3.9%	7.0%	7.0%	4.0%	4.9%	2.8%	1.0%	0.4%	0	0	0	0	31%
	1	0	0	0.5%	6.2%	9.7%	7.8%	3.8%	1.7%	0.5%	0.3%	0	0	0	0	31%
	1.5	0	0	0	0.4%	3.9%	7.8%	5.3%	1.8%	0.4%	0	0	0	0	0	20%
	2	0	0	0	0	0.6%	2.6%	5.9%	2.2%	0.4%	0	0	0	0	0	12%
	2.5	0	0	0	0	0.1%	0.4%	1.9%	2.1%	0.4%	0	0	0	0	0	5%
	3	0	0	0	0	0	0	0.3%	0.7%	0.4%	0	0	0	0	0	2%
	3.5	0	0	0	0	0	0	0	0.2%	0.2%	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	>4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		0	0	4%	14%	21%	23%	22%	11%	3%	1%	0%	0	0	0	

Histogram of all-seasons joint probability distribution (scatter diagram) of spectral significant wave height (H_{m0}) and peak period (T_p) of the 4.5 years record at Le Planier buoy. The all-seasons probabilities are obtained by combining monthly statistics.

Figure 20: Scatter Diagram at Le Planier Candhis Buoy

A-1.3.2.1.2 Mean H_s for different wind speeds

As per IEC61400-3:2009/6.4.1.1, for ultimate load calculations such as those in Design Load Case 1.1 (DLC 1.1), the Normal Sea State (NSS) should be characterised by the expected value of the significant wave height conditioned on the 10-minute mean wind speed value. No site-specific information on the conditional distribution of metocean parameters within Site A is available. However, the Marignane automatic weather station (WMO ID: 07650, 43°26'16"N, 5°12'58"E, elev. 32 m) operated by Météo France is located some 20 km to the north of Le Planier buoy (40 km to the northeast of Site A). 3-hourly winds measured there from 1996 onward are distributed freely online by Météo France[4].

The wave data at Le Planier, 30 km away from Site A, may provide a reasonable approximation of the statistics at Site A. At 70 m, the depth of deployment of Le Planier buoy is the same as the depth set for Site A scenarios. On the other hand, as discussed in A-1.2.1.1, the wind speed data from Marignane AWS should be used with caution until further information is obtained on this record. The relationship with wave statistics at Le Planier is investigated nonetheless as this is the only available wind observations in this area available for the moment. An alternative that will have its own limitations (e.g. distance and depth) would be to use the joint statistics observed at Lion Buoy. This is not available at time of writing, but should Site A be selected as one of the site for fatigue studies, it can be provided to concept developers at a later stage.

There are 11796 valid concurrent observations at Marignane AWS and at Le Planier Candhis buoy, spanning the whole period covered by the Le Planier data provided by Cerema – DTecEMF (January 2011 to May 2015). The scatter plot of spectral significant wave height from Le Planier and wind speed observed at Marignane is shown in Figure 21. In order to facilitate their use in the design load cases, wind speeds observed at 10 m above ground level at Marignane are extrapolated to the hub height of 120 m above sea level with the normal wind profile presented in Section A-1.3.1.1.1. Also plotted are the mean value of H_{m0} for the corresponding wind speed, averaged over a ± 1 m/s range in order to reduce scatter, and a linear least square fit to these mean values. Table 25 provides the result-

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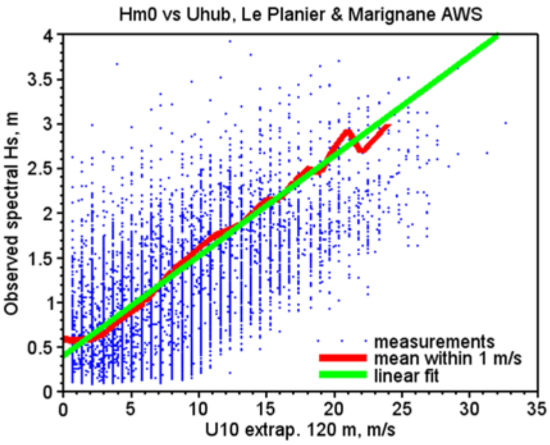
[4] https://donneespubliques.meteofrance.fr/?fond=produit&id_produit=90&id_rubrique=32. Last accessed 2015/10/16.

ing estimate of the expected value of significant wave height conditional on 10-minute mean wind speed at hub height, as well as the linear fit.



Spectral significant wave height (H_{m0}) from observations at the Le Planier buoy operated by Cerema-DTecEMF plotted against 10-minute mean wind speed measured concurrently at Marignane automatic weather station extrapolated to the hub-height of 120 with the normal wind profile (NWP), blue dots, average of H_{m0} for records taken when mean wind speed at Marignane (extrapolated to hub height) was within 1 m/s of the abscissa, red curve, and linear fit to this mean, green curve.

Figure 21: Scatter plot of H_s and U_{hub}

Perhaps partly due to the reduced number of independent observations at large wind speeds, the expected value of H_s estimated directly from averaging is non-monotonous at large wind speed. It may thus be preferable to work with the linearly fit to these mean values, defined in the following equation:

$$H_s = 0.11\, U_{\text{hub}} + 0.4 \tag{9}$$

A-1.3.2.1.3 Sea-states statistics for different wind speeds

As per IEC61400-3:2009/7.4.1, the fatigue load calculations in DLC 1.2 require the use of long term joint probability distributions of metocean parameters such as wave height, peak period, wave direction and water level together with the associated mean wind speed. As argued in the previous section, wind records from Météo France’s Marignane automatic weather station combined with the wave data from the Cerema-DTecEMF buoy deployed at Le Planier provide the best available information on such statistics at Site A, and should be an acceptable approximation for the purpose of providing realistic and coherent metocean parameters to evaluate the platform concepts in LIFES50+.

U_{hub}	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
mean H_s	0.6	0.6	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.4	2.5	2.5	2.7	2.9	2.7	2.8	3.0
Lin. fit	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.1

10-minute mean wind speed at hub height (U_{hub}, upper row), expected value of significant wave height conditional on U_{hub} estimated from the mean of observations (middle row), and from a linear fit to the mean as in Equation (9), lower row. The joint statistics are estimated from 4.5 years of concurrent data at Le Planier and Marignane. Until further information is available on the record from Marignane AWS, this data should be used with caution (see text for details).

Table 25: Site A expected value of significant wave height as function of hub height wind speed

Hm0 bin upper boundary (m)	Peak period bin upper boundary (s) - U_{hub} < 2 m/s, 1631 records													
	1	2	3	4	5	6	7	8	9	10	11	12	13	>13	
0.5	0	0.1%	5.9%	9.5%	11.2%	8.1%	8.4%	4.9%	2.7%	0.9%	0.2%	0	0	0	52%
1	0	0	0.6%	3.6%	7.7%	11.1%	6.9%	2.8%	1.3%	0.6%	0.1%	0	0	0	34%
1.5	0	0	0	0.1%	0.5%	3.2%	3.6%	2.5%	0.5%	0	0.1%	0	0	0	10%
2	0	0	0	0	0	0.1%	0.9%	1.3%	0.5%	0	0	0	0	0	3%
2.5	0	0	0	0	0	0	0.1%	0.2%	0.1%	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0.1%	0.1%	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	7%	13%	19%	22%	20%	12%	5%	2%	0%	0	0	0	

Hm0 bin upper boundary (m)	Peak period bin upper boundary (s) - 10 < Uhub < 12 m/s, 858 records													
	1	2	3	4	5	6	7	8	9	10	11	12	13	>13	
0.5	0	0	0.5%	1.5%	0.9%	0	0.4%	0.2%	0	0	0	0	0	0	4%
1	0	0	0.5%	9.3%	11.3%	3.8%	1.2%	0.3%	0	0	0	0.1%	0	0	27%
1.5	0	0	0	0.9%	8.5%	15.9%	5.9%	1.0%	0.4%	0.1%	0	0	0	0	33%
2	0	0	0	0	0.8%	6.3%	13.0%	5.2%	0.8%	0.1%	0	0	0	0	26%
2.5	0	0	0	0	0	0.1%	3.2%	4.9%	0.8%	0	0	0	0	0	9%
3	0	0	0	0	0	0	0.3%	0.8%	0.4%	0.1%	0	0	0	0	2%
3.5	0	0	0	0	0	0	0.1%	0	0.1%	0.1%	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0.1%	0	0	0	0	0
>4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	1%	12%	21%	26%	24%	12%	3%	1%	0	0%	0	0	

Hm0 bin upper boundary (m)	Peak period bin upper boundary (s) - 20 < Uhub < 25 m/s, 208 records													
	1	2	3	4	5	6	7	8	9	10	11	12	13	>13	
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5	0	0	0	0	1.3%	2.1%	0.4%	0	0	0	0	0	0	0	4%
2	0	0	0	0	5.1%	11.4%	13.9%	1.7%	0	0	0	0	0	0	32%
2.5	0	0	0	0	4.2%	10.1%	15.6%	9.3%	0	0	0	0	0	0	39%
3	0	0	0	0	0	0.8%	3.4%	6.8%	2.1%	0.8%	0	0	0	0	14%
3.5	0	0	0	0	0	0	0.8%	3.8%	3.8%	1.7%	0	0	0	0	10%
4	0	0	0	0	0	0	0	0.4%	0	0	0.4%	0	0	0	0
>4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	11%	24%	34%	22%	6%	3%	0%	0	0	0	

Spectral significant wave height (H_{m0}) and peak period (T_p) joint probability distribution, or (H_{m0},T_p) scatter diagram, obtained from Le Planier buoy and Marignane automatic weather station data, for hub height (120 m) wind speed below 2 m/s (upper table), between 10 and 12 m/s (middle table) and between 20 and 25 m/s (lower panel). These data provide the best available approximation to the join distribution of metocean parameters for Site A, but until further information is obtained on the Marignane AWS record, should be used with caution (see text for details).

Table 26: Site A Scatter Diagrams for Different Wind Speeds

As it is not practical neither for display in this report nor for manual entry to the DLC calculations, the joint statistics obtained from these data will be provided electronically to LIFES50+ concept developers. As illustration, the estimated (H_s, T_p) scatter diagrams for different ranges of wind speeds at hub height are shown in Table 26. The 10-minute mean, 10-meter above ground wind speeds measured at Marignane are extrapolated to hub height (120 m) with the normal wind profile (Section A-1.3.1.1.1). The increase in wave height with wind speed seen in Figure 21 is clearly visible in these tables, as well as an increase in peak period, the latter likely due to the larger contribution of distant-generated swell reaching Le Planier in storm conditions.

A-1.3.2.2 Severe sea-state and extreme sea-state (SSS, ESS)

The Severe Sea State (SSS) is used in Design Load Case (DLC) 1.6 in the reduced DLC table of this design basis, to evaluate ultimate loading during operation. Reference is made to IEC61400-3:2009/6.4.1.3 and DNV-OS-J101:2014-05/3.3.4.4. $H_{s,SSS}$ is specified there in as the significant wave height such that the load effect in combination with the 10-minute mean wind speed has a recurrence period of 50 years. At the moment such statistics are not available for Site A.

Both IEC and DNV accept as a conservative approximation the use of the unconditional 50 year return level of significant wave height, i.e. the significant wave height of the extreme sea-state $H_{s,ESS}$. The latter was set to 7.5 m in LIFES50+ D1.1 [A1]. Hence until further statistical information on the long term joint probability distributions of wind speeds and significant wave height become available, it is proposed that for Site A:

$$H_{s,SSS} \; = \; H_{s,ESS} = H_{s,50\text{ years}} = 7.5\text{ m} \qquad \textbf{(10)}$$

Note: at the moment there is no information for Site A to justify the use of lower extreme values when using three-hourly rather than hourly sea-states.

Peak wave period for such a sea-state may range between 8 and 11 seconds [A1], and following DNV-OS-J101:2014-05/3.3.4.4, DLC 1.6 should use the peak period within this range that result in the highest loads or load effects in the structure.

As per IEC61400-3:2005/6.4.1.5, the Extreme Sea State (ESS) is to consider both the extreme significant height with a recurrence period of 50 years ($H_{s,50\text{ years}}$) and that with a recurrence period of 1 year ($H_{s,1\text{ year}}$). However, the latter will not be used in the reduced load case table of this design basis, and hence due to time constraint is not specified here in this version of this report. Equation **(10)** specifies the 50 year significant wave height. For details on the methodology that was used to obtain this estimate, [A1] should be consulted.

A-1.3.3 Current conditions

A-1.3.3.1 Normal current model: 2% of hub wind speed

The Normal Current Model (NCM) is to be used in the load cases for power production and those for power production with fault in the reduced load case table of this design basis. As per IEC61400-3:2009/6.4.2.4, the normal current model is to include site-specific combination of wind generated currents and breaking wave induced currents associated with normal wave conditions. Due to depth and distance from the shore, wave induced currents at Site A can be neglected.

A-1.3.3.1.1 Surface current speed: 0.02 x hub wind speed

The wind-generated current for Site A, as per IEC61400-3:2009/6.4.2.2 or DNV-OS-J101:2014-05/3.4.3.1, is assumed to be proportional to the one-hour mean wind speed at 10 metres:

$$v_{wind\ generated}(z = 0) = k\, U_{10\text{ m},\ 1\text{ hour}} \qquad \textbf{(11)}$$

While IEC61400-3:2009 accepts $k = 0.01$, DNV-OS-J101/2014-05 recommends a more conservative range of k between 0.015 and 0.03. 0.03 is the value recommended for Site A, based on common practice in coastal oceanography.

In the mean regime (excluding storms with long return periods, see ECM for this case) the Normal Wind Profile (NWP, Section A-1.3.1.1.1) is used from which the 10-minute mean at 10-metre height is 0.71 times the 10-minute mean at hub height. A further correction is applied to convert the 10-minute mean to the 1-hour mean at metres height, which following the guidance note in DNV-OS-J101:2014-05/3.2.3.3 implies an additional factor of 0.92, thus:

$$U_{1\ \mathrm{hour},10\ \mathrm{m}} = 0.65\ U_{\mathrm{hub},\ \ 10\ \mathrm{min}} \qquad \textbf{(12)}$$

And finally

$$v_{wind\ generated}(z = 0) = \ 0.02\ U_{\mathrm{hub},10\ \mathrm{min}} \qquad \textbf{(13)}$$

A-1.3.3.1.2 Current profile: linear decrease to 50 m

As per IEC61400-3:2009/6.4.2.4 the wind-generated current velocity may be characterized by a linear profile decreasing to zero at 20 m depth. DNV-OS-J101:2014-05/3.4.3.1 recommends that when no field measurements are available, a linear profile decreasing to zero at the reference depth of 50 m be used. The latter is recommended for NCM at Site A.

A-1.3.3.2 Extreme Current Model (ECM): wind driven, 90 cm/s

The 50-year return level of the surface current speed at Site A is evaluated in LIFES50+1 Deliverable D1.1 [A1] as:

$$v_{c,50\ years}(0) = 90\ \mathrm{cm/s} \qquad \textbf{(14)}$$

As detailed in [A1], tidal currents being generally weak in this area, ECM is dominated by the wind-driven component. Hence, as for NCM, a linear profile can be assumed for the current velocity in ECM, with a linear decrease to 50 m (see Section A-1.3.3.1.2).

A-1.3.4 Sea-level

A-1.3.4.1 Normal Water Level Range (NWLR): -0.32 to +0.85 m

Reference is made to IEC61400-3:2009/6.4.3.1 for the definition of the Normal Water Level Range and to DNV-OS-J101:2014-05/3.5 for general definitions of the water level parameters. As per IEC, NWLR shall be assumed to be the variation in water level with a recurrence period of 1 year, and absent sufficient site-specific data, can be assumed to be equal to the tidal range i.e. the difference between the Highest Astronomical Tide (HAT) and the Lowest Astronomical Tide (LAT).

Tidal range is small in the Mediterranean except in a few bays and inlets. Tidal range alone is consequently insufficiently conservative to represent the 1-year return level of water level, the range of which is dominated by atmospheric effects. As for the 50-year return level, NLWR shall be proposed based on published results of extreme value analysis of the long-term record from the tide gauge in the port of Marseilles, some 40 km to the northeast of Site A. The complete list of references can be consulted in [A1]. CETMEF [A16] does not provide 1-year return levels and hence the water level changes reported by Pirazolli [A17] are used. However, reference levels are different in the [A16] and [A17] so to ensure consistency with the 50-year return levels, which were referenced to the analysis of CETMEF, results of the extreme value analysis of the joint probability distribution in [A17] must be translated 32 cm upwards. This yields the following 1-year return levels for Site A:

1-year high water level: +0.85 m **(15)**

1-year low water level: -0.32 m **(16)**

A-1.3.4.2 Extreme Water Level Range (EWLR): -0.35 to + 1.13

As detailed in LIFES50+ Deliverable D1.1 [A1], the Extreme Water Level Range (EWLR) for Site A is evaluated based on published studies of the long-term record of the tide gauge in the port of Marseilles. Tidal range is small in this part of the Mediterranean and the water level extremes are dominated by atmospheric effects. The Extreme High Water Level (EHWL) with a 50-year recurrence period is:

$$\mathrm{EHWL} = 1.13\ \mathrm{m} \tag{17}$$

The Extreme Low Water Level (ELWL) with a 50-year recurrence period is:

$$\mathrm{ELWL} = -0.35\ \mathrm{m} \tag{18}$$

[A1] can be consulted for more details.

A-2 Site B: Medium environmental conditions

This location has been selected to open the project to the incipient market of the renewables energies in the United States. Within the site selection process, this site was considered and selected as a "moderate site" in regard to the metocean conditions severity characterization.

A-2.1 Location

Selected site for the Gulf of Maine location is intended to be located at North Atlantic ocean, about 25 km at the southwest of Monhegan Island and 65 km east from Portland (the central point of the proposed site is placed at 43°33'22.4"N 69°27'08.7"W).

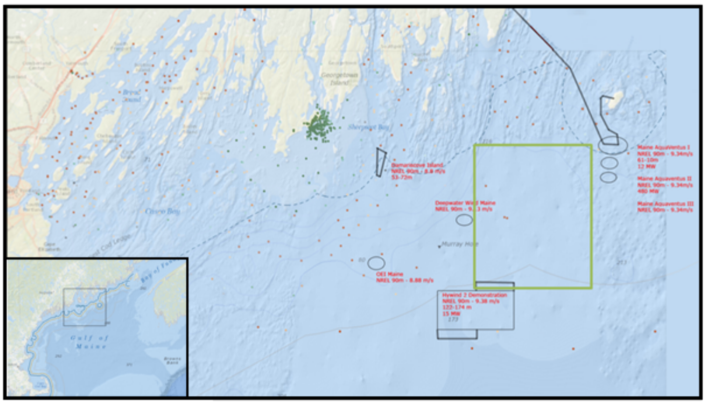


Figure 22: Gulf of Maine site location. Source [B1]

Close to the site, three different measurement buoys that are taken as reference for the site characterization. The location of each of the buoys is shown in the map below.

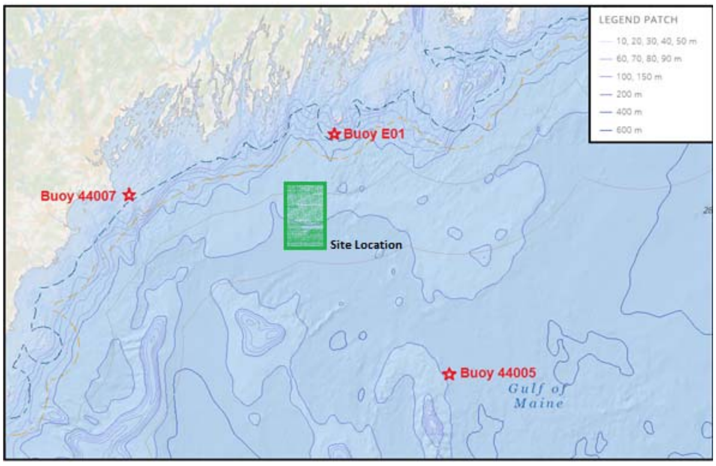


Figure 23: Reference buoys' position. Source [B1]

The **Buoy E01** has been selected as the main source of information because of its proximity to the selected site location. Information regarding to this buoy, so as the raw data resulting of its measurements since 2003 (relative to wind, waves and currents characteristics as well as other metocean characteristics of the site) can be checked in NERACOOS[5] web site. If more information is needed, deliverable D1.1 can also be consulted.

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[5] [B1] [B2] is used as the main source of information for the site B characterization.

A-2.2 Water Depth and Water Levels

A-2.2.1 Bathymetry

The area has a mean depth of 130 m with a maximum depth towards South of 150 m and a minimum depth of 100 m at the North (towards the coastline). The area is located in the plateau of the continental shell; hence seabed is fairly flat all over the site with a very gentle slope deepens from North to South.

Using this information, it has been agreed a design water depth of:

Golf of Maine		
Water Depth	130	m

Table 27: GoM design depth

A-2.2.2 Water Levels

This data is based on tidal statistics obtained for Rockland, closest measuring location with information available of Water Levels: Information is based on NOAA [B2] National Ocean Service benchmark tables.

		Rockland reference values
Highest Observed Water Level	*[m]*	4,319
HAT	*[m]*	3,223
Mean High Water (MHW)	*[m]*	3,100
MSL	*[m]*	1,624
Mean Tide Level (MTL)	*[m]*	1,609
Mean Low Water (MLW)	*[m]*	0,119
LAT	*[m]*	0,000
Lowest Observed Water Level	*[m]*	-0,795

Table 28: GoM characteristic water levels

A-2.3 Wind Climate

In this section relative to the wind climate characterization, buoy E01 (see section A-2.1 or D1.1 for further information) is taken as reference. Wind measurements of this above mentioned buoy provides values for the mean wind speed, wing gust and wind directionality at 4 meters height above MSL and with a measurement period of 10 minutes.

A-2.3.1 Wind Profile

A-2.3.1.1 Operational Conditions

Wind speed at height z can be calculated using the Potential Profile formula (for further information, please refer to D1.1 "*Definition of the target locations: business cases*"):

$$u_{10}(z) = u_{10}(z_0)\left(\frac{z}{z_0}\right)^{0.14} \quad \textbf{(19)}$$

The resulting 10-minutes mean wind speed profile is:

Normal Wind Profile	
Height [m]	Speed [m/s]
4	6,44
5	6,65
10	7,34
20	8,10
50	9,24
100	10,20
119	10,46

Table 29: Operational conditions wind speed profile

A-2.3.1.2 . Extreme Conditions

Wind speed at height z can be calculated using the following profile (for further information, please refer to D1.1 "*Definition of the target locations: business cases*"):

$$u_{10}(z) = u_{10}(H)\left(\frac{z}{H}\right)^{0.11} \tag{20}$$

The resulting extreme wind speed profile ($u_{10,50\ years}$) is:

Extreme Wind Profile	
Height [m]	Speed [m/s]
4	30,3
5	31,0
10	33,5
20	36,1
50	40,0
100	43,1
119[6]	**44,0**

Table 30: Extreme wind speed profile

A-2.3.2 Wind Speed Distribution

A-2.3.2.1 Percentage frequency distribution

The following table summarizes the occurrence probability of the different ranges of mean wind speed taken in form of raw data from the measurements with buoy E01 [B2] . Those wind speeds are registered in 10-minute periods at a height of 4 meters:

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[6] It is worth to remember that this value of the wind speed at 119 meters height with a return period of 50 years is also known as v_{ref}.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual
Wind Speed[m/s]	<1	1,0%	1,5%	1,9%	3,2%	3,7%	4,6%	5,8%	5,3%	3,8%	1,7%	1,3%	0,9%	**2,9%**
	1< u_{10} <2	2,1%	3,3%	4,3%	8,4%	11,7%	14,9%	15,2%	15,4%	11,4%	4,9%	4,6%	2,7%	**8,2%**
	2< u_{10} <3	4,3%	5,0%	6,8%	10,8%	15,8%	19,7%	21,3%	21,8%	15,6%	8,5%	6,4%	4,3%	**11,7%**
	3< u_{10} <4	5,7%	6,0%	9,2%	12,2%	15,1%	18,5%	19,4%	18,8%	15,9%	10,3%	7,4%	6,0%	**12,1%**
	4< u_{10} <5	7,7%	7,6%	8,8%	11,8%	12,0%	14,5%	15,1%	15,0%	14,2%	12,3%	9,0%	6,8%	**11,2%**
	5< u_{10} <6	9,1%	9,9%	9,7%	11,6%	10,5%	9,4%	10,0%	10,0%	13,0%	13,1%	10,2%	8,0%	**10,4%**
	6< u_{10} <7	9,8%	10,3%	11,1%	10,3%	8,9%	6,6%	6,7%	6,5%	10,2%	11,0%	11,2%	10,2%	**9,4%**
	7< u_{10} <8	11,3%	10,5%	11,4%	9,4%	7,8%	4,8%	3,5%	3,4%	7,1%	11,0%	12,2%	11,9%	**8,7%**
	8< u_{10} <9	12,0%	9,7%	10,2%	7,5%	5,5%	3,2%	1,9%	2,0%	4,9%	9,1%	11,5%	10,8%	**7,4%**
	9< u_{10} <10	12,1%	10,1%	9,4%	4,8%	3,5%	2,0%	0,7%	0,6%	2,4%	6,8%	10,0%	10,8%	**6,1%**
	10< u_{10} <11	8,7%	8,7%	7,3%	4,1%	2,8%	0,8%	0,3%	0,3%	1,0%	4,1%	6,9%	9,4%	**4,5%**
	11< u_{10} <12	6,7%	6,7%	4,7%	3,1%	1,5%	0,6%	0,2%	0,3%	0,3%	2,7%	4,1%	7,4%	**3,2%**
	12< u_{10} <13	4,0%	4,8%	2,3%	1,5%	0,6%	0,2%	0,0%	0,2%	0,2%	1,6%	2,6%	4,1%	**1,8%**
	13< u_{10} <14	2,7%	3,2%	1,5%	0,6%	0,4%	0,0%	0,0%	0,2%	0,1%	1,0%	1,3%	3,3%	**1,2%**
	14< u_{10} <15	1,5%	1,4%	0,9%	0,4%	0,2%	0,0%	0,0%	0,2%	0,0%	0,8%	0,7%	1,7%	**0,7%**
	15< u_{10} <16	0,9%	0,7%	0,3%	0,1%	0,1%	0,0%	0,0%	0,0%	0,0%	0,5%	0,4%	1,0%	**0,3%**
	16< u_{10} <17	0,2%	0,3%	0,1%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,3%	0,2%	0,3%	**0,1%**
	17< u_{10} <18	0,2%	0,2%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%	0,1%	0,1%	**0,1%**
	18< u_{10} <19	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	**0,0%**
	19< u_{10} <20	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	**0,0%**
	20< u_{10} <21	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	**0,0%**
	u_{10} >21	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	**0,0%**

Table 31: Wind speed distribution at E01 buoy at 4 m height

A-2.3.2.2 Cumulative Exceedance Distribution: Weibull distribution parameters

A Weibull distribution is assumed according to DNV OS C205 [B4] to represent the long-term probability distributions for the arbitrary 10-minute mean wind speed U10 in a given height z above the ground or above the sea water level.

$$F_{u10}(u) = 1 - \exp\left(-\frac{u-\delta}{A}\right)^{k} \qquad \textbf{(21)}$$

The Weibull coefficients fitting the percentage frequency distribution presented in the previous section are:

Weibull Parameters	
Scale coefficient (A)	6,214
Shape coefficient (k)	1,701
Location coefficient (δ)	0,000
R^2	0,986

Table 32: Weibull distribution parameters

Please refer to D1.1 "*Definition of the target locations: business cases*" for further information.

A-2.3.2.3 Annual Average Wind Speed

Reference height[m]	10-min average wind speed[m/s]
4	6,44
10	7,34
50	9,24
119	10,46

Table 33: Annual average wind speed profile

A-2.3.2.4 10-min Reference Wind Speed (1, 5, 10 and 50 years return period)

Considering Weibull distribution at Section A-2.3.3.2 and shear profile at Section A-2.3.1.2 the resulting wind speeds at Hub Height are:

	Return Period [years]	Wind Speed[m/s]
$U_{10\text{-min}}$ (119m)	50	44,0
	10	41,1
	5	39,8
	1	36,7

Table 34: Reference wind speeds at hub height

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-2.3.3 Wind Directionality

A-2.3.3.1 Wind Rose

		Occurrence Probability[%]
Wind directionality[º][7]	0	6,1
	22,5	5,4
	45	5,1
	67,5	4,5
	90	3,4
	112,5	3,2
	135	3,4
	157,5	4,6
	180	7,2
	202,5	10,2
	225	9,5
	247,5	7,6
	270	6,7
	292,5	7,6
	315	8,7
	337,5	6,9

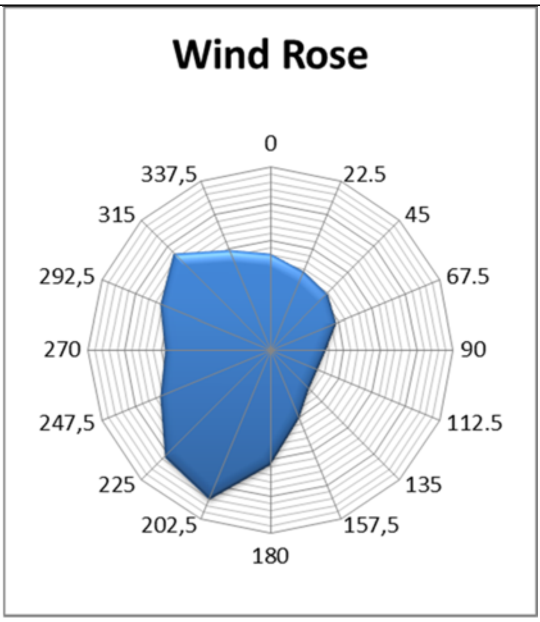

Table 35 GoM wind rose

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[7] Considered bin size: 22,5º

A-2.3.3.2 Scattergrams of ten minutes average wind speed

		Wind Direction[º][8]															
		0	22,5	45	67,5	90	112,5	135	157,5	180	202,5	225	247,5	270	292,5	315	337,5
Mean Wind Speed[m/s]	$u_{10}< 1$	409	360	354	352	390	321	412	445	424	461	494	503	465	396	430	411
	$1< u_{10} <2$	1559	1392	1373	1425	1418	1483	1619	1939	2300	2393	2555	2395	2068	1880	1599	1576
	$2< u_{10} <3$	2305	1758	1853	2160	2176	2380	2751	3288	4029	4618	4328	4043	3426	2800	2349	2232
	$3< u_{10} <4$	2428	2060	2160	2399	2131	2058	2230	3033	4589	6059	5617	4737	3818	3137	2543	2488
	$4< u_{10} <5$	2516	2403	2347	2434	1725	1689	1845	2689	4391	6161	6186	4427	3503	3123	2640	2653
	$5< u_{10} <6$	2598	2381	2449	2201	1370	1155	1338	2018	3879	5762	5545	3853	2794	2856	2918	2697
	$6< u_{10n} <7$	2486	2541	2115	1921	1191	1039	1204	1703	3128	5026	4488	2985	2482	2855	3433	2850
	$7< u_{10} <8$	2605	2438	1991	1622	1025	798	907	1315	2463	4127	3688	2205	2197	2700	3930	3344
	$8< u_{10} <9$	2416	2278	1838	1313	810	745	690	1061	2032	3295	2779	1929	1921	2441	4123	3298
	$9< u_{10} <10$	1796	1757	1333	940	687	526	451	842	1388	2145	1875	1672	1448	2477	3945	2621
	$10< u_{10} <11$	1400	1125	1069	653	539	427	347	523	940	1644	1365	1256	1394	2387	3425	1893
	$11< u_{10} <12$	1100	833	890	507	381	381	335	369	630	1045	817	907	1196	1904	2554	1414
	$12< u_{10} <13$	890	681	684	384	300	245	262	212	400	582	502	621	761	1284	1606	835
	$13< u_{10} <14$	726	503	494	249	221	171	172	154	182	257	240	412	505	948	944	560
	$14< u_{10} <15$	423	267	317	220	207	129	106	96	90	199	131	242	286	561	512	294
	$15< u_{10} <16$	274	174	217	179	110	50	69	55	38	92	53	165	191	425	297	153
	$16< u_{10} <17$	160	131	114	130	51	43	31	25	18	35	34	67	82	187	139	105
	$17< u_{10} <18$	108	106	68	27	15	53	16	4	18	9	14	26	38	86	54	75
	$18< u_{10} <19$	31	37	33	45	3	21	4	1	3	10	12	8	18	49	29	47
	$19< u_{10} <20$	11	28	11	20	1	1				5	3	5	21	8	10	15
	$20< u_{10} <21$	4	16	2	9		1					2	4	14	4	9	6
	$21< u_{10} <22$	1	8		1							1	2	4	1	1	6
	$u_{10} >22$												4				1

Table 36: Wind speed/direction scatter diagram

---

[8] Considered bin size: 22,5º

A-2.3.4 Turbulence Intensity

Reference values provided by IEC-61400 [B5] will be assumed, considering wind turbine class is IC.

Class	I_{ref}
IC	0.12

I_{ref}, is defined as the expected value of the turbulence intensity at 15 m/s. If the turbulence intensity is required for other values, following table can be used:

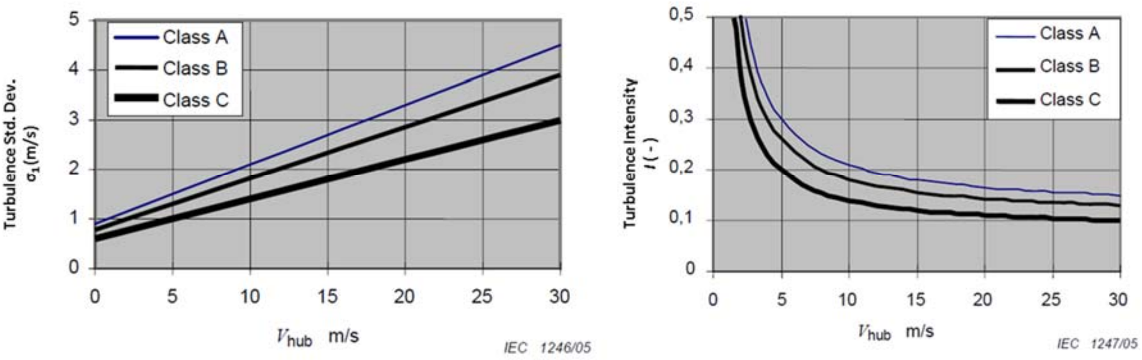

Figure 24: Turbulence Intensity for different Wind Turbine Classes, as defined in IEC-64001 [B5]

A-2.3.5 Spectral Density

Kaimal[9] model can be assumed to characterize the wind energy over frequencies (spectral density).

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[9] Further information of Kaimal model for wind model can be check in IEC-61400 [B5]

A-2.3.6 Wind Gust Characteristics

A-2.3.6.1 Percentage frequency distribution

		Annual[%]
Wind Gust[m/s]	U <2	4,27
	2< U <3	8,09
	3< U <4	10,11
	4< U <5	10,38
	5< U <6	9,72
	6< U <7	8,92
	7< U <8	8,13
	8< U <9	7,40
	9< U <10	6,78
	10< U <11	5,92
	11< U <12	4,87
	12< U <13	4,08
	13< U <14	3,20
	14< U <15	2,47
	15< U <16	1,76
	16< U <17	1,23
	17< U <18	0,82
	18< U <19	0,62
	19< U <20	0,47
	20< U <21	0,33
	21< U <22	0,21
	22< U <23	0,11
	23< U <24	0,06
	24< U <25	0,03
	25< U <26	0,02
	U >26	0,02

Table 37: Wind gust percentage frequency distribution

A-2.3.6.2 Wind Gust reference values (1, 5, 10 and 50 years return period)

Percentage frequency distribution is associated to a Weibull Distribution. The defining parameters associated to this distribution are the following:

Weibull Parameters for wind Gust distribution	
Scale coefficient	7,525
Shape coefficient	1,765
Location coefficient	0,010
R^2	0,962

Table 38: Weibull distribution parameters for the wind gust in GoM

Based into this Weibull distribution, the following parameters are obtained for different return periods.

	Return Period[years]	Wind Gust[m/s]
Wind Gust (4 m)	50	40,0
	10	38,1
	5	37,2
	1	35,2

Table 39: Wind gust reference values at measurement height

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information

A-2.4 Wave Climate

The wave climate characterization (raw data of significant wave height and associated wave period) is also performed taking as main reference the buoy E01. However, information regarding to the wave directionality cannot be found in this source, and buoy 44007[10] is considered. These two buoys have the same resolution in the raw data, given the mean measurement of each 30 minutes.

A-2.4.1 Significant Wave Height- Peak Period Distribution

A-2.4.1.1 H_s, T_p Scattergrams

This significant wave height/peak period scatter diagram is used to represent the probability of occurrence of each certain wave height and peak period combination for the Gulf of Maine selected site.

		Peak Period (s)								
		1<Tp<2	2<Tp<3	3<Tp<4	4<Tp<5	5<Tp<6	6<Tp<7	7<Tp<9	9<Tp<11	Tp>11
Significant Wave Height[m]	<1	0,03%	4,69%	7,29%	7,02%	3,91%	5,91%	13,49%	6,27%	0,08%
	1< Hs <2		0,00%	0,92%	6,64%	6,85%	7,32%	7,90%	8,36%	0,16%
	2< Hs <3			0,00%	0,09%	0,55%	2,71%	2,91%	3,31%	0,15%
	3< Hs <4				0,00%	0,01%	0,12%	1,11%	1,04%	0,08%
	4< Hs <5						0,00%	0,19%	0,47%	0,04%
	5< Hs <6							0,02%	0,21%	0,01%
	6< Hs <7								0,08%	0,01%
	7< Hs <8								0,02%	0,01%
	Hs >8								0,00%	0,00%

Table 40: GoM significant wave height-peak period distribution

In this table, cells with a value of “0,00%” means this wave condition has happened in very few cases unlike blank cells, which means those wave height-period combination have not happened in all the available historical data (2003-2015).

A-2.4.1.2 . Wave height’s associated Weibull Distribution

A Weibull distribution is selected according to DNV OS C205 [B4] to represent the long-term probability distributions of the Hs.

---

[10] The demonstration of the accuracy of this supposition can be consulted in deliverable D1.1.

$$F_{Hs}(h) = 1 - \exp\left(-\frac{h-\delta}{A}\right)^k \qquad \textbf{(22)}$$

Weibull coefficients fitting the percentage frequency distribution presented in the previous section are:

Weibull Parameters	
Scale coefficient (A)	0,744
Shape coefficient (k)	0,976
Location coefficient (δ)	0,015
R^2	0,990

Table 41: Weibull defining parameters of wind gust distribution

The good correlation of this distribution with respect to the distribution directly obtained from the raw data can be checked in Figure 25.

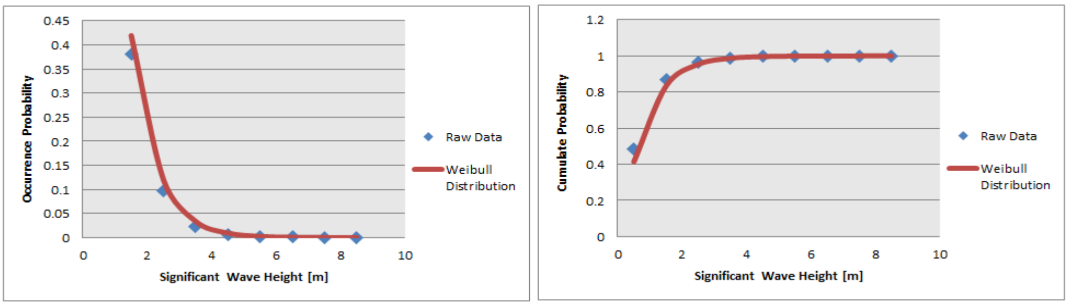

Figure 25: Significant wave height from raw data and Weibull distribution comparison

Please refer to D1.1 "*Definition of the target locations: business cases*" for further information.

A-2.4.1.3 Wave characteristic reference values (1, 5, 10 and 50 years return period)

From this Weibull distribution, the wind climate reference values are obtained and gathered in the following table:

Return period[years]	Significant Wave Height, Hs[m]	Representative Peak Period Range, T_{max}-T_{min}[s][11]	Representative Peak Period, Tp[s]
50	10,9	9-16	15,0
10	9,4	9-16	13,8
5	8,9	9-16	13,4
1	7,7	9-16	12,4

Table 42: Reference values for GoM significant wave height and its associated peak periods

For each of these values, the wave peak period has been extrapolated as the most probable value associated to that height, in order to do so a curve fitting analysis (see below) has been performed to allow

---

[11] According to the information in Table 40, it is not possible to determine a more accurate range for the representative range of peak periods of waves higher than 5 meters.

for determining the most probable values to be associated to those wave heights that are not contained within the available data.

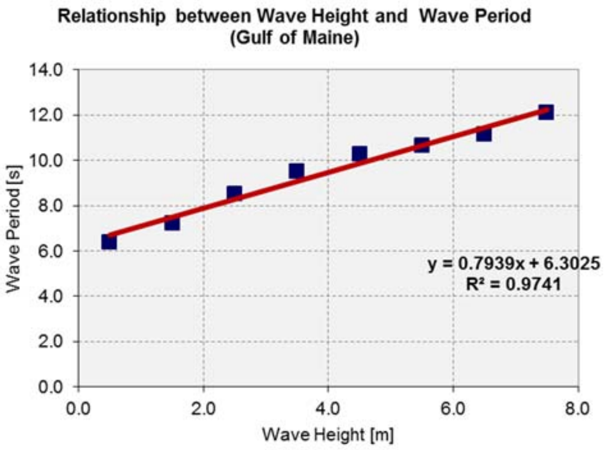

Figure 26: Extrapolation curve for Peak period-Significant wave height correlation

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-2.4.2 Wave Directionality[12][13]

A-2.4.2.1 Wave Rose

		Distribution[%]
Wave directionality[º] [14]	0	1,01
	30	1,10
	60	1,83
	90	16,01
	120	38,00
	150	29,51
	180	8,30
	210	1,73
	240	0,94
	270	0,44
	300	0,51
	330	0,83

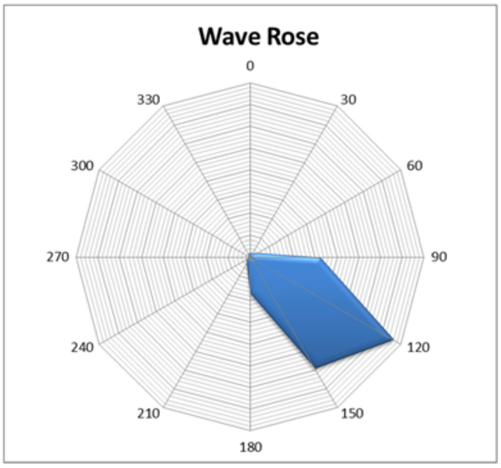

Table 43: GoM Wave rose

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[12] Due to unavailability of data, wave directionality is defined using as reference data form buoy 44007 (position of this buoy can be seen in Figure 23), also near the selected site.
[13] Please refer to DB pt B chpt 5.1.2 for Reference Coordinate System
[14] Considered bin size: 30º

A-2.4.2.2 Wave directionality Scatter Diagrams

		Wave Directionality[Aº] [15]											
		0	30	60	90	120	150	180	210	240	270	300	330
Significant Wave Height[m]	<0,4	0,50%	0,30%	0,60%	2,60%	6,90%	4,40%	0,90%	0,40%	0,30%	0,10%	0,20%	0,30%
	0,5-1,4	0,60%	0,70%	1,10%	10,30%	27,00%	21,60%	6,70%	1,20%	0,70%	0,20%	0,30%	0,50%
	1,5-2,4			0,20%	2,50%	3,30%	3,00%	0,80%	0,01%	0,01%	0,10%	0,01%	
	2,5-3,4			0,01%	0,50%	0,50%	0,50%	0,01%					
	3,5-4,4			0,01%	0,10%	0,10%	0,10%						
	4,5-5,4			0,01%	0,01%	0,10%	0,01%						
	5,5-6,4				0,01%	0,10%							
	6,5-7,4												
	7,5-8,4			0,01%		0,01%							
	>8,5												
(*) 0º direction is corresponding to North direction.													

Table 44:Wave directionality for GoM selected site

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[15] Considered bin size: 30º

A-2.4.3 Wave height occurrence distribution

Following table summarizes the occurrence probability associated to the significant wave height in the Gulf of Maine selected site. This occurrence probability is shown for each month and can be used to determine the percentage of time at which a particular wave height does not exceed a certain value.

		Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Significant Wave Height[m]	Hs <= 0	0,01%	0,00%	0,00%	0,00%	0,00%	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Hs <= 0,5	8,30%	9,08%	13,35%	10,77%	15,88%	21,47%	17,05%	31,19%	20,11%	19,45%	10,79%	9,31%
	Hs <= 1	40,90%	41,74%	44,11%	47,01%	58,03%	73,45%	76,69%	82,35%	67,44%	56,07%	39,44%	39,64%
	Hs <= 1,5	66,48%	66,24%	66,87%	72,15%	84,74%	91,28%	96,21%	95,29%	88,12%	75,35%	65,07%	64,03%
	Hs <= 2	81,61%	81,92%	82,00%	85,74%	94,84%	97,04%	99,71%	98,06%	96,13%	86,64%	81,25%	80,14%
	Hs <= 2,5	90,34%	90,68%	90,70%	92,95%	98,31%	99,04%	99,96%	99,07%	98,82%	93,23%	90,11%	88,51%
	Hs <= 3	94,87%	95,09%	95,39%	96,97%	99,50%	99,58%	100,00%	99,43%	99,54%	96,38%	95,23%	92,88%
	Hs <= 3,5	97,32%	97,21%	97,52%	98,55%	99,76%	99,83%	100,00%	99,61%	99,86%	98,00%	97,68%	95,58%
	Hs <= 4	98,67%	98,46%	98,55%	99,17%	99,88%	99,96%	100,00%	99,82%	99,95%	98,72%	98,73%	97,44%
	Hs <= 4,5	99,38%	99,15%	99,23%	99,50%	99,96%	99,98%	100,00%	99,89%	99,98%	99,31%	99,32%	98,43%
	Hs <= 5	99,67%	99,44%	99,61%	99,65%	99,98%	99,99%	100,00%	99,92%	100,00%	99,64%	99,59%	98,97%
	Hs <= 5,5	99,82%	99,62%	99,78%	99,77%	99,99%	100,00%	100,00%	99,99%	100,00%	99,86%	99,79%	99,47%
	Hs <= 6	99,92%	99,76%	99,91%	99,87%	99,99%	100,00%	100,00%	100,00%	100,00%	99,91%	99,90%	99,75%
	Hs <= 6,5	99,97%	99,85%	99,95%	99,92%	99,99%	100,00%	100,00%	100,00%	100,00%	99,95%	99,95%	99,87%
	Hs <= 7	99,99%	99,94%	99,97%	99,96%	100,00%	100,00%	100,00%	100,00%	100,00%	99,99%	99,98%	99,92%
	Hs <= 7,5	100,00%	99,96%	99,99%	99,98%	100,00%	100,00%	100,00%	100,00%	100,00%	99,99%	100,00%	99,96%
	Hs <= 8	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Table 45: Significant wave height occurrence probability distribution

This occurrence distribution can be also represented within the following graphic, which provides the non-exceedance probability of certain significant wave heights for the different months of the year, and gives an illustrative view of how likely is that a given significant wave height will not be exceeded during the month under consideration.

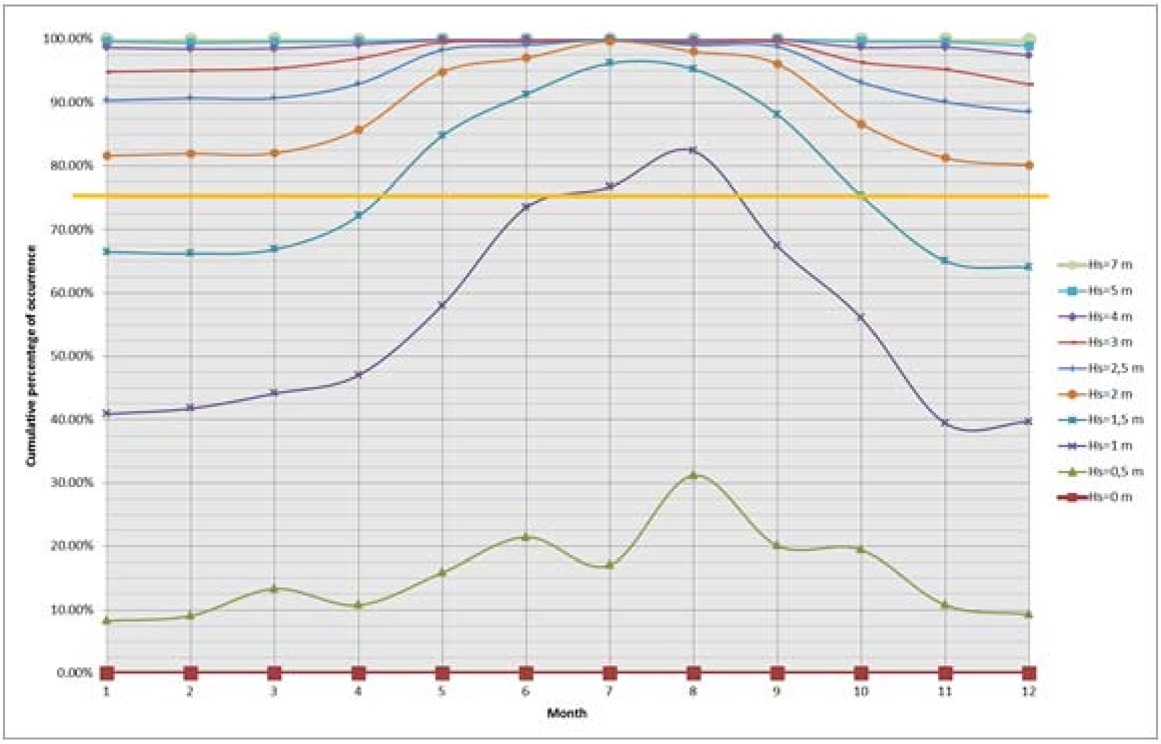

Figure 27: Significant wave height occurrence probability graphic representation

A-2.4.4 Wave spectrum model

Since the wave climate in the Gulf of Maine selected site is not very bound to the wind climate, a Pierson-Moskowitz wave spectrum model can be assumed for its modelling [B6] [B7] .

Please refer to D1.1 "*Definition of the target locations: business cases*" for further information.

A-2.5 Wind-Wave Combined Conditions

A-2.5.1 Wind-Wave climate Scattergrams

		Significant Wave Height[m]								
		Hs <1	1< Hs <2	2< Hs <3	3< Hs <4	4< Hs <5	5< Hs <6	6< Hs <7	7< Hs <8	Hs >8
Wind Speed at 10m[m/s]	$u_{10}<1$	681	410	59	14	8				
	$1< u_{10}<2$	3174	2291	401	84	24	6	5	1	
	$2< u_{10}<3$	5501	4003	726	162	73	7	4		
	$3< u_{10}$-<4	6043	4515	851	197	79	26	3		1
	$4< u_{10}<5$	5887	4867	894	260	101	36	8	1	
	$5< u_{10}<6$	5376	5073	1057	256	110	48	19	9	
	$6< u_{10}<7$	4094	4633	1147	339	130	43	10	5	4
	$7< u_{10}<8$	2945	5064	1276	500	147	38	17	4	3
	$8< u_{10}<9$	1694	4745	1623	496	163	63	9	3	2
	$9< u_{10}<10$	1121	4120	1843	506	162	47	31		1
	$10< u_{10}<11$	687	3216	1956	570	151	47	33	5	2
	$11< u_{10}<12$	441	2018	1933	564	142	51	24	6	
	$12< u_{10}<13$	321	1181	1762	680	185	69	18	6	
	$13< u_{10}<14$	189	617	1311	706	196	53	11	2	2
	$14< u_{10}<15$	142	310	676	625	187	53	23	5	1
	$15< u_{10}<16$	90	187	381	507	209	76	28	8	3
	$16< u_{10}<17$	67	92	132	332	207	70	19	8	5
	$17< u_{10}<18$	51	68	55	157	188	72	20	5	
	$18< u_{10}<19$	43	34	26	52	97	53	28	8	8
	$19< u_{10}<20$	12	22	7	15	31	44	19	9	4
	$20< u_{10}<21$	4	3	2	3	18	23	15	13	8
	$21< u_{10}<22$	4	3			6	11	7	4	1
	$u_{10}>22$	4	5	1		2	6	9	4	12

Table 46: 10 minute wind speed at 10 m – significant wave height occurrence distribution

		Significant Wave Height[m]								
		<1	1< Hs <2	2< Hs <3	3< Hs <4	4< Hs <5	5< Hs <6	6< Hs <7	7< Hs <8	Hs >8
Wind Direction[º]	0	1802	2841	1260	486	201	52	38	9	16
	22,5	1527	2653	1141	478	214	77	27	10	7
	45	1587	2649	1005	388	139	55	25	6	6
	67,5	1698	2266	796	239	90	55	20	4	7
	90	1569	1553	484	212	67	13	1		
	112,5	1531	1451	417	201	96	28	16	5	1
	135	1764	1568	452	179	97	30	4	1	
	157,5	2356	2155	566	282	82	34	11	2	1
	180	3643	3695	1026	285	79	20	9	2	
	202,5	4571	5063	1378	480	128	30	8	8	2
	225	4075	4557	1433	487	124	41	9	3	1
	247,5	3074	3511	1238	501	216	110	48	7	
	270	2460	2964	1418	645	226	112	40	16	1
	292,5	2494	3227	1822	842	344	140	37	16	5
	315	2347	3947	2135	793	294	90	50	11	2
	337,5	2073	3377	1548	527	219	55	17	6	8

Table 47: Wind directionality at 10 m – significant wave height occurrence distribution

A-2.5.2 Wind-Wave misalignments

No metocean data is available about the correlation of wind directionality and wave directionality.

A-2.6 Currents Data

The buoy E01 has also been used as the main source for the current climate characterization. This buoy provides data for the hourly mean surface current speed and mean hourly direction.

A-2.6.1 Current Induced by Wind (Surface Speed)

The mean wind current speed:

Current induced by wind [m/s]	
$V_{c,wind}(0)$	0,154

Table 48: Current induced by wind speed at sea surface

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-2.6.2 Deep Water Current (Surface Speed)

The mean tide generated current speed:

Current induced by tides [m/s]	
$V_{c,tide}(0)$	0,016

Table 49: Current induced by tides speed at sea surface

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-2.6.3 Current Speed Profile

In this section is defined a different profile for each one of the two components of the current speed on the base of the recommendations of DNV-OS-J101 [B7] :

- Current induced by wind: Wind current profile is represented by a linear profile.

$$v_{c,wind}(z) = v_{c,wind}(0) \cdot \left(\frac{d_0 + z}{d_0}\right) \; for - d_0 \leq z \leq 0 \qquad \textbf{(23)}$$

Where d_0 is taken as half of the water depth at Maine following DNV recommendations, hence $d_0 = 65\,m$

- Current induced by tides profile: Tide current profile is represented by a Potential Profile (α=0,14):

$$v_{c,tide}(z) = v_{c,tide}(0) \cdot \left(\frac{d + z}{d}\right)^{\alpha} \; for\ z \leq 0 \qquad \textbf{(24)}$$

The mean current speed at different depths for each of the components of the current speed mentioned above (wind current and tidal current), so as for the total current speed is the following.

Current Profile			
Depth [m]	Wind component [m/s]	Tidal component [m/s]	Total Current speed [m]
Surface	0.154	0.016	0.170
-1	0.152	0.016	0.168
-2	0.149	0.016	0.165
-5	0.142	0.016	0.158
-10	0.130	0.016	0.146
-20	0.107	0.016	0.122
-30	0.083	0.015	0.098
-40	0.059	0.015	0.074
-50	0.036	0.015	0.051
-60	0.012	0.015	0.027
-70	0.000	0.014	0.014
-80	0.000	0.014	0.014
-90	0.000	0.014	0.014
-100	0.000	0.013	0.013
-110	0.000	0.012	0.012
-120	0.000	0.011	0.011
-130	0.000	0.000	0.000

Figure 28: Current speed profile

A-2.6.4 Current Directionality

		Occurrence Probability[%]
Current Directionality Distribution[º] [16]	0	3
	22,5	3
	45	3
	67,5	4
	90	4
	112,5	5
	135	5
	157,5	6
	180	7
	202,5	9
	225	12
	247,5	14
	270	11
	292,5	7
	315	5
	337,5	4

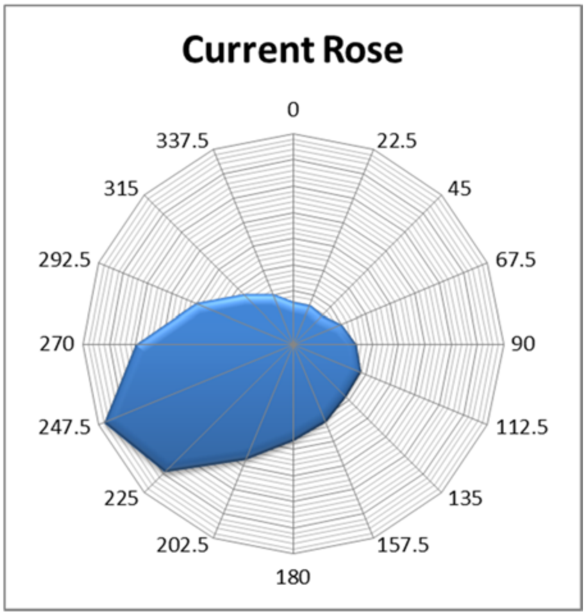

Table 50: Current rose for GoM

This current directionality can be also represented versus its associated current speed as in the following scatter diagram.

---

[16] Considered bin size: 22,5º

		Current Directionality[º][17]															
		0	22,5	45	67,5	90	112,5	135	157,5	180	202,5	225	247,5	270	292,5	315	337,5
Current Speed[m/s]	v_c < 0,10	0,96%	1,03%	0,96%	1,04%	1,06%	1,11%	1,26%	1,45%	1,54%	1,65%	1,80%	1,74%	1,52%	1,30%	1,08%	1,07%
	0,10 < v_c < 0,20	1,53%	1,48%	1,47%	1,83%	2,25%	2,67%	2,70%	3,14%	3,68%	4,40%	5,34%	5,55%	4,64%	3,63%	2,70%	1,98%
	0,20 < v_c < 0,30	0,32%	0,27%	0,30%	0,50%	0,78%	0,98%	0,86%	0,93%	1,14%	2,01%	3,71%	4,39%	3,42%	1,97%	0,90%	0,49%
	0,30 < v_c < 0,40	0,04%	0,04%	0,05%	0,09%	0,15%	0,14%	0,15%	0,13%	0,23%	0,39%	1,12%	1,64%	0,89%	0,31%	0,08%	0,05%
	0,40 < v_c < 0,50	0,02%	0,01%	0,01%	0,02%	0,02%	0,04%	0,03%	0,03%	0,03%	0,09%	0,33%	0,43%	0,23%	0,03%	0,02%	0,02%
	0,50 < v_c < 0,60	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,02%	0,10%	0,18%	0,04%	0,01%	0,01%	0,01%
	0,60 < v_c < 0,70	0,00%	0,00%	0,00%	0,00%	0,01%	0,00%	0,00%	0,00%	0,00%	0,01%	0,02%	0,05%	0,01%	0,00%	0,00%	0,00%
	0,70 < v_c < 0,80	0,00%	0,00%	0,00%	0,00%	0,00%			0,00%	0,00%		0,00%	0,01%	0,00%	0,00%		0,00%
	0,80 < v_c < 0,90	0,00%						0,00%	0,00%		0,00%	0,00%	0,00%			0,00%	0,01%
	0,90 < v_c < 1,00	0,00%	0,00%									0,01%	0,00%				0,00%
	v_c > 1,00	0,00%										0,01%	0,00%				

(*)A cell with a value of "0,00 %" means this condition has happened during the measurement period once or in too few cases

Table 51: Current directionality in GoM

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[17] Considered bin size: 22,5º

A-2.6.5 . Current characteristic reference values (1, 5, 10 and 50 years return period)

Also the current speed occurrence distribution has been adjusted using a “three parameters” Weibull distribution.

A Weibull distribution is selected to represent the long-term probability distributions of the current speed.

$$F_{vcurrent}(v) = 1 - \exp\left(-\frac{v-\delta}{A}\right)^{k} \tag{25}$$

Weibull coefficients fitting the percentage frequency distribution presented in the previous section are:

Weibull Parameters	
Scale coefficient	0,104
Shape coefficient	1,084
Location coefficient	0,021
R^2	0,993

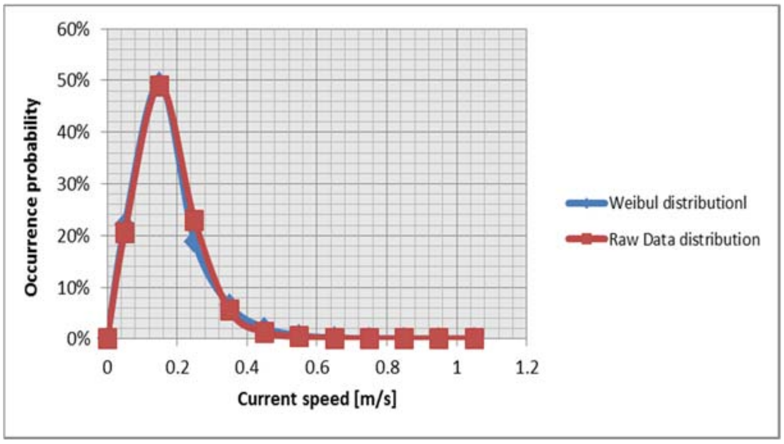

Table 52: Weibull parameters associated to the current speed distribution

Using this distribution, the extreme current speed values are:

Current Speed	Return Period[years]	Total Current speed[m/s]	Wind induced current speed[m/s][18]	Tides induced current speed[m/s]
	50	1.13	0.70	0.43
	10	1.0	0.66	0.34
	5	0.9	0.64	0.31
	1	0.82	0.59	0.23

Table 53: Surface current speed reference values

It is assumed that the same procedure for the extrapolation of current speed to different water depths as in case of average current speed (section A-2.6.3) can be used.

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[18] The speed of the current induced by wind and the speed of the current induced by tides have been obtained under the assumption that the same procedure as for the mean current speed calculation is applicable. This procedure is explained in detail in the next sections.

A-2.6.6 Wind-Current Combined Conditions

		Surface Current Speed[m/s]					
		v_c <0,25	0,25< v_c <0,50	0,50< v_c <0,75	0,75< v_c <1,00	1,00< v_c <1,25	v_c >1,25
Wind Speed at 10m[m/s]	u_{10} <1	0,47%	0,37%	0,04%	0,00%		
	1< u_{10} <2	2,93%	1,89%	0,28%	0,02%		
	2< u_{10} <3	4,99%	3,17%	0,41%	0,02%	0,00%	
	3< u_{10} <4	5,79%	3,80%	0,53%	0,03%	0,00%	
	4< u_{10} <5	5,93%	3,92%	0,53%	0,02%		
	5< u_{10} <6	5,65%	3,73%	0,46%	0,02%	0,00%	
	6< u_{10} <7	5,52%	3,39%	0,32%	0,02%		
	7< u_{10} <8	5,00%	3,07%	0,41%	0,01%		
	8< u_{10} <9	4,37%	2,74%	0,34%	0,02%		
	9< u_{10} <10	4,02%	2,64%	0,33%	0,01%		
	10< u_{10} <11	3,07%	2,31%	0,28%	0,01%		
	11< u_{10} <12	2,57%	1,91%	0,23%	0,01%		
	12< u_{10} <13	2,06%	1,53%	0,25%	0,00%		
	13< u_{10} <14	1,40%	1,24%	0,22%	0,00%		
	14< u_{10} <15	0,93%	0,97%	0,16%	0,01%		
	15< u_{10} <16	0,58%	0,69%	0,12%	0,00%		
	16< u_{10} <17	0,35%	0,38%	0,12%	0,01%	0,00%	
	17< u_{10} <18	0,20%	0,29%	0,09%	0,01%	0,00%	
	18< u_{10} <19	0,10%	0,19%	0,06%	0,00%	0,00%	
	19< u_{10} <20	0,06%	0,08%	0,04%	0,01%		
	20< u_{10} <21	0,03%	0,05%	0,04%	0,00%		
	21< u_{10} <22	0,01%	0,03%	0,01%	0,00%		
	u_{10} >22	0,00%	0,02%	0,01%			

(*) A cell with a value of "0,00 %" means this condition has happened during the measurement period but once or in too few cases

Table 54: Wind-Current combined conditions: Speed Correlation

		Wind Direction[º] [19]															
		0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
Current Direction[º] [20]	0	283	257	334	312	260	280	314	417	544	598	516	400	304	283	351	291
	22.5	251	209	211	243	177	237	296	383	674	818	683	446	364	397	394	276
	45	201	164	178	154	140	160	223	366	604	897	656	516	433	400	356	260
	67.5	159	125	106	126	125	124	167	277	463	769	684	494	370	365	313	200
	90	136	113	95	96	110	81	143	281	467	704	643	489	363	364	294	207
	112.5	146	118	110	127	112	113	156	268	541	791	742	585	459	453	389	249
	135	265	169	193	178	179	155	202	309	604	955	893	804	753	729	573	367
	157.5	481	324	297	242	218	208	220	335	579	907	960	861	943	1069	1166	659
	180	756	530	429	355	248	219	198	279	385	536	660	602	637	904	1289	927
	202.5	724	522	521	308	214	158	156	195	227	277	311	292	317	456	735	731
	225	459	421	365	241	175	136	118	127	144	191	187	170	145	223	313	384
	247.5	303	287	255	185	119	124	87	71	87	103	110	93	87	140	199	231
	270	231	260	205	164	110	126	66	71	100	105	85	87	84	95	151	170
	292.5	224	262	294	197	150	109	86	77	117	142	86	103	94	104	156	186
	315	232	304	272	252	201	160	137	124	160	196	152	144	115	125	194	213
	337.5	250	295	329	343	266	249	259	230	285	329	292	232	175	199	237	236

Table 55: Wind-Current combined conditions: Directionality Correlation

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[19] Considered bin size: 22,5º

[20] Considered bin size: 22,5º

A-2.7 . Soil Conditions

Soil conditions for Gulf of Maine selected site has been agreed taking into account the reference information available in public sources, which defines the characteristic soil type near the selected site has a moderate compression resistance, but considering a standard profile, which was defined within the WP1.

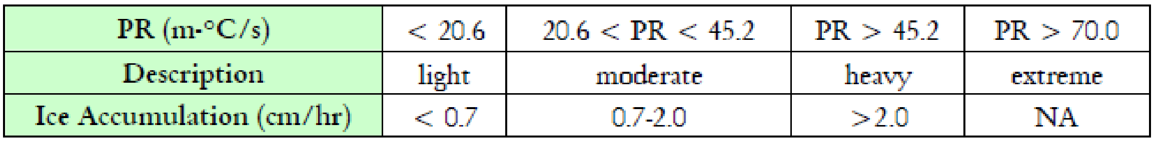
Soil Profile Characteristics			
Layer	Soil Type	Depth range[m]	Cu[kPa]
1	Very Dense Sand	0 - 4	35
2	Soft Clay	4 – 10	60
3	Stiff Clay	>10	200

Table 56: Medium compressive strength soil profile designed for GoM

A-2.8 Other Environmental Conditions

A-2.8.1 Ice (sea spray/precipitation)

Following guidance values, based on NOAA researchers' experience [B8] , can be used for a preliminary estimation of ice accumulation on offshore floating structures.



PR (m-°C/s)	< 20.6	20.6 < PR < 45.2	PR > 45.2	PR > 70.0
Description	light	moderate	heavy	extreme
Ice Accumulation (cm/hr)	< 0.7	0.7-2.0	>2.0	NA

Figure 29: Thickness increasing due to icing [B8]

This reference table is based on the PR ration, which results because of the site environmental conditions following this empirical formula:

$$PR = \frac{V_a \left(T_f - T_a\right)}{1 + 0.4\left(T_s - T_f\right)} \qquad \textbf{(26)}$$

Where V_a is the wind speed in m/s, T_a is the air temperature, T_s is the sea surface temperature[ºC] and T_f is the freezing point of sea water[ºC].

A-2.8.2 Sea Water Characteristics

Information of this section is obtained from [B9] . Please refer to D1.1 "*Definition of the target locations: business cases*" for further information.

A-2.8.2.1 Temperature

Measurement depth[m]	Sea water temperature[ºC]		
	Maximum	Mean	Minimum
1	22,5	12,0	1,0
2	22,5	11,5	1,0
20	16,5	9,0	1,0
50	13,5	8,0	1,0

Table 57: Sea water temperature

A-2.8.2.2 Density

Measurement depth[m]	Sea water density[kg/m3]		
	Maximum	Mean	Minimum
1	1.026,4	1.024,2	1.019,3
20	1.026,5	1.025,3	1.023,1
50	1.026,5	1.025,6	1.024,3

Table 58: Sea water density

A-2.8.2.3 Salinity

Measurement depth[m]	Sea water salinity[psu]		
	Maximum	Mean	Minimum
1	33,5	32,0	25,8
20	33,5	32,4	30,8
50	33,6	32,6	31,1

Table 59: Sea water salinity

A-2.8.3 Air Characteristics

Information of this section is obtained from [B9] . Please refer to D1.1 "*Definition of the target locations: business cases*" for further information.

A-2.8.3.1 Temperature

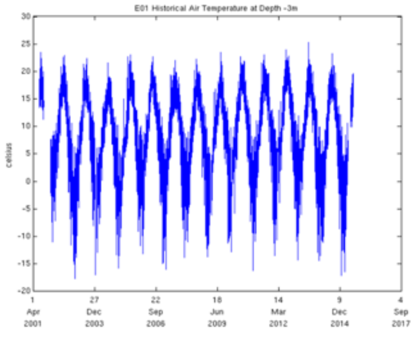
Air temperature			
	Maximum	24	[ºC]
	Mean	9	[ºC]
	Minimum	-18	[ºC]

Table 60: Air temperature at sea surface level in GoM selected site

A-2.8.3.2 Density

No specific information is available regarding to the air density. Following the IEC 61400-1 [B5] international standard it is selected a value of 1225 kg/m^3 for the air density.

A-2.8.4 Marine Growth

The following thickness of marine growth can be taken:

Marine Growth	
Water Depth (m)	Thickness (mm)
+2 to -40	100
below -40	50

Table 61: Thickness increasing due to marine growth in GoM [B6] [B7]

The density of marine growth may be set to 1325 kg/m3.

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-2.8.5 Seismicity

Gulf of Maine selected site can be considered as a location with a very low seismic activity [B10] .

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-3 Site-C: Severe environmental conditions

This location has been selected as representative for an upper bound, in terms of extreme environmental conditions, for the development of floating platforms.

A-3.1 . Location

West of Barra is located 19km West of Barra Island immediately within the 12 NM limit. The central latitude and longitude of the proposed area are 56,886ºN, 7,948ºW. This site was identified by Marine Scotland as a potential area where tests sites for deep water floating technology could be located.

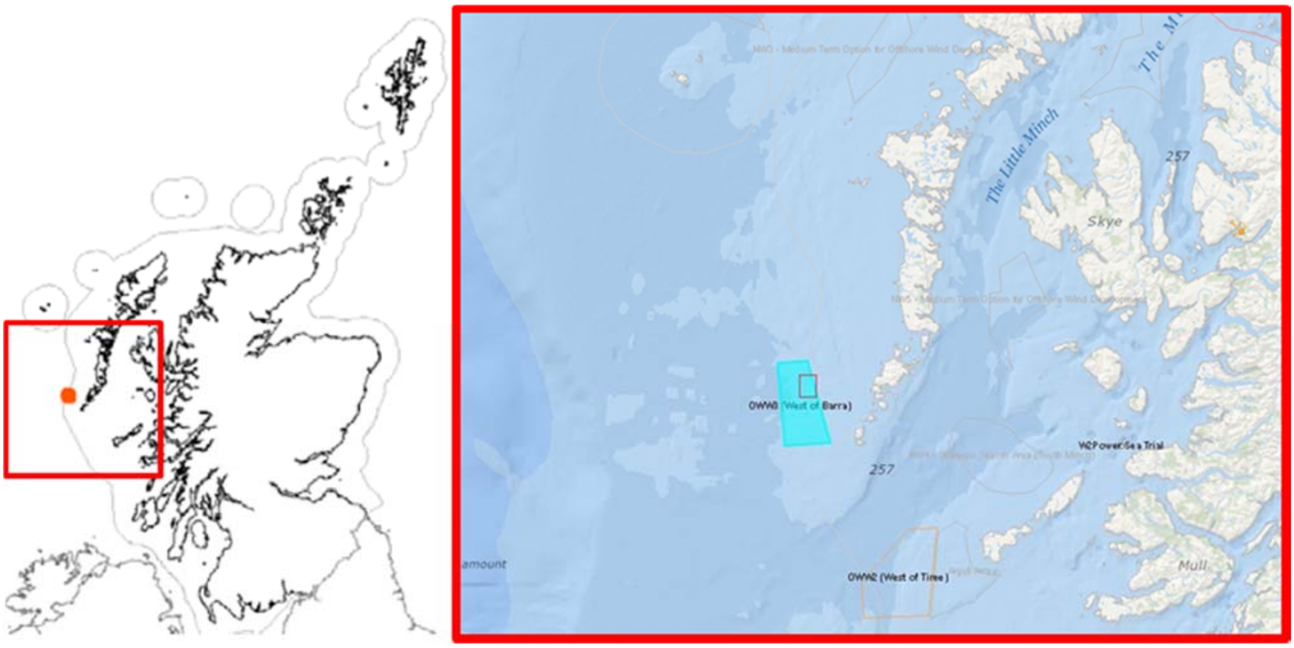


Figure 30: West of Barra proposed site location

Characterization of the metocean conditions has been performed on the basis of available data provided by the HSE[21] and obtained from the NEXT hindcast model.

A-3.2 Water Depth and Water Levels

A-3.2.1 Bathymetry

The selected site is characterized by a mean depth of **100 m**. Bathymetry of West of Barra selected site has its deepest point at the western area of the site, 118 meters, and the shallowest spots, found at the south east corner, with 56 meters of water depth. Design water depth has been agreed within the WP1 members in:

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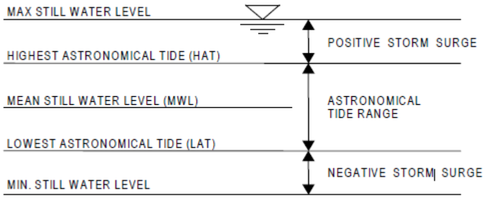
[21] Main source of information can be found in [C1] and [C2] . Within this reference, the selected grid point for the data acquisition is 15609. If more information is needed, deliverable D1.1. "*Oceanographic and meteorological conditions for design*" can be consulted.

West of Barra		
Water Depth	100	m

Table 62: WoB agreed design depth

A-3.2.2 Water Levels

Sea water levels for the astronomical tide range have been obtained from measured values at West of Barra location (reference: Wind and wave frequency distributions for sites around the British Isles. Fugro GEOS – HSE). Summary of West of Barra´s water levels as defined in DNV-RP-C205 [C3] are given below.



HSWL	*[m]*	4.16
HAT	*[m]*	3.16
MWL	*[m]*	2.32
LAT	*[m]*	-1.48
LSWL	*[m]*	-2.48

Table 63: WoB characteristic

A-3.3 Wind Climate

A-3.3.1 Wind Profile

A-3.3.1.1 Operational Conditions

The **"Logarithmic Profile"** is selected as the most suitable for the calculation of the wind speeds at operational conditions for different heights in the West of Barra site (for further information, please refer to D1.1 "*Definition of the target locations: business cases*"):

$$V(z) = V_{hub} \cdot \frac{ln(z/z_0)}{ln(z_{hub}/z_0)} \tag{27}$$

The resulting 10 minutes mean wind speed profile is the following:

Normal Wind Profile	
Height	Speed
[m]	[m/s]
10	9,50
20	10,16
50	10,97
100	11,58
119	11,74

Table 64: Normal wind speed profile for WoB site

A-3.3.1.2 . Extreme Conditions

Wind shear profile in extreme conditions have been considered to follow a **power law relationship with alpha factor (α = 0.12)** (for further information, please refer to D1.1 “*Definition of the target locations: business cases*”):

$$\boldsymbol{u(z) = u_{hub} \cdot (z/z_{hub})^{0.12}} \tag{28}$$

The extreme wind speed profile would be the following:

Extreme Wind Profile	
Height	Speed
[m]	[m/s]
10	26,47
20	35,63
50	44,13
100	48,97
119	50,00

Table 65: Extreme conditions wind speed profile

A-3.3.2 Wind Speed Distribution

A-3.3.2.1 Exceedance distribution

Following table summarizes the exceedance probability for the 1-hour averaged wind speed values obtained from the aforementioned time series.

Wind Speed[m/s]	$0,0 < u_{1\text{-hour}} < 0,3$	100,00 %
	$0,3 < u_{1\text{-hour}} < 1,6$	100,00 %
	$1,6 < u_{1\text{-hour}} < 3,4$	99,97 %
	$3,4 < u_{1\text{-hour}} < 5,5$	95,82 %
	$5,5 < u_{1\text{-hour}} < 8,0$	82,67 %
	$8,0 < u_{1\text{-hour}} < 10,8$	60,08 %
	$10,8 < u_{1\text{-hour}} < 13,9$	35,00 %
	$13,9 < u_{1\text{-hour}} < 17,2$	14,79 %
	$17.2 < u_{1\text{-hour}} < 20.8$	4,20 %
	$20.8 < u_{1\text{-hour}} < 24.5$	0,73 %
	$24.5 < u_{1\text{-hour}} < 28.5$	0,11 %
	$28.5 < u_{1\text{-hour}} < 32.7$	0,00 %

Table 66: HSE Wind speed distribution at WoB site at 10 m height

A-3.3.2.2 . Weibull distribution parameters

A Weibull distribution has been fitted by the Least Square Method (LSM) to the exceedance frequencies values provided in precious section (A-3.3.2.1).

The parameters defining this Weibull function are provided below as well as the correlation coefficient of the fitting function.

Weibull Parameters	
Scale coefficient	9,089
Shape coefficient	2,096
Location coefficient	1,400
R^2	0,999

Table 67: Weibull distribution parameters

A-3.3.2.3 Hourly Annual Average Wind Speed

Reference height[m]	Average hourly wind speed[m/s]
10	9,50
50	10,97
119	11,74

Table 68: Annual average wind speed profile

A-3.3.2.4 10-min Reference Wind Speed (1 and 50 years return period)[22]

Return Period	Max. annual wind speed (10-min average @ Hub height – 119 m.)	
1	40.07	
50	53.79	V_{ref}[23]

Table 69: Reference wind speeds in WoB site

---

[22] Due to the severity of the climate in West of Barra selected site, the value calculated of the v_{ref} using data of HSE studies [C4] [C4] is not adequate for the design of a "I-class" wind turbine (v_{ref} value is above the 50 m/s limit for this turbine class). Therefore, it is found an agreement between the WP1 members, turbine designer (DTU) and concept developers (Olav Olsen, Iberdrola, Nautilus and Ideol) to stablish the 50-year return period wind speed at hub height in 50 m/s.

[23] It is worth to remember that this value of the wind speed at hub height (119 meters above MSL) with a return period of 50 years is also known as v_{ref}.

A-3.3.3 Wind Directionality[24]

A-3.3.3.1 Wind Rose

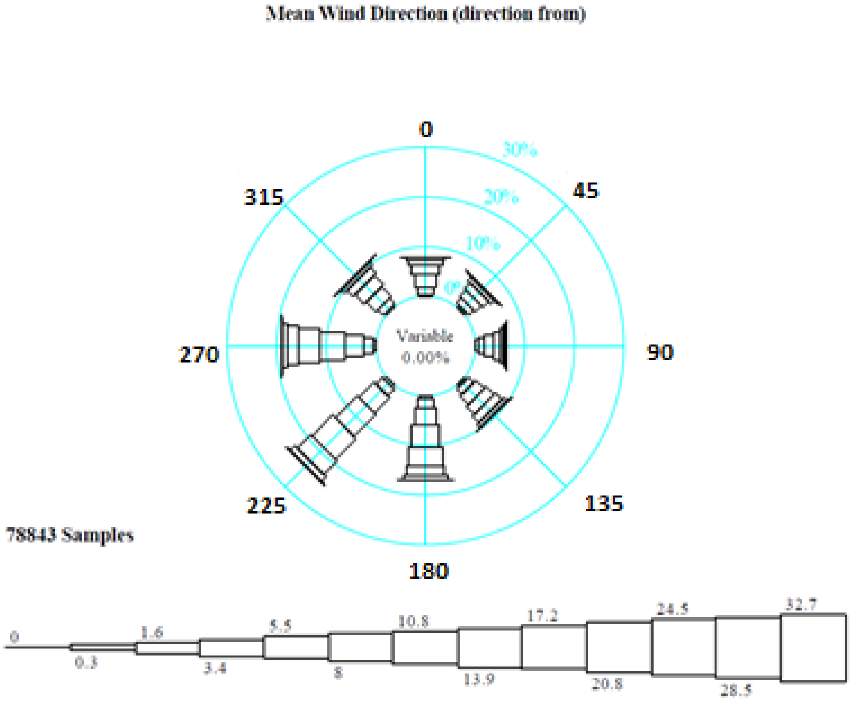


Figure 31: West of Barra wind rose (Wind speed is referred to 1-hour averaged values at 10 m ASL, Wind direction refers to 1-hour averaged values at 19.5 m. Data Source: NEXT hindcast model)

A-3.3.3.2 Scattergrams of ten minutes average wind speed

The following table gathers up the mean wind speed for the different incoming wind direction sectors. The direction, clockwise from true North, is from which the wind is blowing. Directionality measures were performed for 1-hour average direction at a height of 19,5 m (despite the mean wind speed, that is given at 10 m height).

---

[24] Please refer to DB pt B chpt 5.1.2 for Reference Coordinate System

Mean Wind Speed at 10 m[m/s]	Mean Wind Direction[º][25]							
	0	45	90	135	180	225	270	315
0 -1,60	2	4	6	2	3	4	2	
1,60-3,40	333	413	403	430	535	469	366	326
3,40-5,50	1091	1138	1116	1229	1515	1527	1576	1170
5,50-8,00	1932	1385	1395	1782	2668	3385	3049	2217
8,00-10,80	1421	1294	1105	1841	3496	4850	3750	2016
10,80-13,90	928	641	510	1408	2847	4729	3451	1420
13,90-17,20	397	215	192	605	1576	3035	1782	549
17,20-20,80	52	55	68	162	561	948	731	160
20,80-24,50	5	5	1	30	86	182	132	46
24,50-28,50					3	27	46	10
28,50-32,70							1	1
32,70-51,50								

Table 70: Wind directionality in WoB selected site

A-3.3.4 Turbulence Intensity

Reference values provided by IEC-61400 [C5] will be assumed, considering wind turbine class is IC.

Class	I_{ref}
IC	0,12

I_{ref}, is defined as the expected value of the turbulence intensity at 15 m/s. If the turbulence intensity is required for other values, following table can be used:

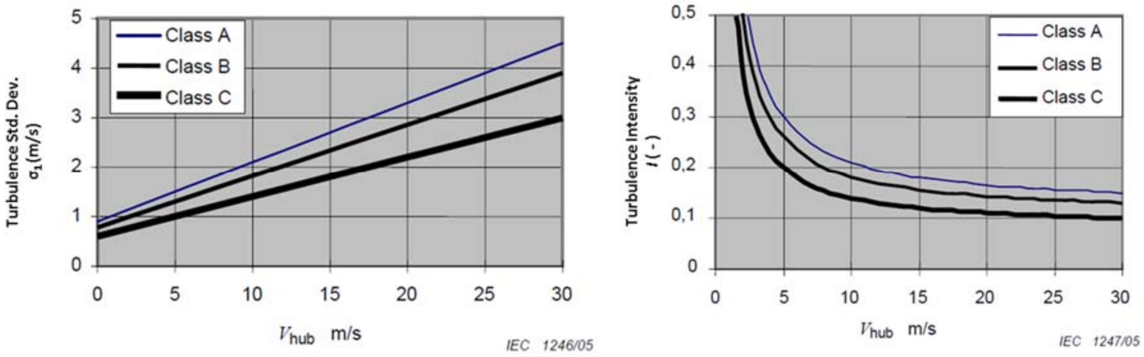


Figure 32: Turbulence Intensity for different Wind Turbine Classes, as defined in IEC-64001[C5]

A-3.3.5 Spectral Density (Kaimal model)

Kaimal model can be assumed to characterize the wind energy over frequencies (spectral density).

---

[25] Considered bin size: 45º

A-3.3.6 Wind Gust Characteristics

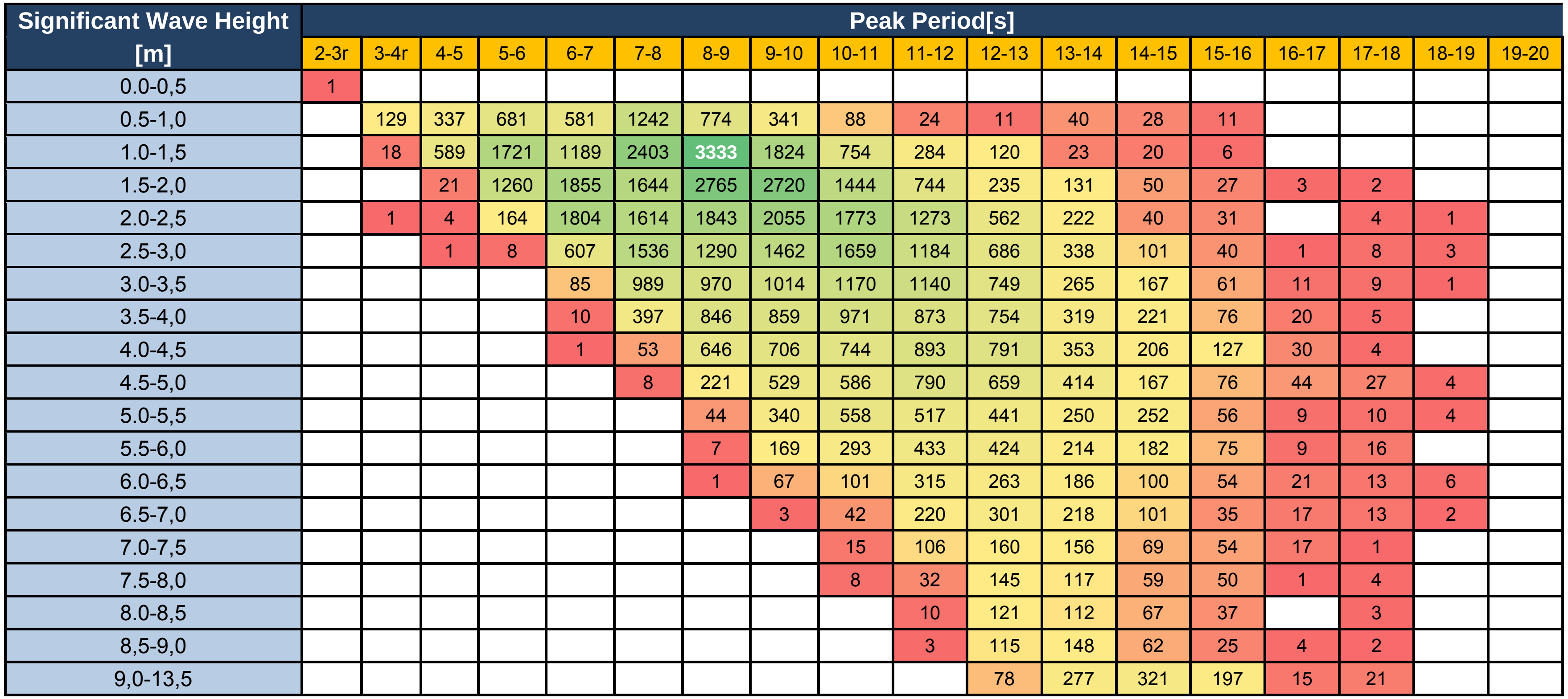
No information is available at West of Barra site in regards to wind gust. Hence, reference is done to IEC-641001 [C5] , where it can be found mathematical models that allow characterizing wind gust and accounting for its effects on the design load cases.

A-3.4 Wave Climate

A-3.4.1 A.3.4.1. Significant Wave Height- Peak Period Distribution

A-3.4.1.1 H_s, T_p Scattergrams

The significant wave height and spectral peak period frequency distributions show the joint frequency of occurrence of wave height and period for an average year.



Significant Wave Height [m]	Peak Period[s]																	
	2-3r	3-4r	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
0.0-0,5	1																	
0.5-1,0		129	337	681	581	1242	774	341	88	24	11	40	28	11				
1.0-1,5		18	589	1721	1189	2403	3333	1824	754	284	120	23	20	6				
1.5-2,0			21	1260	1855	1644	2765	2720	1444	744	235	131	50	27	3	2		
2.0-2,5		1	4	164	1804	1614	1843	2055	1773	1273	562	222	40	31		4	1	
2.5-3,0			1	8	607	1536	1290	1462	1659	1184	686	338	101	40	1	8	3	
3.0-3,5					85	989	970	1014	1170	1140	749	265	167	61	11	9	1	
3.5-4,0					10	397	846	859	971	873	754	319	221	76	20	5		
4.0-4,5					1	53	646	706	744	893	791	353	206	127	30	4		
4.5-5,0						8	221	529	586	790	659	414	167	76	44	27	4	
5.0-5,5							44	340	558	517	441	250	252	56	9	10	4	
5.5-6,0							7	169	293	433	424	214	182	75	9	16		
6.0-6,5							1	67	101	315	263	186	100	54	21	13	6	
6.5-7,0								3	42	220	301	218	101	35	17	13	2	
7.0-7,5									15	106	160	156	69	54	17	1		
7.5-8,0									8	32	145	117	59	50	1	4		
8.0-8,5										10	121	112	67	37		3		
8,5-9,0										3	115	148	62	25	4	2		
9,0-13,5											78	277	321	197	15	21		

Table 71: Significant wave height – Peak period frequency distribution

A-3.4.1.2 Wave height's associated Weibull Distribution

According to DNV OS C205 [C3] , data presented in section A-3.4.1.1 has been statistically analysed and fitted to a Weibull curve. Parameters of this best fit distribution function are given below as well as its correlation factor.

Weibull Parameters	
Scale coefficient	0,744
Shape coefficient	0,976
Location coefficient	0,015
R^2	0,990

Table 72: Defining parameters of the Weibull distribution associated to WoB wave height distribution

Please refer to D1.1 "*Definition of the target locations: business cases*" for further information.

A-3.4.1.3 Wave characteristics reference values (1, 5, 10 and 50 years return period)

Based on Weibull distribution and assuming 3 hour storms sea states, significant wave heights associated to 50, 20, 10 and 1 year return period are provided in the following table. For each of these values, the wave peak period has been estimated as the most probable value associated to that height.

Return period[years]	Significant Wave Height, Hs[m]	Representative Peak Period Range, T_{max}-T_{min}[s] [26]	Representative Peak Period, T_p[s]
50	15,6	12-18	15,3
20	14,7	12-18	15,0
10	14,0	12-18	14,9
1	11,5	12-18	14,3

Table 73: Reference values of significant wave height in WoB and its associated peak periods

For each of these values, the wave peak period has been extrapolated as the most probable value associated to that height, in order to do so a curve fitting analysis (see below) has been performed to allow for determining the most probable values to be associated to those wave heights that are not contained within the available data.

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[26] According to the information in Table 71 it is not possible to determine a more accurate range for the representative range of peak periods of waves higher than 5 meters.

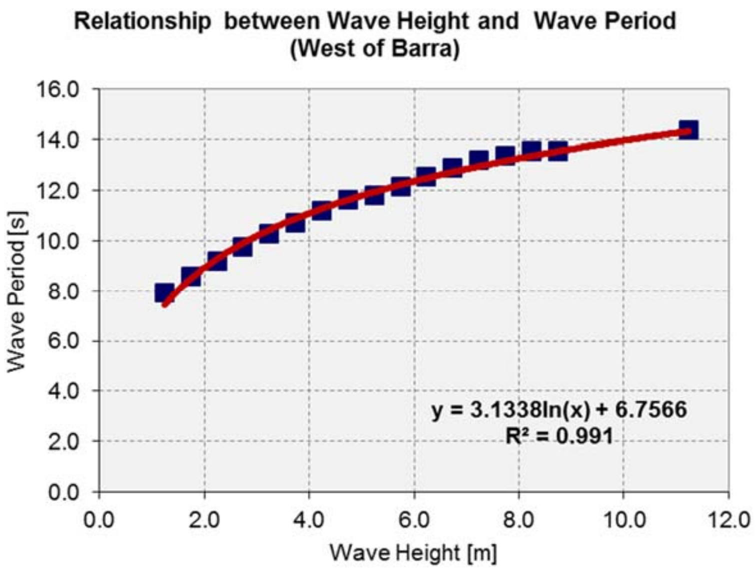

Figure 33: Extrapolation curve for Peak period-Significant wave height correlation

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-3.4.2 . Wave Directionality[27]

A-3.4.2.1 Wave Rose

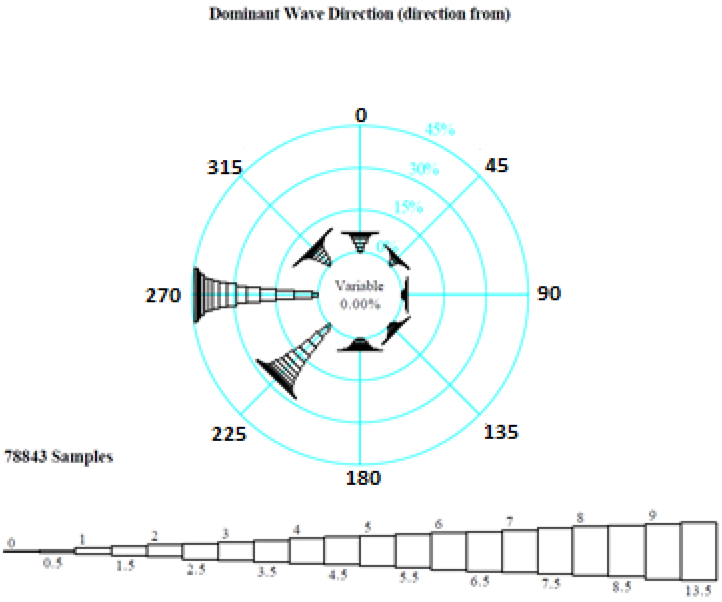

Figure 34: West of Barra wave rose (Significant wave height)[28]

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[27] Please refer to DB pt B chpt 5.1.2 for Reference Coordinate System

[28] Data in the wave height scale, given at the bottom of the wind rose, is provided at buoy conditions: mean significant wave height given in 1-hour period.

A-3.4.2.2 Wave directionality Scatter Diagrams

The following table gathers up dominant wave direction for the different incoming wave direction sectors. The direction, clockwise from true North, is from which the waves are travelling. The dominant wave direction is the direction associated with the peak of the total wave spectrum.

Significant Wave Height[m]	Dominant Wave Direction[º][29]							
	0	45	90	135	180	225	270	315
0,00-0,50				1				
0,50-1,00	410	568	151	44	59	1100	1435	520
1,00-1,50	1159	950	330	326	311	2933	5156	1119
1,50-2,00	1344	597	324	376	490	3279	5111	1380
2,00-2,50	1029	356	190	541	684	2951	4507	1133
2,50-3,00	624	217	89	403	499	2375	3755	962
3,00-3,50	343	175	63	227	371	1972	2870	610
3,50-4,00	234	107	65	170	294	1587	2544	350
4,00-4,50	151	44	58	117	301	1343	2292	248
4,50-5,00	104	14	14	81	160	1221	1705	226
5,00-5,50	73	12	13	28	136	870	1191	158
5,50-600	56	2	8	26	84	542	1030	74
6,00-6,50	9		11	24	35	339	658	51
6,50-7,00				1	15	316	582	38
7,00-7,50					9	192	348	29
7,50-8,00					9	114	268	25
8,00-8,50						100	233	17
8,50-9,00						105	237	17
9,00-13,50						190	664	55
13,50-20,00								

Table 74: Wave directionality

A-3.4.2.3 Wave height occurrence distribution and Weather Window

The table below summarizes the occurrence probability associated to the significant wave height for each month in the selected locations for the wind farm design in the West of Barra. This occurrence probability is show for each month and can be used to determine the percentage of time at which a particular wave height is not exceeded.

---

[29] Considered bin size: 22,5º

		Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Significant Wave Height[m]	Hs <= 0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Hs <= 0,5	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Hs <= 1	0.31%	0.77%	0.73%	1.41%	13.86%	11.84%	13.49%	12.46%	8.49%	0.97%	0.39%	0.12%
	Hs <= 1,5	0.93%	5.29%	3.39%	14.07%	46.22%	43.16%	48.88%	43.83%	23.29%	13.28%	5.86%	2.63%
	Hs <= 2	6.50%	12.49%	9.90%	36.66%	70.21%	71.90%	68.88%	68.36%	45.34%	33.10%	15.20%	8.33%
	Hs <= 2,5	18.59%	24.17%	22.30%	58.58%	81.82%	86.54%	85.97%	82.36%	60.05%	52.03%	25.65%	22.07%
	Hs <= 3	31.02%	35.12%	35.23%	72.20%	89.96%	93.75%	93.74%	89.23%	70.83%	65.55%	42.33%	37.05%
	Hs <= 3,5	40.14%	46.77%	46.16%	81.81%	94.16%	97.70%	97.24%	93.31%	78.78%	75.40%	55.86%	49.97%
	Hs <= 4	49.49%	58.35%	56.75%	87.63%	96.53%	98.75%	98.98%	95.77%	85.54%	81.42%	68.83%	61.11%
	Hs <= 4,5	58.37%	70.20%	65.75%	91.88%	98.30%	99.34%	99.61%	97.91%	90.09%	86.21%	78.77%	72.51%
	Hs <= 5	68.08%	77.91%	74.23%	94.22%	99.09%	99.71%	99.90%	99.61%	92.90%	90.56%	85.62%	80.87%
	Hs <= 5,5	75.94%	83.28%	80.27%	96.08%	99.45%	99.92%	100.00%	99.87%	95.34%	93.31%	91.37%	85.77%
	Hs <= 6	81.07%	87.81%	85.08%	97.79%	99.76%	100.00%	100.00%	99.91%	97.02%	95.25%	94.89%	89.87%
	Hs <= 6,5	85.00%	90.33%	89.02%	98.35%	99.99%	100.00%	100.00%	100.00%	97.85%	96.56%	96.40%	92.11%
	Hs <= 7	88.79%	92.39%	92.34%	98.92%	100.00%	100.00%	100.00%	100.00%	98.29%	97.65%	97.61%	94.12%
	Hs <= 7,5	90.78%	94.05%	94.29%	99.27%	100.00%	100.00%	100.00%	100.00%	98.50%	98.25%	98.56%	95.22%
	Hs <= 8	92.45%	95.07%	95.68%	99.54%	100.00%	100.00%	100.00%	100.00%	98.73%	98.64%	99.04%	96.12%
	Hs <= 8,5	93.83%	95.88%	97.00%	99.78%	100.00%	100.00%	100.00%	100.00%	99.03%	98.89%	99.23%	96.97%
	Hs <= 9	95.52%	96.89%	97.98%	99.86%	100.00%	100.00%	100.00%	100.00%	99.49%	99.10%	99.48%	97.77%
	Hs <= 13	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 75: Significant wave height occurrence probability distribution

This occurrence distribution can be also represented within the following graphic. This occurrence probability is shown for each month and can be used to determine the percentage of time at which a particular wave height does not exceed a certain value.

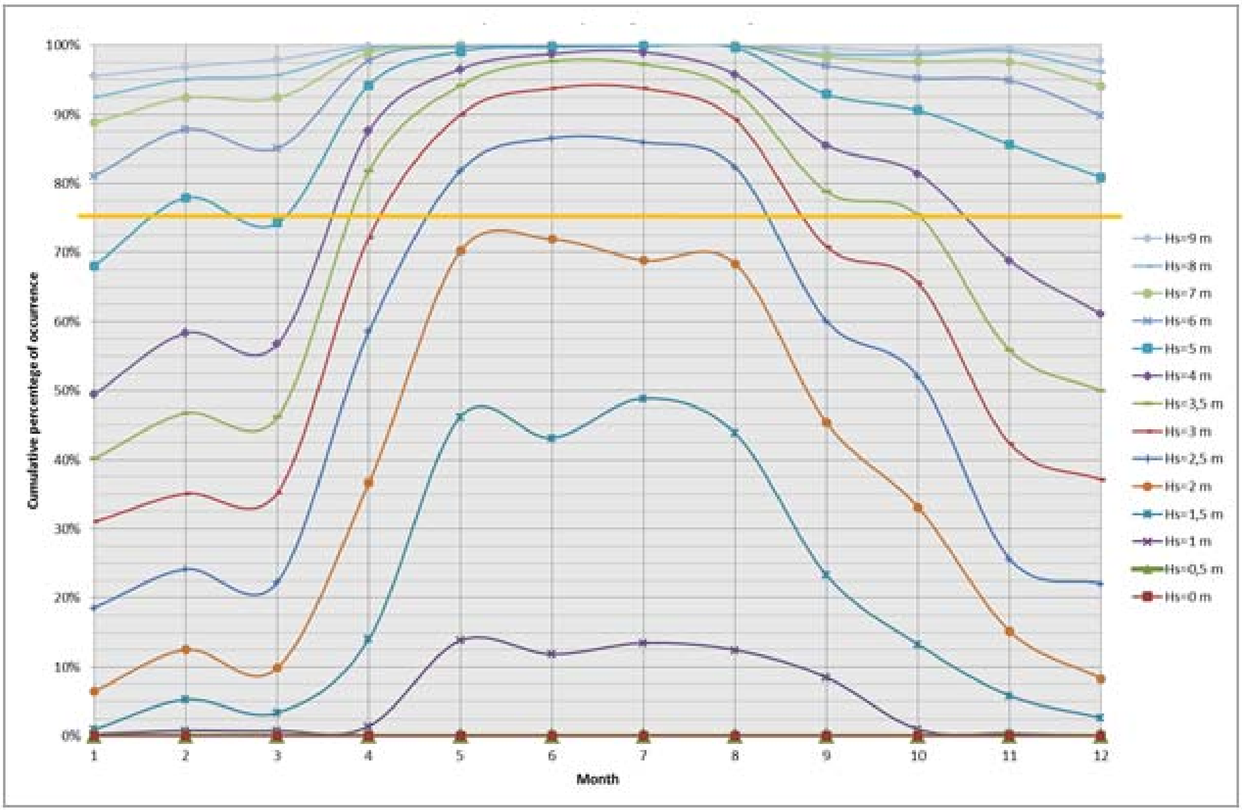


Figure 35: Significant wave height occurrence probability graphic representation

A-3.4.3 Wave Spectrum Model

A Jonswap wave spectrum is usually sufficient for the representation of the power spectral density of wind generated waves (as is the case of West of Barra). However, for floating offshore structures that may be usually affected by swells of 20-25 seconds period, a two-peak power spectrum model (see [C3]) shall be used, based on the recommendations given in DNV standards [C6] and [C3] .

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-3.5 Wind-Wave Combined Conditions

Only the correlation between the mean wind speed and the significant wave height is available for West of Barra site.

A-3.5.1 Wind-Wave climate Scattergrams

Significant Wave Height[m]	Mean Wind Speed at 10 m (m/s)												
	0,00-0,30	0,30-1,60	1,60-3,40	3,40-5,50	5,50-8,00	8,00-10,80	10,80-13,90	13,90-17,20	17,20-20,80	20,80-24,50	24,50-28,50	28,50-32,70	32,70-51,50
0,00-0,50						1							
0,50-1,00		5	1054	2316	897	14	1						
1,00-1,50		14	1061	4055	5701	1444	9						
1,50-2,00		1	632	2070	5126	4736	335	1					
2,00-2,50		3	284	1083	3024	5167	1809	21					
2,50-3,00			139	468	1570	3645	2933	169					
3,00-3,50			58	197	762	2080	2981	550	3				
3,50-4,00			40	119	398	1190	2586	997	21				
4,00-4,50			4	33	193	747	2157	1324	96				
4,50-5,00			2	10	81	409	1441	1418	164				
5,00-5,50			1	10	32	184	767	1180	301	6			
5,50-6,00				1	22	87	452	869	370	21			
6,00-6,50					4	39	207	532	320	25			
6,50-7,00					3	12	116	463	334	24			
7,00-7,50						12	64	276	194	31	1		
7,50-8,00						2	38	195	137	44			
8,00-8,50						2	22	152	138	33	3		
8,50-9,00						2	10	98	201	45	3		
9,00-13,50							6	106	458	258	79	2	
13,50-20,00													

Table 76: Wind- Wave combined distribution: Hs-u_{10} correlation

A-3.5.2 Wind-Wave misalignments

No metocean data is available about the correlation of wind directionality and wave directionality. On that base, the wind-wave misalignment should be defined in WP7 based on standards for the development of the required DLCs.

A-3.6 Currents Data

Please refer to D1.1 "*Definition of the target locations: business cases*" for further information.

A-3.6.1 Current Induced by Wind

Return period [years]	Wind induced current speed (at surface)[m/s]
1	0,88
50	1,15

Table 77: Current induced by wind speed at sea surface

A-3.6.2 Deep Water Current

Return period [years]	Tidal current		Storm surge current		Combined current	
	Vc[m/s]	Dir[°]	Vc[m/s]	Dir[°]	Vc[m/s]	Dir[°]
1	0,39	50	0,53	0	0,84	21
50	0,44	50	0,60	0	0,94	21

Table 78: Deep water current speed at sea surface

A-3.6.3 Current Speed Profile

According to DNV-RP-C205 [C3] , the two following mathematical models can be used to estimate the variation of current speed with depth depending on the type of current under consideration:

Current induced by wind

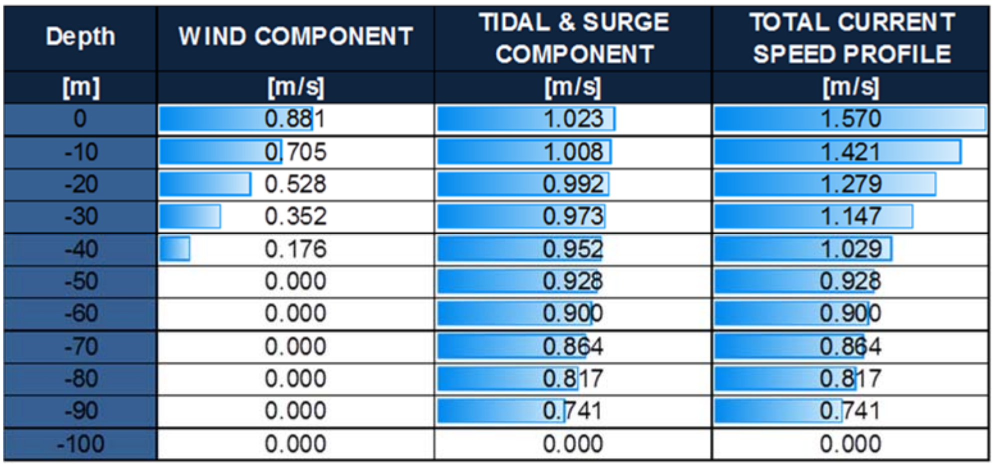
$$v_{c,wind}(z) = v_{c,wind}(0) \cdot \left(\frac{d_0 + z}{d_0}\right) \; for - d_0 \leq z \leq 0 \tag{29}$$

Where d_0 is taken as half of the water depth at West of Barra following DNV recommendations, hence $d_0 = 50\ m$

Tidal current

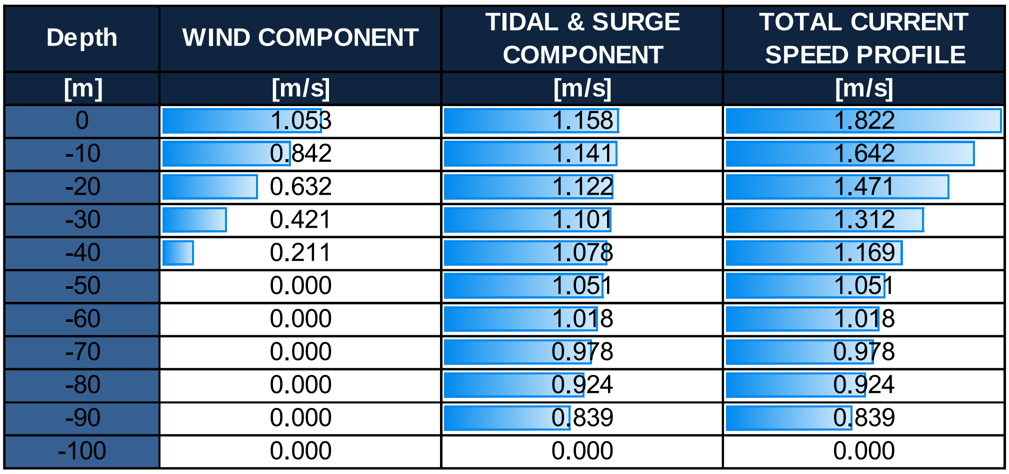
$$v_{c,tide}(z) = v_{c,tide}(0) \cdot \left(\frac{d + z}{d}\right)^{\alpha} \; for\ z \leq 0 \tag{30}$$

Resulting current speed profiles for each of the currents defined in section A-3.6.1 and A-3.6.1 are given in the following tables for the 1-year and 50-year return period currents respectively. Last column of this table represents the vectorial summation of the aforementioned component.



Depth [m]	WIND COMPONENT [m/s]	TIDAL & SURGE COMPONENT [m/s]	TOTAL CURRENT SPEED PROFILE [m/s]
0	0.881	1.023	1.570
-10	0.705	1.008	1.421
-20	0.528	0.992	1.279
-30	0.352	0.973	1.147
-40	0.176	0.952	1.029
-50	0.000	0.928	0.928
-60	0.000	0.900	0.900
-70	0.000	0.864	0.864
-80	0.000	0.817	0.817
-90	0.000	0.741	0.741
-100	0.000	0.000	0.000

Figure 36: 1 Total current speed profile associated to the 1 year return period probability



Depth [m]	WIND COMPONENT [m/s]	TIDAL & SURGE COMPONENT [m/s]	TOTAL CURRENT SPEED PROFILE [m/s]
0	1.053	1.158	1.822
-10	0.842	1.141	1.642
-20	0.632	1.122	1.471
-30	0.421	1.101	1.312
-40	0.211	1.078	1.169
-50	0.000	1.051	1.051
-60	0.000	1.018	1.018
-70	0.000	0.978	0.978
-80	0.000	0.924	0.924
-90	0.000	0.839	0.839
-100	0.000	0.000	0.000

Figure 37: Total current speed profile associated to the 50 years return period probability

A-3.6.4 Current Directionality

Most probable current speed directions can be provided.

	Most probable heading	
	Direction[º]	Compass Coordinates
Wind induced current	90	E
Tidal & Surge current	21	NNE
(*) 0º direction is relative to North.		

Table 79: Most probable current directionality

A-3.6.5 Current characteristic reference values (1 and 50 years return period)

	Return period[years]	Current speed[m/s]
Current Speed extreme values	50	1,82
	1	1,57

Table 80: Reference values for current speed in WoB

A-3.7 Soil Conditions

Soil conditions for West of Barra selected site has been agreed taking into account the reference information available in public sources, which defines the characteristic soil type in the selected site has mainly a rocky type seabed (high compression resistance, similar to granite), but considering a standard profile, which was defined inside WP1.

Soil Profile Characteristics			
Layer	Soil Type	Depth Range[m]	Compressive strength[MPa]
1	Rock (Basalt)	>0	200

Table 81: Soil profile designed for WoB selected site

A-3.8 Other Environmental Conditions

A-3.8.1 Ice (sea spray/precipitation)

No specific information is available on site. However in the following clause it has been summarized relevant information to account for this environmental condition in the design. Please refer to D1.1 "*Definition of the target locations: business cases*" for further information.

A-3.8.1.1 Sea ice and Iceberg

Figure 38 shows limit areas in the North-West Europe region for sea ice and collision with icebergs events with an associated annual probability of exceedance of 10^{-2} and 10^{-4}.

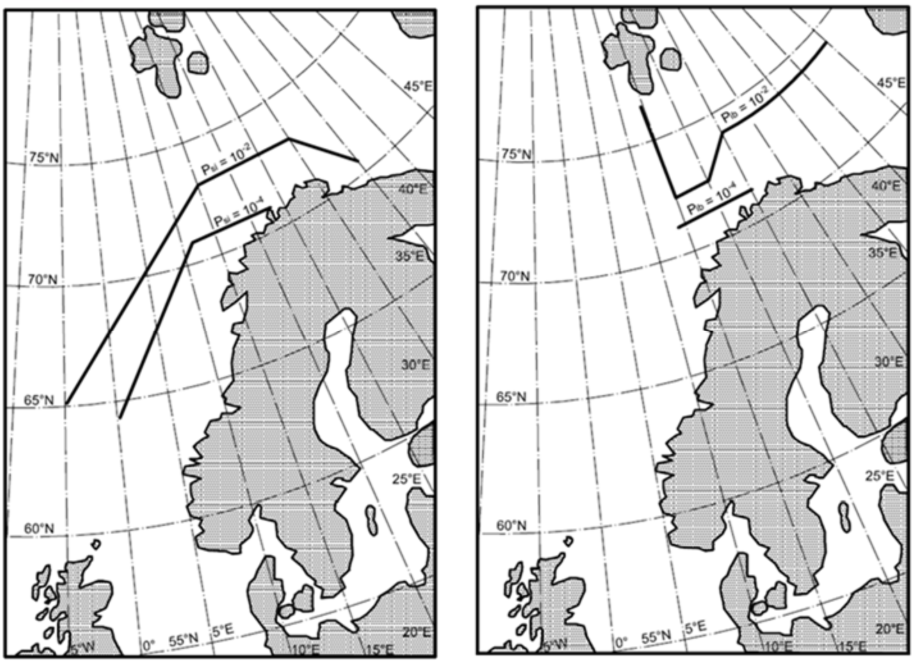


Figure 38: Annual probabilities of exceedance for sea ice (left) and collision with icebergs (right). ISO 19901-1:2005[C7]

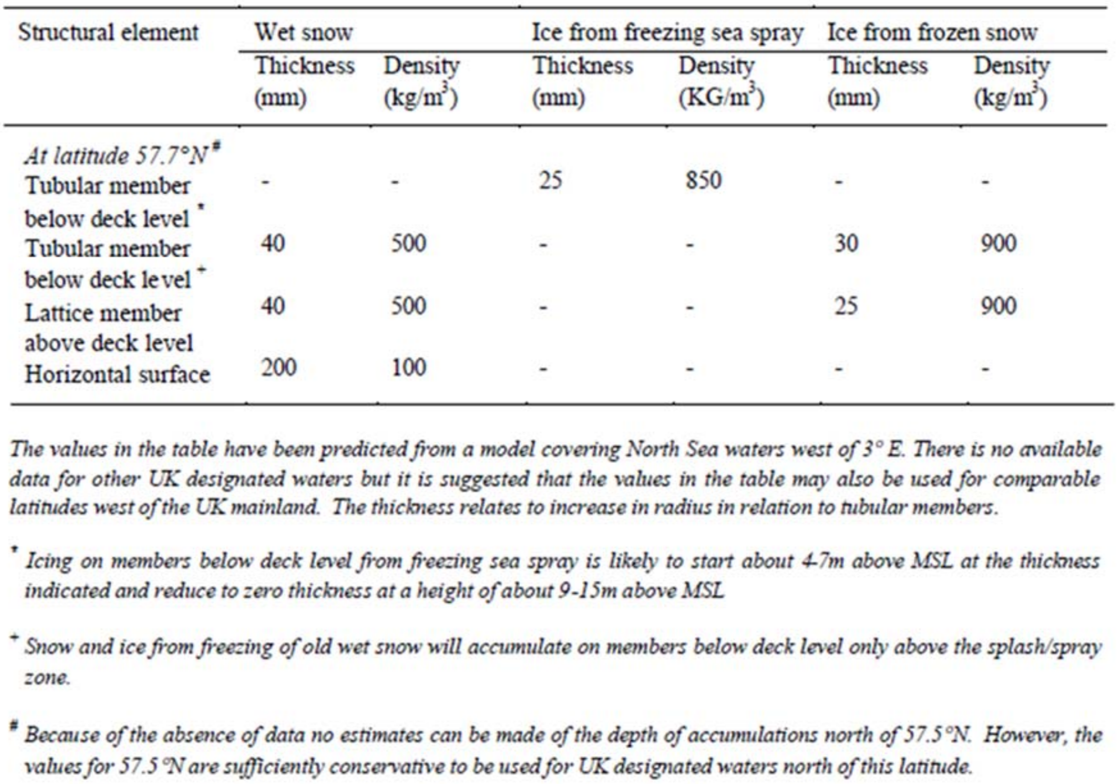
West of Barra site is located on a region where these events have an associated annual probability of exceedance lower than 10^{-4}.

A-3.8.1.2 . Ice and snow accumulation

Snow accumulation is more likely to occur than ice at West of Barra. Snow may settle on non-horizontal windward-facing parts of an installation if the snow is sufficiently wet.

On vertical surfaces it is only likely to stay in position as snow for a few hours although it may then freeze hence remaining as ice. Snow accumulation will affect all exposed elements above the splash/spray zone.

Figure 39 provides indicative values for snow and ice accumulation at 57.7 º N.



Structural element	Wet snow		Ice from freezing sea spray		Ice from frozen snow	
	Thickness (mm)	Density (kg/m^3)	Thickness (mm)	Density (KG/m^3)	Thickness (mm)	Density (kg/m^3)
At latitude 57.7°N[#]						
Tubular member below deck level [*]	-	-	25	850	-	-
Tubular member below deck level [+]	40	500	-	-	30	900
Lattice member above deck level	40	500	-	-	25	900
Horizontal surface	200	100	-	-	-	-

The values in the table have been predicted from a model covering North Sea waters west of 3° E. There is no available data for other UK designated waters but it is suggested that the values in the table may also be used for comparable latitudes west of the UK mainland. The thickness relates to increase in radius in relation to tubular members.

[*] *Icing on members below deck level from freezing sea spray is likely to start about 4-7m above MSL at the thickness indicated and reduce to zero thickness at a height of about 9-15m above MSL*

[+] *Snow and ice from freezing of old wet snow will accumulate on members below deck level only above the splash/spray zone.*

[#] *Because of the absence of data no estimates can be made of the depth of accumulations north of 57.5°N. However, the values for 57.5°N are sufficiently conservative to be used for UK designated waters north of this latitude.*

Figure 39: Extreme snow and ice accumulations. Source OTH 2001/010 [C8]

A-3.8.2 Sea Water Characteristics

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-3.8.2.1 Temperature

Measurement depth[m]	Sea water temperature[ºC]		
	Maximum	Mean	Minimum
Sea surface	18,0	10,4	4,0

Table 82: Sea water temperature

A-3.8.2.2 Density

Measurement depth[m]	Sea water density[kg/m3]		
	Maximum	Mean	Minimum
Sea surface	1.026,4	1.024,2	1.019,3

Table 83: Sea water density

A-3.8.2.3 Salinity

Measurement depth[m]	Sea water salinity[psu]		
	Maximum	Mean	Minimum
Sea surface	-	35,0	-

Table 84: Sea water salinity

A-3.8.3 . Air Characteristics

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-3.8.3.1 Temperature

Air temperature at West of Barra		
Probable extreme max air temperature	22	[º C]
Probable extreme min air temperature	-4	[º C]
LODMAT	-4	[º C]

Table 85: Air temperature at sea level

A-3.8.3.2 Density

No specific information is available on site. Air density may be considered as 1.225 kg/m^3 following IEC 61400 [B5] standard.

A-3.8.4 Marine Growth

The following thickness of marine growth can be taken according to NORSOK N-003:

Marine Growth	
Water Depth [m]	Thickness[mm]
+2 to -40	100
below -40	50

Table 86: Thickness increasing due to marine growth in GoM [C6]

The density of marine growth may be set to 1.325 kg/m3.

Please refer to D1.1 “*Definition of the target locations: business cases*” for further information.

A-3.8.5 Seismicity

The UK does not have a significantly high seismicity activity; however it may pose a moderate potential hazard to sensitive installations. Figure 40 contains on the left side onshore and offshore UK´s earthquakes recorded up to 2007 and on the right side the revised seismic hazard map for the UK.

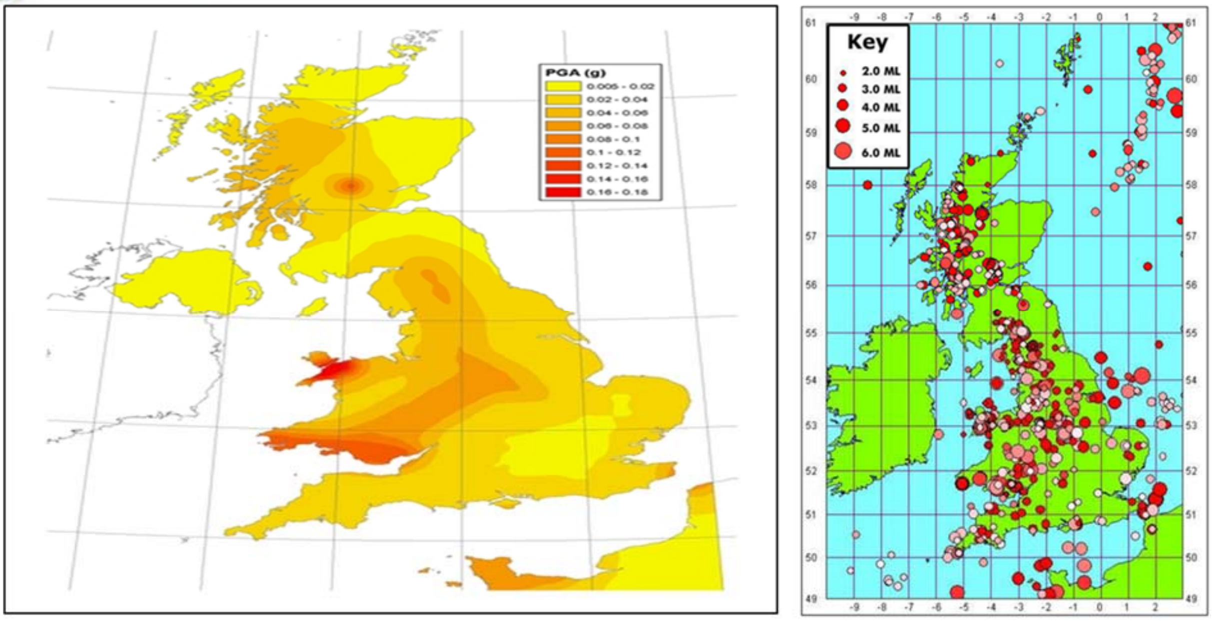


Figure 40: Seismic Hazard Map for the UK (Left side). Historical earthquakes recoded at UK until 2007 [C7]

As illustrated in previous figure, the UK areas subjected to highest seismic hazard is Snowdonia followed by South of Wales. Moreover, studies carried out by EQE International Limited in conjunction with NORSAR (Oslo) for the Health and Safety Executive (HSE) classifies the West of Barra area as sparsely active.

A-4 Selected Site Reference Data Summary

Met-ocean key parameters						
Modelling DNV-0S-J101 Sec3		**Parameters**	**Gulf of Maine**	**West of Barra**	**Golfe de Fos**	**units**
Wind		**$U_{mean,\ hub}$**	10,46	11,74	-	**m/s**
	EWM (3.2.5.4)	**$U_{10,hub,50\text{-}yr}$ (*)**	44,0	50,0	37,0	**m/s**
		$U_{hub,50\text{-}yr} = 1{,}4 \cdot U_{10,hub,50\text{-}yr}$	61,6	70,0	51,8	**m/s**
		$U_{hub,1\text{-}yr} = 0{,}8 \cdot U_{hub,50\text{-}yr}$	48,9	56,0	41,4	**m/s**
		$\sigma_U = 0.11 \cdot U_{10,hub}$	4,8	5,5	4,1	**-**
Waves	**ESS (3.3.4.7)**	**$H_{s,50\text{-}yr}$;[$T_{p,min}$; $T_{p,max}$]**	10,9[9-16]	15,6[12-18]	7,5[8-11]	**m;[s;s]**
		$H_{s,1\text{-}yr}$;[$T_{p,min}$; $T_{p,max}$]	7,7[9-16]	11,5[12-18]	4[6-11]	**m;[s;s]**
Current	**ECS**	**$V_{c,50\text{-}yr}$**	1,13	1,82	0,9	**m/s**
Water level	**MSL**		130 (+1,624)	100 (+2,32)	70 (+0,74)	**m**
	EWLR	**$HSWL_{50\text{-}yr}$**	4,319	4,16	1,13	**m**
		$LSWL_{50\text{-}yr}$	-0,795	-2,48	-0,35	**m**
Soil Type (compressive resistance)			Medium	Hard (rock)	Soft	**-**
Soil conditions	**Compressive Strength**		-	200 (Basalt)	-	**Mpa**
	Layer length		-	20	-	**m**
	Friction angle Layer 1		35 (very dense sand)	-	30 (dense sand)	**phi/kPa (**)**
	Layer 1 length		4	-	3	**m**
	Friction angle Layer 2		60 (soft clay)	-	60 (soft clay)	**phi/kPa (**)**
	Layer 2 length		6	-	4	**m**
	Friction angle Layer 3		200 (stiff clay)	-	250 (stiff clay)	**phi/kPa (**)**
	Layer 3 length		9	-	10	**m**
Others (*)	**Water temperature (3.8.3.1)**	**$T_{max,50\text{-}yr}$**	22,5	19	30	**ºC**
		$T_{min,50\text{-}yr}$	1	3	5	**ºC**
	Marine growth DNV-RP-C205 6.7.4.2	**Thickness**	See section A-2.8.4	See section A-3.8.4	100	**mm**
		density	1.325	1.325	1.325	**kg/m^3**

(*) Density and temperature data are measured at 1m depth.

(**) phi(º) if sand Cu (kPa) if clay

Figure 41: Summary table for selected sites characterization

A-5 References

A-5.1 Site A: Moderate Environmental Conditions. Golf de Fos

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A-5.2 Site B: Medium Environmental Conditions. Gulf of Maine

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