ASSESSMENT OF POTENTIAL LOCATIONS FOR OWC INSTALATION AT THE PORTUGUESE COAST

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ABSTRACT

This work aims to determine the exploitable wave energy resource at six potential sites, located in the Azores, Madeira and Sines. For that purpose, the third-generation wave model SWAN is used to estimate the sea-wave conditions over the last 40 years. Boundary conditions of the sea states and wind fields are provided by the climate reanalysis datasets ERA5. Using those results as inputs to the SWAN model, the sea-states were propagated shoreward, in order to estimate and analyse the wave conditions in the regions of interest. By combining the average energy flux per unit-length of wave front and the probability of occurrence of each sea state, the average exploitable annual energy per unit length of wave crest can be computed. The variability of this energy flux is analysed since it is of fundamental importance for the efficiency of the Wave Energy Converters (WEC).

Keywords: Wave Energy Converter, Oscillating Water Column, SWAN, Exploitable Energy

1. INTRODUCTION

In the last decades, the increase in the need for renewable energy sources has led to a steep increase in the research and development of Wave Energy Converters (WEC) with the aim of satisfying the growing demand for clean and renewable energy. Its predictability, seasonal stability, low visual impact, and the overall high energy carried by ocean waves (Clément et al. 2002) make the possibilities for this energy exploitation to exceed the expectation in wind or solar energy for electrical production. For the exploitation of the wave energy resources, various technological solutions exist. In this study we consider the introduction of an Oscillating Water Column (OWC) within the trunk of a breakwater.

The design and construction of the structure are of the most critical issues in what concerns efficiency, environmental impact, and financial viability of the OWC technology, which uses waves to compress and expand air so as to rotate an air turbine, which in turn produces electricity. The installation of WEC nearshore has often been dismissed due to the lower gross energy densities without further consideration of the differences between the characteristics of offshore and nearshore wave energy resources. However, a simple scaling of the wave climate inadequately describes the nearshore wave climate. A better representation is required to correctly assess the nearshore wave energy resource potential. With the integration of the plant structure into a breakwater, come several advantages (Reis et al. 2015) like sharing construction costs, simplified access for construction, operation and maintenance, and it does not produce extra environmental impact.

The objective of this paper is to establish the wave climate at six chosen spots in Portugal through a numerical model using SWAN (Booji et al. 1999) which is a third-generation wave model, developed at Delft University of Technology, that computes random, short-crested wind-generated waves in coastal regions and inland waters. Although similar works have already been performed (Matos 2015, Rusu & Guedes Soares 2012), the present work considers a much longer period and introduces the concept of exploitable energy for this specific WEC technology.

2. EXPLOITABLE WAVE ENERGY ASSESSMENT - METHODOLOGY

The wave power density P is the rate at which the wave energy per unit length of wave crest is transmitted in the direction of wave propagation. Considering the deep-water approximation:

$$P = \frac{\rho g^2}{64\pi} T_e H_s^2 \qquad [1]$$

where ρ is the seawater density, g the acceleration of gravity, H_s the significant wave height and T_e the wave energy period. The significant wave height and the wave energy period are computed from the spectral moments.

As the minimum water depth at the points of interest is about 30 m, to fit within the deep-water approximation $h > L/2$, one assumes the wavelength (L) of the incoming waves does not exceed 60 m. The wave energy flux along a linear feature depends on the wave power density and on the angle between the wave direction and the orientation of the line crossed by the waves. The wave energy flux across a linear feature is then given by [2], in which P is the incoming wave power density given by Eq. 1 and φ is the angle between the wave direction and the perpendicular to the breakwater.:

$$P_\varphi = P\cos(\varphi) \qquad [2]$$

It is also necessary to consider the effect of the resource variability on performance. Non-linearities in device's hydrodynamics and the geometry constraints of the electro-mechanical plant do induce a power level threshold above which the incoming energy is unexploitable and it would be appropriate to disregard such sea-states (Cahill & Lewis 2011). This threshold obviously depends on the device technology/design, so there is no definite value for it. Considering the range of the overall average of wind-energy converter load factors (between 25% and 50%) it appears that a reasonable value for it may be four times the average incident wave power (Folley & Whittaker 2009). This new representation of the wave energy resource is called the exploitable wave energy resource since it is more closely related to the amount of wave energy exploitable by the WEC. Even if it is assumed that this concept provides a more rigorous estimation of the recoverable energy for wave energy converters, the threshold value must be refined by carrying out large scale tests on the selected device.

3. MODELLING THE NEARSHORE WAVE CLIMATE

3.1. SWAN application

SWAN (version 43.31) is used in this paper to propagate the wave climate from offshore to nearshore. This is a third-generation spectral wave model based on solving the spectral action balance equation, which determines the evolution of the action density in space and time (Booij et al. 1999). The energy density is specified using the two-dimensional wave spectrum, with the wave energy distributed over frequency and propagation direction. Three regions were considered in this study: Sines harbour area (1), Azores Central Group Island (2) and Madeira Island (3). Various nested computational domains, embracing each zone of interest, were defined.

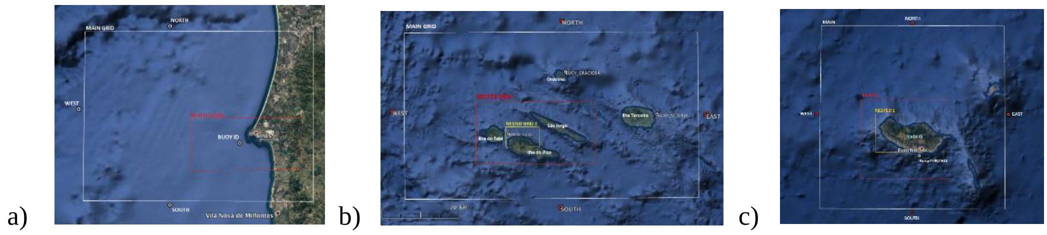

Fig. 1. Study areas: a) Sines; b) Azores (São Roque do Pico and Madalena do Pico); c) Madeira.

The implementtation of the SWAN model was made for 36 directions and 28 frequencies logarithmically spaced from 0.04 Hz to 0.6 Hz with a JONSWAP spectrum, the simulations being performed in the stationary mode.

A 40-year hindcast was considered, from 01/01/1979 to 31/07/2019, to obtain a set of offshore wave data at the four borders of the main grids every 6 hours. These data were extracted from the fifth generation ECMWF atmospheric reanalysis of the global climate, ERA5, and their reliability has been evaluated. The reanalysed wind field, also provided by ERA5 dataset, is forced as input for all computational grids. It is defined to fit the main grid of each zone with a 0.25º/0.25º resolution every 6-h covering the whole test period. Due to their weak impact on the sea waves of the 3 zones, current effects were not considered. The default bottom friction coefficient proposed by the JONSWAP group (0.067m^{2}s^{-3}, Hasselmann et al., 1973) is used. This bottom friction coefficient has been found to be suitable for fully developed wave conditions in shallow water (Bouws & Komen 1983), although clearly variations will undoubtedly occur with different seabed conditions. The physical processes activated in the SWAN simulations were set by balancing the relevance of each factor in the studied area against its tendency to increase the calculation time.

3.2. Nearshore wave climate modelling results

The SWAN simulation outputs are compared to the in-situ measurement from buoys, to detect if the wave model previously built is introducing discrepancies. In general, H_s are slightly overestimated, while T_p are underestimated. Those erroneous estimations could, in a way, compensate each other in the calculation of the wave power density since it is proportionate to $T_e H_s^2$.

In each of the three zones, two target points are selected in front of the breakwater axis as close to the breakwaters as the SWAN grid resolutions allowed – Zone 1: Sines harbour dock West and East / Zone 2: São Roque do Pico and Madalena do Pico / Zone 3: Paul do Mar and Seixal. Since the bathymetric lines are parallel at each location, the wave energy is only affected by refraction. Thus, the energy calculated at the target points is considered as a viable approximation of the energy available in front of the breakwater position. Here, only the results for Madalena do Pico are presented, since it is the zone of most energetic interest as explained later in this section.

Following **2**, two filters were applied to the SWAN model results at each point. After computing the exploitable power from equation [1] every 6h over the 40 year-period, the negative values were dismissed with their corresponding set of sea states, which represent the waves heading offshore. Then, the mean incident wave power was calculated for each point and used to determine the threshold above which all values are excluded. These filtered climate data series, coming from the six target sites, are employed to calculate variability coefficients and to generate wave roses and scatter diagrams of the $H_s - T_e$ joint distributions. Such a diagram presents the occurrence probability of different sea states expressed as a percentage of the total number of occurrences. It is structured into bins of $2s \times 0.25m$ ($\Delta T_e \times \Delta H_s$). From those diagrams the wave states can be described (Table 1a). To truly describe the energy resource at each location, the average exploitable energy flux has been computed for each bin of the Hs-Te scatter diagram (Table 1b).

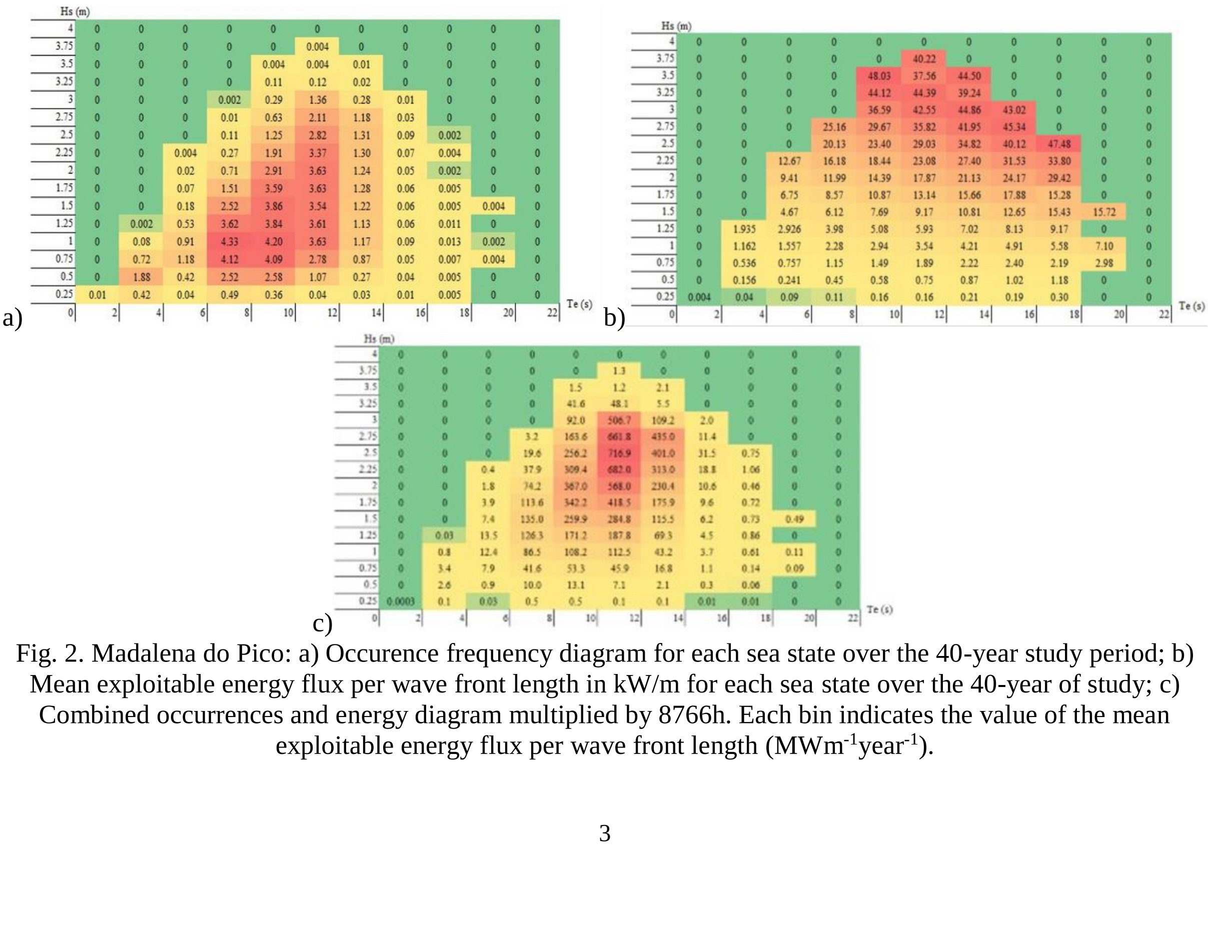

Fig. 2. Madalena do Pico: a) Occurence frequency diagram for each sea state over the 40-year study period; b) Mean exploitable energy flux per wave front length in kW/m for each sea state over the 40-year of study; c) Combined occurrences and energy diagram multiplied by 8766h. Each bin indicates the value of the mean exploitable energy flux per wave front length (MWm^{-1}year^{-1}).

By multiplying the mean annual number of hours (8766h) with the average exploitable energy flux per wave front length and the occurrence probability of each bin ($T_e - H_s$), the average annual exploitable energy per unit wave crest length for each sea state is obtained (Table 1c). The largest contributions for the total annual mean recoverable energy come from sea states with both high occurrences and high wave power density (red bins). These results suggest that WEC developers should design their devices in to operate efficiently over sea conditions that provide the largest contributions to the total annual of wave energy, instead of aiming only the more common sea states that in general offer a small contribution to the overall energy exploitable. From this point of view, the Madalena do Pico spot seems to be more advantageous with regard to the high overall potential annual energy to recover (9150MWm^{-1}year^{-1}) and to the low complexity in the design, since the range of energy periods that contributes the most to the more powerful states is narrow (Table 1c). Furthermore, the seasonal and annual variability factors are remarkably low at that location so the wave climate is highly predictable.

4. CONCLUSIONS

A third-generation spectral wave model, together with hind-cast data from the ERA5 reanalysis dataset, has been set-up to investigate over six selected locations, their energetic potential. Because of the large temporal scale of the study (40 years), it should be born in mind that, some choices in term of modelling were made by balancing the calculation time against the impact of each factor on the accuracy of the study, for instance the activated parameters in each grid, the computational grid resolutions, the stationary mode, and the forced input data at 4 cardinal points instead of continuous spectral inputs at the borders. All those simplifications introduce non-negligible errors; nevertheless, the amount of information produced by such a study gives an accurate overview of the general tendencies. The concept of exploitable wave energy resource was considered in this study since it provides a more appropriate representation in the context of a non-axisymmetric wave energy converter. It was observed, on one hand, that the concentration of occurrences should fit the power distribution pattern to positively impact the total amount of exploitable energy. On the other hand, the energy period deviation of the highest values of occurrences should be as narrow as possible because in this case, the design of an effective converter, regarding its Eigen-periods, would be eased by the narrower range of wave energy period that the device should be able to convert.

ACKNOWLEDGEMENT

This work has been performed within the projects OWC-HARBOUR - Harbour protection with dual chamber oscillating water column devices (PTDC/EME-REN/30866/2017) and To-SEAlert, Ref. PTDC/EAM-OCE/31207/2017, funded by the Portuguese Foundation for Science and Technology.

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