Co-location Opportunities for RENewable energies and AQUAculture facilities, decision support for operational Multi-Use Platform activities at coastal areas”

(RENAQUA Decision Support System)

Usefulness of the CMEMS Products

15th January 2020

INDEX

List of Acronyms

DIAS	Data Information Access Service
DSS	Decision Support System
HSOM	Health - Safety and Operational Maintenance
IH-MSP	IHCantabria's Platform for Marine Spatial Planning
M2M	Machine to machine communication
Metocean	meteo-oceoanographic
MINECO	Spanish Ministry of Economy, Industry and Competitiveness
MITECO	Spanish Ministry for the Ecological Transition
MRE	Marine Renewable Energy
MUP	Multi-Use Platforms
NCEP	National Centers for Environmental Predictions
NCML	NetCDF Markup Language
NGA	National Geospatial Intelligence Agency
NOAA	National Oceanic and Atmospheric Administration
O&M	Operations & Maintenance
OGC	Open Geospatial Consortium
RENAQUA	RENewable energies and AQUAculture facilities
SDGs	Sustainable Development Goals
TDS	THREDDS Data server
UCLA	University of California, Los Angeles
UI	User Interface
UX	User Experience
WCS	Web Coverage Service
WEkEO	We knowledge Earth Obsevation
WMS	Web Map Service

1 CMEMS PRODUCTS IN THE RENAQUA SERVICE

The RENAQUA DSS is a CMEMS DEMONSTRATION that provides a Global service for the Aquaculture and Marine Renewable Energy Sectors. This downstream service provides information about the opportunities for marine fish and marine renewable energy farming at Global scale.

This study analysed the potential zones for the exploitation of offshore wind and wave energy at the global scale, as well as the opportunities for co-location (sites which are suitable for both wind and wave energy). The proposed methodology was based on a five-step approach, comprised of:

- (i) a wind and wave energy resource assessment, to identify zones with favourable conditions for energy exploitation;
- (ii) a structural survivability assessment, to identify feasible areas likely to ensure the integrity and durability of the wind and wave devices;
- (iii) a logistics assessment, to evaluate the possibility of carrying out installation, operations, and maintenance activities;
- (iv) an assessment of the distance to consumer centers, to estimate the feasibility of transmission to the main urban areas; and
- (v) an estimate of the extractable power of the identified potential zones.

The suitability of the study areas (coastlines with depths of up to 500 m) was estimated using the suitability index, regarding the probability of meeting favourable conditions for each evaluated aspect. Long-term data series with fine spatial and temporal resolutions were used to evaluate the spatiotemporal dynamics of metocean conditions.

1.1 MARINE RENEWABLE ENERGY (MRE)

Energy exploitation feasibility is based on the assessment of independent and complementary aspects regarding the operation of wave and wind farms. Wave and wind conditions were analysed to estimate energy production. Elements related to the integrity and durability of offshore structures were evaluated according to the severity of meteorological-ocean conditions. Operational suitability regarded the possibility of carrying out operation and maintenance (O&M) activities on offshore energy platforms. The suitability for energy transport was evaluated based on the proximity of electrical substations. At local scale, Operational HSOM was developed making use of downscaling techniques. Table 2 provides a summary of the inputs, indicators generated and final output.

Marine Renewable Energy (MRE)		
Inputs	**Indicator**	**Result**
• Type of device • MetOcean conditions	Energy resource suitability	Renewable energy opportunities (suitable zones worldwide)
• Marine structure parameters • MetOcean conditions	Structural suitability	
• Type of device • O&M requirements	Operational suitability	
• O&M requirements	Consumer centers	
• MetOcean conditions	HSOM	Accessibility and maintenance of the BiMEP Platform (local scale)

Table 2. RENAQUA DSS - MRE data-flow

Datasets for energy resource suitability

MRE resource suitability				
Variable	**Data Source / Product**	**Spatial resolution**	**Temporal resolution**	**Period**
Waves resource: - (CGE ≥ 15 kW/m) - (1 ≤ Hs ≤ 6 m) - (5 ≤ Tp ≤ 14 s)	GOW (IHCantabria)	0,25	Daily	1979 - 2010
Wind resource: - (≥ 400 W/m2)	NCEP Climate Forecast System Reanalysis	0,027	Hourly	1985 - 2015

Table 3. MRE – resource suitability

Energy production suitability was obtained by the mean of available energy, significant wave height, peak wave period and wind speed values. Thresholds of these elements were considered to estimate wave and wind energy production. Wind exploitation was evaluated based on the percentage of time the wind speed and its available potential remain within the production threshold. In addition, maximum significant wave height for which turbines shut down production due to safety reasons was also considered. The wave energy suitability assessment was based on the percentage of time a site presented waves that could be harvested energetically, within wave height and period thresholds. Wave energy flow was also considered, since this parameter indicates the availability of resources.

Datasets for structural suitability

MRE - structural suitability				
Variable	**Data Source / Product**	**Spatial resolution**	**Temporal resolution**	**Period**
Bathymetry	ETOPO	0,017	-	2015
Waves (RP50 ≤ 15 m)	GOW (IHCantabria)	0,25	Daily	1979 - 2010
Wind (≤ 40 m/s)	NCEP Climate Forecast System Reanalysis	0,027	Hourly	1985 – 2015
Currents (≤ 2 m/s)	GLOBAL_REANALYSIS_PHY_001_030	0,083	Daily	1993 - 2016

Table 4. MRE – structural suitability

Structural suitability was obtained by integrating V50, Hs50, C50 with the critical value method (minimum value of suitability). Extreme conditions (50-year return period) for different elements were considered as reference parameters to evaluate site severity and influence on design and structure. These conditions were evaluated according to the percentage of time that currents, wave and wind variables met the established thresholds over the entire time series.

Datasets for operational suitability

MRE - operational suitability				
Variable	**Data Source / Product**	**Spatial resolution**	**Temporal resolution**	**Period**
Waves (Hs ≤ 2 m)	GOW (IHCantabria)	0,25	Daily	1979 - 2010
Wind (≤ 10 m/s)	NCEP Climate Forecast System Reanalysis	0,027	Hourly	1985 – 2015
Distance to Port	World Port Index (NGA)	-	-	2014

Table 11. MRE – operational suitability

Operational suitability was determined by the weighted mean of distance to the ports, wind speed and significant wave height values. Feasibility to conduct O&M activities considered distance to ports and site accessibility. The distance to the nearest port was calculated based on an Euclidean distance up to 40 km, considering that smaller distances have higher suitability and vice versa (0 - 1 scale). Accessibility was determined by the number of 8-hour weather windows that occur per year to perform vessel-structure access maneuvers, according to the thresholds considered.

Datasets for consumer centers

MRE – consumer centers				
Variable	**Data Source / Product**	**Spatial resolution**	**Temporal resolution**	**Period**
Distance to Centers	World Urban Areas (UCLA)	-	-	2014

Table 12. MRE – consumer centers

The suitability of a site regarding energy transport was estimated calculating the Euclidean distance of the nearest electrical substations. The premise considered was that the closer an offshore farm is to an energy substation, the lower the cost of installation and energy losses due to dissipation. Energy transport suitability values were calculated according to the maximum distances considered.

Datasets for Operational HSOM

At local scale, several downscaling techniques were implemented for HSOM activities:

TRL Plus DSS		
Variable	**Data Source / Product**	**Downscaling technique**
Currents	IBI_ANALYSIS_FORECAST_PHYS_005_001	COAWST model
Waves	IBI_ANALYSIS_FORECAST_WAV_005 005	SWAN model
Winds	HARMONY (AEMET)	Statistical downscaling

Table 13. TRL Plus DSS – CMEMS products

- Currents - COAWSTbimep oceanographic operational system is based on COAWST modelling system (a Coupled-Ocean-Atmosphere-Wave-Sediment Transport Modelling System) (Warner et al., 2010). COAWST is comprised of the Model Coupling Toolkit to exchange data fields between the ocean model ROMS, the atmosphere model WRF, the wave model SWAN, and the sediment capabilities of the Community Sediment Transport Model.
- Waves - The numerical model SWAN (Simulation Waves Nearshore; N Booij et al 1999), version 41.01, is used in the wave prediction system. The wave prediction system provides a 4-day wave conditions forecast (the first 2 days is forcing with HARMONIE winds, the next 2 days with Winds BiMEP Operational) with hourly resolution. The system is daily run. Different data providers are used to run the SWAN model.
- Winds - The hybrid downscaling method combines the numerical modelling (dynamical downscaling) with mathematical tools (statistical downscaling). Different MetOcean data sets and services are necessary to apply the hybrid downscaling method. The

high-resolution dataset and the predictor are hindcast data and the predictand is forecast data. Two different configurations of predictor and predictand were selected to predict the wind speed, in order to cover different temporal horizons and to get different forecasts in the area. In the first configuration, the predictor is the wind from the Global atmospheric reanalysis CFSR (Climate Forecast System Reanalysis, Saha et al. 2010) and the predictand is the wind from the Global Forecast System (GFS, NCEP Office Note 442, 2003), which is the operational data provider. In the second configuration, the predictors are the winds from SeaWind BiMEP (Metocean Analysis of BiMEP for Offshore Design, www.trlplus.com/metoceaninformation). The predictands are the winds from the model HARMONIE (HIRLAM-ALADIN Research on Meso-scale Operational NWP In METOCEAN PREDICTION SYSTEM FOR BIMEP 12 Europe. Simarro and Hortal, 2012).

The downscaled metocean information is finally used to simulate the mooring behaviour and the accessibility to the BiMEP Platfrom.

The mooring behaviour is calculated providing 5 aerodynamic solver types, QuasiStatic or Dynamic: the QuasiStatic solver defines the thrust and generated power developed over the turbine rotor by using a look-up table. The look up table relates the wind velocity perceived by the rotor with the correspondent rotor Ct (thrust coefficient) and Cp (power coefficient) coefficients. The velocity perceived by the rotor takes into account the incoming wind speed and the velocity of the rotor movement.

- Constant. The QuasiStatic Constant option defines the incoming wind speed as a 3-components vector defined in a Cartesian reference system with origin in the rotor center, the x-axis perpendicular to the turbine rotor, and the z-axis parallel to the tower and pointing upward.
- Uniform. The QuasiStatic Uniform option generates an incoming wind speed field variable in time with a constant pattern in space, a time series that defines the fluctuation of a velocity 3-components vector. The series is defined by the user in a table which relates arbitrary time points with a velocity 3-components vector. The vector is defined in a Cartesian reference with origin in the rotor center, the x-axis perpendicular to the turbine rotor and the z-axis parallel to the tower and pointing upward. Values between the user defines set points are obtained by linear interpolation.

The Dynamic solver is based in an unsteady BEM model (Hansen 2015). Such model is based on the momentum balance of the mass of air passing throughout the rotor and resolve the velocity triangle in each node of the discretized rotor blades. The aerodynamic forces calculated in each node are integrated to find the forces and moments developed over the entire rotor. In order to simulate the turbine controller operations, the BEM model is linked with the Basic DTU Wind Energy controller (Hansen 2013), which has been tuned to avoid negative damping effects.

- Constant. The Dynamic Constant option creates a steady incoming wind speed over the rotor. Such velocity field is set by defining a 3-components vector at the rotor center position. The vector is defined in a Cartesian reference system with axes parallel to the inertial reference frame, and with origin at the rotor center. Thus, the relative orientation between the turbine rotor and the wind speed direction changes with rotor movements. The distribution of the incoming wind velocity in space is defined by a wind profile characterized by the exponential law with exponent equal to 0.14.
- Uniform. The Dynamic Uniform option sets an incoming wind velocity field variable in time with a constant pattern in space. Such information is provided by the user in a table which relates arbitrary time points with a velocity 3-components vector. The vector is defined in a Cartesian reference system with axes parallel to the inertial reference frame, and with origin at the rotor center. Thus, the relative orientation between the turbine rotor and the wind speed direction changes with rotor movements. The distribution of the incoming wind velocity in space is defined by a wind profile characterized by the exponential law with exponent equal to 0.14
- 3D full field. The Dynamic 3D full field option generate an incoming wind velocity field variable in time and space. The wind dataset is built with TurbSim (Jonkman 2006), a stochastic, full-field, turbulent-wind simulator developed at NREL by using a Kaimal turbulence model. The user provides the mean wind velocity, the IEC 61400 1 turbulent class and the wind main direction.

The downscaled meteocean data is also used to other of the main modules for the TRL Plus DSS, the dynamic analysis of accessibility to the BiMEP Platform. An accessibility module capable to evaluate the coupled dynamics of a floating concept and a crew transfer vessel. This is a crucial issue for O&M strategies and the management of the different tests at BiMEP. Running floating wind turbines in a long-term perspective still presents large uncertainties, due to the exposure of such systems to severe metocean conditions and the short experience with full-scale prototypes. Generally speaking, boats can ensure personnel transfer in two ways: either landing on the wind turbine through a fender and a structure-mounted ladder or using gangways through which people can walk to the wind turbine. Due to the BiMEP characteristics, the main accessibility system will be by structure-mounted ladder.
A proof of concept is shown here. It attempts to evidence the technical capabilities that TRL+ provides as a potential service provider. The floating platform chosen in this study is the OC4 semi-submersible, designed by the National Renewable Energy Laboratory NREL. This system is conceived to support a 5MW wind turbine and is composed of a main column and three off set columns (equipped with heave plates). It is moored to the seabed by means of three

catenary lines, see Figure 1. The platform is assumed to be approached, for inspection or maintenance, by a small crew transfer catamaran vessel equipped with a fender on its bow.

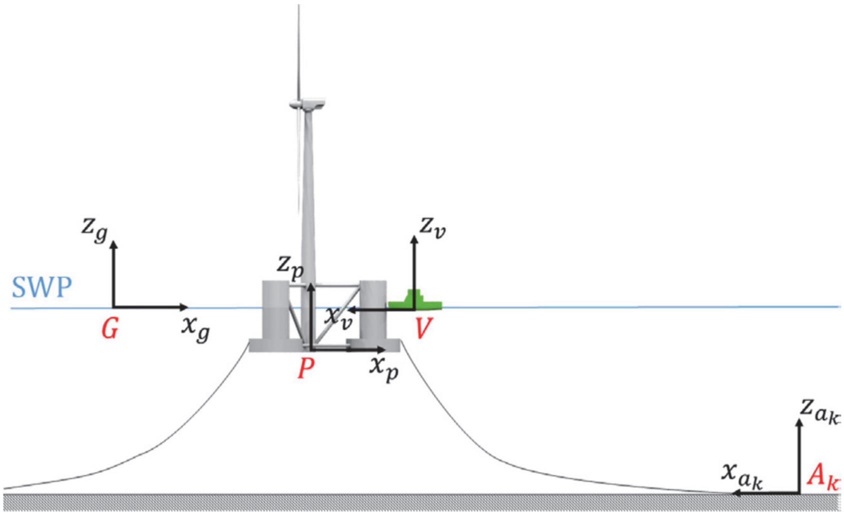

Figure 1. Schema of a floating wind turbine

The methodology proposed it is based in a multi-body hydrodynamic frequency domain simulation (Guanche *et al* 2016). A frequency domain approach implies the assumption of linear force-displacements relationships; therefore, potential non-linear phenomena have been linearized accordingly, including the mooring system. A set of transfer functions were built upon the basis of the motion restrictions of a coupled vessel-platform system. Based on them it is possible to calculate short-term response given certain wave conditions and statistical assumptions.

It has to be noticed that the implementation carried out in the DSS TRL+ includes the following restrictions to the relative movement between the vessel and the platform, which are more complex that those included in the Guanche R. et al 2016 in order to have a more realistic performance of the system: relative yaw, pitch and roll limitations and relative vertical displacements.

The results of the calculation of limiting significant wave height are shown in the following accessibility rose, a polar diagram see Figure 2, where the angular position indicates the wave heading with respect to the vessel while the radial position indicates the wave peak period. The limiting significant wave height was computed comparing the relative movements transfer functions with the operational limits shown in the top left corner of the figure, where the confidence factor (p = 0.5) is also shown.

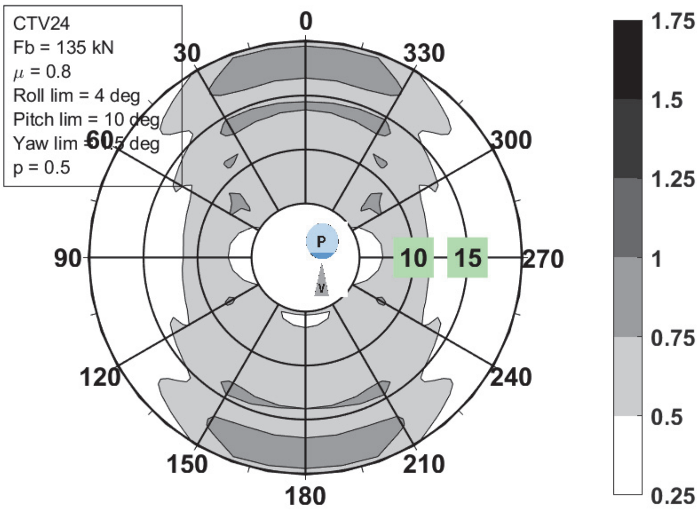

Figure 2. Accessibility rose for the BiMEP Platform

Finally, when the accessibility rose is known, computing the accessibility for the current sea state only implies considering the platform orientation and doing a simple 2D interpolation.

1.2 AQUACULTURE

In the case of the aquaculture activity, the system recognizes suitable zones for open sea fish farming according to the biological requirements for the fish (biological suitability), the structural resistance of the cage (structural suitability) and the O&M activities (operational suitability). Biological suitability regarded the adequacy of environmental conditions (physicochemical factors) to the farming requirements necessary for fish growth. The integrity and durability of the cage against meteorological-ocean conditions were evaluated by structural suitability. Operational suitability evaluated the feasibility of carrying out O&M activities in the cage (feeding, fishing, cleaning, among others). At local scale, Operational HSOM was developed making use of available metocean downscaled products. The following table provides a summary of the inputs, indicators generated and final output.

Aquaculture		
Inputs	**Indicator**	**Result**
• 7 marine fish • Physicochemical factors • Fish requirements	Biological suitability	Fish farming opportunities (suitable zones wordwide)
• MetOcean conditions • Cage parameters	Structural suitability	
• MetOcean conditions	Operational suitability	

• O&M requirements		
• MetOcean conditions	HSOM	Accessibility and maintenance of the PIAGUA Platform (local scale)

Table 4. RENAQUA DSS - Aquaculture data-flow

Physicochemical Factors for biological suitability

Aquaculture – biological suitability				
Variable	**Data Source / Product**	**Spatial resolution**	**Temporal resolution**	**Period**
Temperature (SST)	Copernicus GLOBAL_REANALYSIS_PHY_001_030	0,083	Daily	1993 - 2016
Salinity	Copernicus GLOBAL_REANALYSIS_PHY_001_030	0,083	Daily	1993 - 2016

Table 5. Aquaculture - biological suitability

Biological suitability thresholds are based on previous studies (Gifford et al., 2001; Santhanam et al., 2015; UNDP/FAO, 1989) and a specialized information system (Froese and Pauly, 2015). For optimum species growth, cage location needs to meet certain conditions in concomitance, regarding temperature and salinity. Therefore, these variables were evaluated according to the percentage of time they remained within the biological thresholds for each species over the entire time series.

Datasets for structural suitability

Aquaculture – structural suitability				
Variable	**Data Source / Product**	**Spatial resolution**	**Temporal resolution**	**Period**
Bathymetry	ETOPO and EMODNET	0,017 / 0,001	-	2015 / 2018
Slope	ETOPO and EMODNET	0,017 / 0,001	-	2015 / 2018
Waves (<5m)	GOW (IHCantabria)	0,25	Daily	1979 - 2010
Currents (<1,5m/s)	GLOBAL_REANALYSIS_PHY_001_030	0,083	Daily	1993 - 2016

Table 6. Aquaculture – structural suitability

Structural and operational thresholds were based on the Norwegian Standard NS 9415.E.2009 (Standard Norge, 2009). The suitability for structural strength of the cage has been defined according to integration, by the critical value method, of wave conditions (<5m) and currents

(<1,5m/s). The metocean conditions were determined by the percentage of time that the site presented suitable conditions according to the thresholds adopted.

Datasets for operational suitability

Aquaculture – operational suitability				
Variable	**Data Source / Product**	**Spatial resolution**	**Temporal resolution**	**Period**
Distance to Port	World Port Index (NGA)	-	-	2014
Waves (<1m)	GOW (IHCantabria)	0,25	Daily	1979 - 2010
Wind (<15 m/s)	NCEP Climate Forecast System Reanalysis	0,027	Hourly	1985 - 2015

Table 7. Aquaculture - operational suitability

The suitability to perform O&M activities in the cage was calculated using the weighted mean of the distance to ports and site accessibility elements. The thresholds were determined by the Euclidean distance to ports (up to 40 km), the significant wave height (<1m) and wind speed (15m/s) that promote weather windows.

Datasets for Operational HSOM

At local scale, the following table provides the downscaled metocean products required for the development of the PIAGUA DSS HSOM modules:

PIAGUA DSS		
Variable	**Data Source / Product**	**Downscaling technique**
currents / tide	IBI_ANALYSIS_FORECAST_PHYS_005_001	downscaling provided by Puertos del Estado
temperature	IBI_ANALYSIS_FORECAST_PHYS_005_001	downscaling provided by Puertos del Estado
salinity	IBI_ANALYSIS_FORECAST_PHYS_005_001	downscaling provided by Puertos del Estado
Waves	IBI_ANALYSIS_FORECAST_WAV_005_005	downscaling provided by Puertos del Estado
Wind	IMETEO	downscaling is not required

Table 8. PIAGUA DSS – CMEMS products

Puertos del Estado provides several operational forecast products that are downscaled from the Copernicus Marine Products (Sotillo 2019). The metocean data is accessible through their opendap catalogue (http://opendap.puertos.es).

Based on the downscaled metocean products the O&M activities for the PIAGUA farm are analysed: Suggested Feeding Rate (SFR) and operability.

The SFR index is calculated through a look-up table that relates the temperature and the % of food that should be provided, whereas the operability is based on three levels of thresholds, based on expert criteria, which provide the level of recommendation for Aquaculture activities in relation with forecasting metocean conditions (currents, winds and waves).

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