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Intra-annual wave resource characterization for energy exploitation: A new decision-aid tool

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ABSTRACT

The wave energy resource is usually characterized by a significant variability throughout the year. In estimating the power performance of a Wave Energy Converter (WEC) it is fundamental to take into account this variability; indeed, an estimate based on mean annual values may well result in a wrong decision making. In this work, a novel decision-aid tool, *i*WEDGE (intra-annual Wave Energy Diagram GEnerator) is developed and implemented to a coastal region of interest, the Death Coast (Spain), one of the regions in Europe with the largest wave resource. Following a comprehensive procedure, and based on deep water wave data and high-resolution numerical modelling, this tool provides the monthly high-resolution characterization matrices (or energy diagrams) for any location of interest. In other words, the information required for the accurate computation of the intra-annual performance of any WEC at any location within the region covered is made available. Finally, an application of *i*WEDGE to the site of a proposed wave farm is presented. The results obtained highlight the importance of the decision-aid tool herein provided for wave energy exploitation.

1. Introduction

Wave energy has emerged as one of the renewables with the capacity to contribute large amounts of energy to society [1]. For this purpose, different types of Wave Energy Converters (WECs) are close to achieving a commercial stage [2–4]. There exist a wide variety of WECs which can be classified based on different criteria, such as the distance to the shoreline and water depth, the size and orientation relative to the waves, and the principle of operation. Regarding the principle of operation, three main types can be distinguished: overtopping devices (OTDs) [5], oscillating water columns (OWCs) [6,7] and wave activated bodies (WABs) [8].

Overall, the selection of the suitable converter depends on different aspects, amongst which the magnitude and distribution of the available resource is of major importance. Therefore, along with the development of WECs, a good climate description is crucial for a proper decision making and planning of the resource exploitation. In particular, the distribution of the energy resource in a region is the basis for the combined selection of the most appropriate location and type of WEC, as well as to define its optimum configuration. Furthermore, the optimum configuration of a WEC should be defined through an exhaustive analysis of different power performance parameters of a selected WEC-site combination. This is of special interest in the case of islands or when a specific energy demand is to be supplied [9–13] and energy storage is required [14]. In this vein, it is important to bear in mind that the information required at a given coastal location for WEC performance computations is a characterization matrix (or energy diagram) describing the available energy and occurrence of the different combinations of the relevant spectral parameters or *energy bins* [15]. This information is then combined with the power matrix of the WEC in question to compute the various performance parameters.

In addition, it has been shown that the regions with the greatest wave energy potential exhibit an important intra-annual variability of the resource [16,17] which may lead to a significant intra-annual variability in the power performance of WECs. Thus, to compute the power performance of a WEC at a coastal site exhibiting significant intra-annual energy variability on the basis of mere annual figures may lead to an incorrect decision making regarding the definition of the wave farm configuration. Instead, intra-annual matrices of the resource covering a period (e.g., monthly, seasonal...) capable of reflecting the existing variability of the resource should be generated at the location of interest. In spite of this, regional assessments usually focus on averaged

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resource values, giving little information regarding its intra-annual distribution. As a result, the required information for generating intra-annual characterization matrices is currently only available at specific coastal sites, normally those where a buoy has been in operation during large periods, which are not necessarily those where wave energy exploitation is being considered. At present, numerical modelling is also being used to generate large wave datasets which could be used for the same purpose [18,19]. In the case of the North Atlantic Region, the dataset recently provided within the HIPOCAS project [20] is of special interest. It consists of 44 years (from 1958 to 2001) of hindcast wave (and wind) data with a three-hourly frequency obtained after running the WAM model, which in turn was forced with data resulting from the regional atmospheric model REMO. However, it has been shown that the wave energy resource may show significant variations in short distances (even less than hundreds of meters). Therefore, the spatial resolution provided in this dataset, $30' \times 30'$ enhanced near the coastline to $15' \times 15'$, is not adequate for properly capturing the variation in the resource throughout a region of interest.

In this work, an aid-decision tool, *i*WEDGE (Intra-annual Wave Energy Diagram GEnerator), is developed and implemented to the Death Coast, N Spain (Fig. 1), by characterizing the wave resource following a comprehensive procedure. As a result, a high-resolution dataset of the intra-annual wave energy resource is made available allowing the generation of monthly characterization matrices at any location within this coastal region and, therefore, the computation of the monthly power performance of any WEC at any location of interest. The structure of this article is as follows. In Section 2, the deep water wave energy resource is assessed in front of the Death Coast based on a large wave buoy dataset, and the energy bins providing the bulk of wave energy are selected. In Section 3, the relevant deep water information is transferred to the coast and the resulting data stored with a structure allowing its easy reading and manipulation. Next, in Section 4, the tool developed is used to produce the monthly characterization matrices at a location where a wave farm has been recently proposed. Finally, in Section 5, the most relevant conclusions are drawn, confirming the interest of the present intra-annual aid-decision tool for wave energy exploitation within a coastal region.

2. Deep water energy bin characterization

The deep water energy bins in front of the Death Coast can be accurately characterized by analysing the dataset recorded by a buoy located approximately at the middle point of the deep water boundary (Fig. 1). The buoy has been in operation since 1998 providing hourly records of the relevant parameters characterizing the wave energy resource. In particular, it provides information of the different spectral moments m_n (more specifically of the minus first and zero moments) and therefore allows the accurate computation of the spectral wave height, H_{m0}, and energy period, T_e, of each hourly sea state [21]. In addition, information regarding mean wave direction, θ_m is also available.

This large dataset is analyzed and used to compute 3D monthly matrices composed of trivariate energy bins of H_{m0}, T_e, θ_m. The selected size of the energy bins is set to 0.5 m of H_{m0}, 0.5 s of T_e and 22.5° of θ_m. For this purpose, each hourly sea state is assigned to the corresponding energy bin and its probability of occurrence, O_b, within each month determined.

The wave power of each bin is then computed according to

$$J = \frac{\rho g}{32} H_{m0}^2 \left(1 + \frac{2kh}{\sinh(2kh)}\right)\left(\frac{gT_e}{2\pi}\tanh(kh)\right) \quad (1)$$

where ρ is the density of seawater, g the acceleration of gravity, k the wave number and h the water depth at the buoy location. In deep water assumption Eq. (1) simplifies to [22]:

$$J = \frac{\rho g^2}{64\pi} T_e H_{m0}^2 \quad (2)$$

Finally, the energy provided by each bin, E_b, is obtained according to its occurrence as:

$$E_b = J O_b \quad (3)$$

In Fig. 2, the omnidirectional representation of the 3D monthly matrices (the direction is omitted for clarity purposes) covering 95% of the total available resource is shown for the months of January and July. The magnitude and distribution of the available resource amongst the different energy bins are very different.

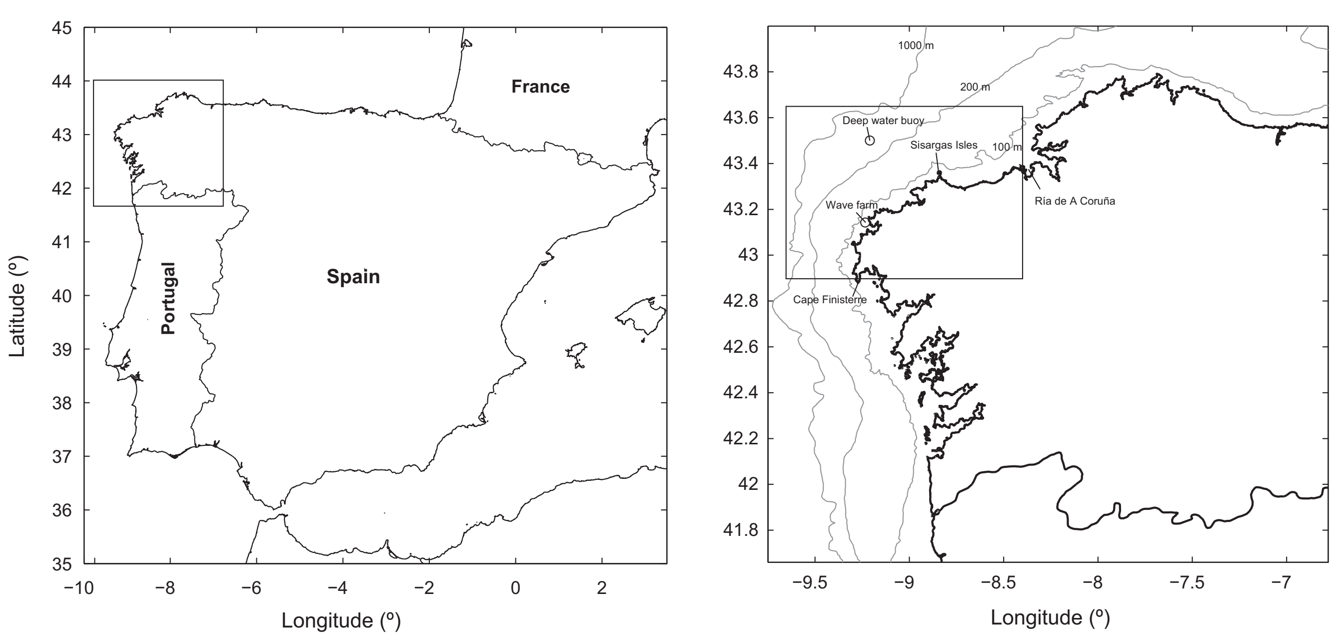

Fig. 1. General view of the Iberian Peninsula (left) and detailed of the NW coast (right) within which the Death Coast is located (square).