Marine Renewable Energy Resources Atlas for Western Iberia

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Abstract: Marine renewable energies comprehend a vast number of technologies including tidal, waves and offshore wind technologies. Numerical modelling contributes to support the development of such activities in several ways. Through atmospheric, waves and hydrodynamic models, areas with enough energetic resources for these industries could be identified. Furthermore, operation and maintenance services rely on the sea conditions that operational modelling is able to provide through forecasts services. The forecasts of extreme events is also be valuable for the survivability of the installed devices. In this communication, the off-shore wind, waves and tidal energy potential were obtained by exploring the results of numerical models for the Western Iberia region. This work will present the main outcomes of the EnergyMare Project (Atlantic area Interreg project Contract Number: 2011-1/157). The numerical models presented have been implemented operationally and their results and forecasts can be accessed at http://forecast.maretec.org/.

Key words: western Iberia, numerical modelling, MOHID, marine renewable energies, operational modelling, resource assessment.

1. INTRODUCTION

Marine renewable energies comprehend a vast number of technologies including tidal, waves and offshore wind technologies. Numerical modelling could contribute to support the development of such activities in several ways. Through atmospheric, waves and hydrodynamic models, the areas with enough energetic resource for these industries could be identified and operation and maintenance services (O&M Services) would be performed with safer seas through forecasts services. These forecasts could also be valuable for the survivability of the installed devices as extreme events could be identified and thus possible damages could be reduced by taking measures. Moreover, operational modelling could evaluate the amount of available energy and how much would be produced by the devices thus the electric system would be more efficient in accommodating the generated energy.

In this document, the off-shore wind, waves and tidal energy potential were obtained by exploring the results of numerical models for the Western Iberia region. The document consist on a description of the numerical model applications and the calculations performed with the modelling results to evaluate each marine renewable energy along with the maps that describe each resource. The full report including the validation of the numerical models could be found at Campuzano *et al.* (2015). The numerical models presented in this document have been implemented operationally and their results and forecasts are available at http://forecast.maretec.org/.

2. METHODS

2.1. Wind Power

In order to evaluate the wind power density for the development of offshore wind projects, wind intensities and directions were analysed by numerical model forecasts for a six-year period (Jun 2009-Jun 2015). Hourly model results were obtained by a MM5 model (Meteorological Model 5; Grell *et al.*, 1994) application based in two nested grids with a horizontal resolution of 27 km and 9 km respectively implemented by the IST meteorological group (http://meteo.ist.utl.pt; Trancoso, 2012).

Wind velocity model results at 10 m height were interpolated to a 0.06 degrees regular grid. Those values were transposed to 100 m height, which is the hub height commonly used by offshore wind developers, i.e. the WindFloat pre-commercial device to be installed in northern Portugal. The wind profile of the atmospheric boundary layer, until approximate 2 km, is generally best approximated using the log wind profile equation that accounts for surface roughness and atmospheric stability by using the following equation (Equation 1):

$$u=u_r(z/z_r)^{\alpha} \qquad \text{Equation 1}$$

where u is the wind speed at height z, and u_r is the known wind speed at a reference height z_r. The α exponent is an empirically derived coefficient that varies dependent upon the stability of the atmosphere and that according to Hsu *et al.* (1994) would have an optimum value of 0.11 for open water conditions. Replacing the values in Equation 1, wind speeds for the total period at 100 m would be obtained:

$$u_{100}=u_{10}(100/10)^{0.11}$$

With the average wind speed, the wind power density (P_{wind}) per m^2 of rotor swept area can be obtained by applying Equation 2:

$$P_{wind}= 1/2\rho|U|^3 \qquad \text{Equation 2}$$

where ρ correspond to the air density, 1.225 kgm^{-3}, and |U| is the modulus of the wind speed. Applying the formula to the 100 m height winds, the average wind power density for the six year period was obtained (Figure 1).

2.2. Wave Power

In order to model the generation, propagation and dynamics of the waves reaching the Portuguese continental coast the NOAA WAVEWATCH III (R) Model V3.14 was implemented.

In the case of the Portuguese coast, swell waves are generated in the western side of the Atlantic Ocean. To simulate the waves arriving to the Portuguese coast, three nested levels with increasing horizontal resolution -0.5, 0.25 and 0.05 degrees- covering the North Atlantic Ocean (NAt), the southwest part of Europe (SWE) and the Portuguese Continental Coast (PCC) respectively, were defined.

Two bathymetric sources were combined to populate all levels grids: the European Marine Observation and Data Network (EMODnet) Hydrography portal (http://www.emodnet-hydrography.eu) completed by the 30" resolution global bathymetry data SRTM30_PLUS (Becker *et al.*, 2009) for regions where EMODnet data were absent.

The wave energy resource was evaluated for the period 2000-2010. The NCEP FNL Operational Model Global Tropospheric Analyses, continuing from July 1999 with 1 degree of horizontal resolution (NCEP/NWS/NOAA/U.S. Department of Commerce, 2000) was used to feed the wave model with winds intensities and directions.

Wave power (P) in kilowatts (kW) per meter of wavefront length was estimated using the deep waters formula, valid for water depths larger than half the wavelength:

$$P = 0.49 * H_s^2 * T_m$$

where H_s correspond to the significant wave height and T_m is the average wave period. Once this formula is applied to the PCC domain for the 2000-2010 period,, it was obtained the wave power distribution for the PCC domain (Figure 2).

2.3. Tidal Power

In order to evaluate the tidal power for the Portuguese continental coast, a numerical model application was run using the MOHID Water model which is part of the MOHID Modelling System (http://www.mohid.com; Neves, 2013). MOHID is an open source numerical model programmed in ANSI FORTRAN 95 using an object orientated philosophy. This system is being developed since 1985 mainly by the MARETEC group at the Instituto Superior Técnico (IST) of the Universidade de Lisboa. The model adopted an object oriented philosophy integrating different scales and processes. The core of the model is a fully 3D hydrodynamic model which is coupled to different modules comprising water quality, atmosphere processes, discharges, oil dispersion, jet mixing zone model for point source discharges.

For this particular study, a 2-Dimensional domain covering the West Iberia region comprised by the range of latitudes (33.48N, 45.90N) and longitudes (4.20W, 13.50W) with a grid of 620x828 cells and a horizontal resolution of 0.015° (≈ 1.3 km) was set. That grid has been populated with bathymetric data derived from the EMODnet Hydrography portal. The MOHID water model was forced with the FES2012 global tide model (Carrère *et al.*, 2012) along the ocean boundary for the year 2011.

The power potential for square metre of cross-sectional area for the Portuguese Continental coast was obtained using Equation 3:

$$P= 1/2\rho|U|^3 \qquad \text{Equation 3}$$

where ρ is the density of water, 1027 kgm^{-3}, and |U| is the instantaneous current velocity (ms^{-1}). For this study the velocities used were the peak velocities associated to the spring and neap tides obtaining the Figure 3 and Figure 4 respectively.

3. RESULTS

3.1. Wind Power

Wind power shows a gradient from North to South in Western Iberia, with maximum values found in the Galicia region in Spain and decreasing landwards. In Portugal the resource appears to be relatively constant along its Western coast, while sheltered coasts in the Algarve region present the lowest values. Annual values above 200 Wm^{-2} can be found relatively close to the western Portuguese coasts. This resource presents a strong seasonality summer average power density is halve the annual value (Campuzano *et al.*, 2015).

3.2. Wave Power

Wave power distribution shows a clear gradient with a NW-SE orientation (Figure 2). Maximum values around 50 kWm^{-1} are found in the open ocean off the Northern coast while minimum values are located in the areas sheltered by geographic features from this direction i.e. the Tagus and Sado estuarine mouths and the Algarve southern coast. On average the Portuguese coastal area has a wave power around 30 kWm^{-1} though this value would present a strong seasonality. The obtained results were in agreement with the ones obtained by Pontes *et al.* (2003). Wave density power present a strong seasonality, spring and autumn values distributions and energy values are similar while maximum are obtained during the winter period and minimum during summer periods (Campuzano *et al*., 2015).

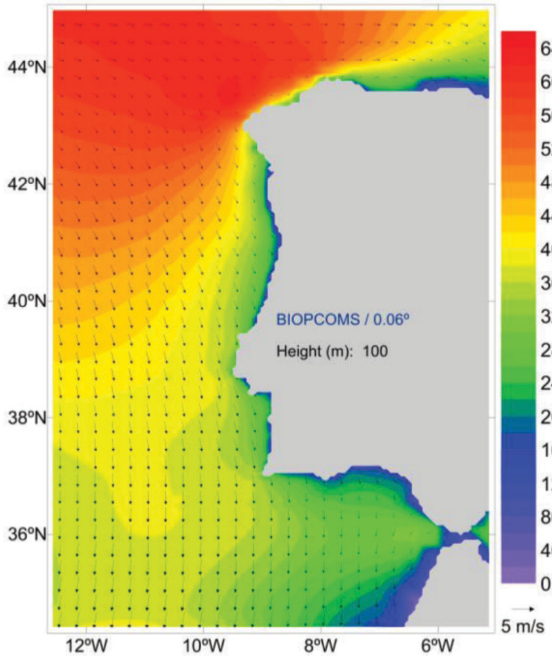

Fig. 1. Annual Mean Wind Power Density at 100 m in W/m2 for the Jun 2009-Jun 2015 period. Black arrows indicate the wind direction and intensity.

3.3. Tidal Power

Tidal power in the open ocean of the Portuguese coast is a less important marine renewable resource as peak velocities are generally under 1 ms^{-1}, even during spring tides. For that reason tidal power has been represented using a logarithmic scale (Figures 3 and 4). Maximum values due to the barotropic tide in Portugal are under 50 Wm^{-1} while in the Strait of Gibraltar region values are near 2800 Wm^{-1}.

Modelling results allow observing some of the circulation features present in Western Iberia as the Strait of Gibraltar circulation, the submarine mountains signal and the currents occurring in the Tagus Plateau in central Portugal. The latter feature has been identified as a diurnal trapped continental shelf wave (CSW) which generation is linked to the coastal bathymetry (Fortunato *et al.*, 2002; Quaresma and Pichon, 2013). The Tagus Plateau CSW would increase the currents intensities on that region influencing the peak velocities observed during spring and neap tides and their associated energy (Figures 3 and 4). In general the obtained tidal energy values are very low when compared to some locations in the UK coast with areas with higher power than 20 KWm^{-1} (ABPmer, 2008).

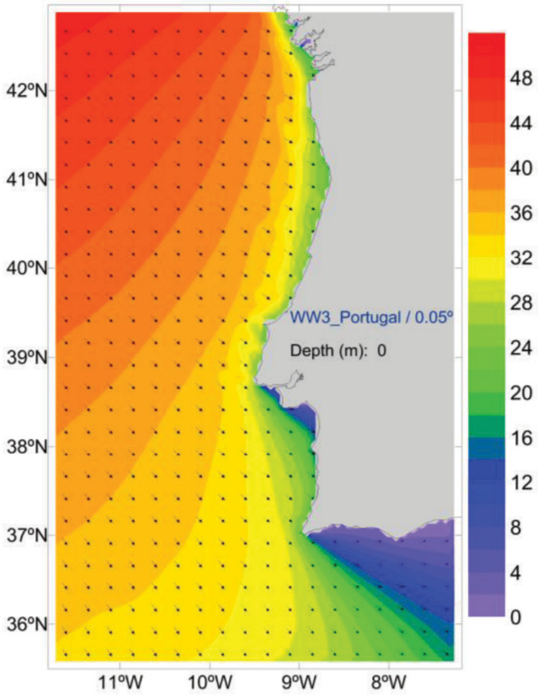

Fig. 2. Annual Mean Wave Power Density in kW/m for the 2000-2010 period. Black arrows indicate the mean wave direction.

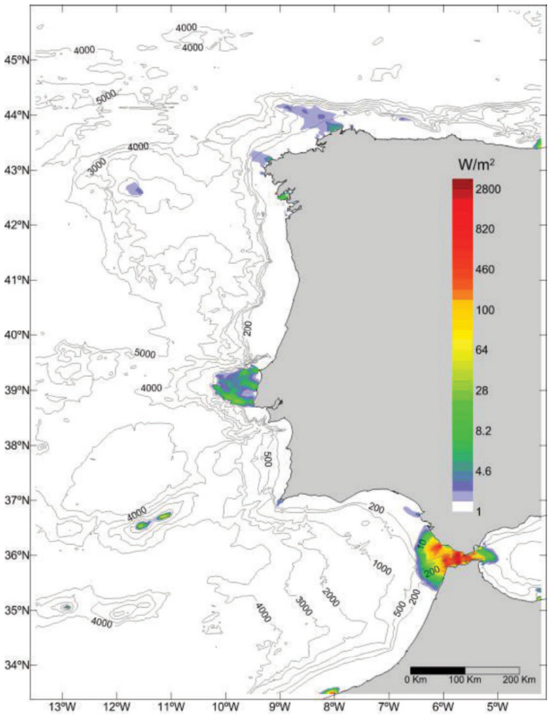

Fig. 3. Spring tidal power. Values are represented in logarithmic scale. Isobaths of 200 m, 500 m, 1000 m, 2000 m, 3000 m, 4000 m and 5000 m were added.

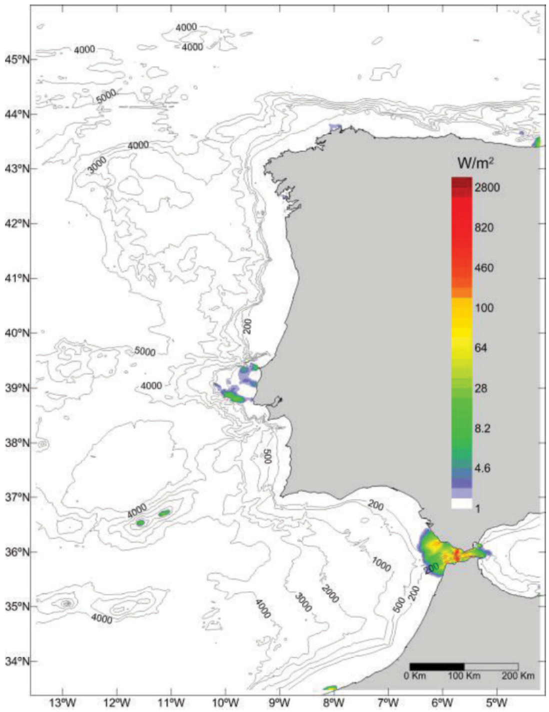

Fig. 4. Neap tidal power. Values are represented in logarithmic scale. Isobaths of 200 m, 500 m, 1000 m, 2000 m, 3000 m, 4000 m and 5000 m were added.

4. CONCLUSIONS

In this communication, we have presented a comprehensive description of the methods used and the main results of the resource evaluation of the Marine Renewable sources of Energy found in the open coasts of Portugal. This Atlas would allow to better plan, design and manage deployments of energy extracting devices and perform safer operations at sea due to numerical model forecasts. The full atlas can be found at Campuzano *et al*. (2015).

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