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Wave energy potential along the western Portuguese coast

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ABSTRACT

An assessment of nearshore wave energy resource along the Portuguese coast is presented, focusing on identify appropriate locations for testing and developing Wave Energy Converter (WEC) for commercial exploit. The analysis covers the whole west seaside, to which a partition defined by 7 linear sections parallel to the coastline at 50 m depth was considered. Available wave energy at each linear sector was calculated from nearshore wave parameters, using as input the offshore wave conditions provided by a 15-year ocean wind-wave model simulation and considering a simplified but well-established analytical procedure for shoreward wave transformation. Two alternative measures of the nearshore wave energy resource were considered, the standard omni-directional wave power density and the more restricted normally-directed wave energy flux.

Offshore wave direction combine to shoreline orientation proved to be determinant on the evaluation of the wave energy resource in each section, since sectors of the shoreline directly facing the offshore annual average wave direction have limited reduction in available wave energy as compare to offshore values. Independently of the wave energy measured criteria used, the analysis suggests that the sector from Peniche to Nazaré is the more suitable location for nearshore wave energy exploitation, with annual wave energy around 200 MWh m^{-1}, closely followed by the adjacent sector from Nazaré to Figueira da Foz.

1. Introduction

Wave energy exploitation is undoubtedly one of the renewable energy sources with the highest potential for development over the next few years. The possibilities of energy exploitation using this resource far exceed using wind or solar energy for electrical production. The predictability, stability, lower visual impact and the overall higher energy carried by ocean waves [1], make this resource a good candidate to substitute non-renewable electricity plants on the long term.

Wave energy can be seen has a concentrated form of wind energy, due to the fact that waves are generated by wind blowing over the ocean surface [2]. The Atlantic coastlines of Europe present a large amount of this energy resource due to their exposure to the Westerly winds that blow over the North Atlantic, creating and driving the waves to the Western European countries [1]. Worldwide assessments of the wave energy potential [3–5] have identified that the western coasts of the northernmost countries of Europe (Fig. 1) receive the most amount of this resource with average annual wave power reaching over 70 kW/m offshore Ireland [6,7]. The southernmost part of Europe coastline (Canary Islands) receives only about 25 kW/m of wave power, while the northernmost parts of the Atlantic European Coastline receive about 30 kW/m offshore Norway [7].

Regional studies allow for more accurate wave energy assessments, helping with the identification of local phenomena and areas of greater interest in terms of the available wave energy. Waters et al., determined the annual average wave power density off the Swedish Coast to be between 2.4 and 5.2 kW/m [8]. Iglesias et al. [9] used a 10-year hindcast simulation to assess the wave energy resource along the offshore coast of Galicia, founding values for the annual wave energy between 128 MWh m^{-1} and 439 MWh m^{-1} and average wave power density ranging from 15 kW/m to 50 kW/m. The Marine Institute for Sustainable Energy of Ireland conducted a large scale study of the wave energy pattern, identifying areas of high energy availability around the island. By summing the hourly wave power density distribution, the authors obtained the mean annual theoretical energy resource with values reaching 550 MWh m^{-1} of crest width on the most exposed parts of the coast [10].

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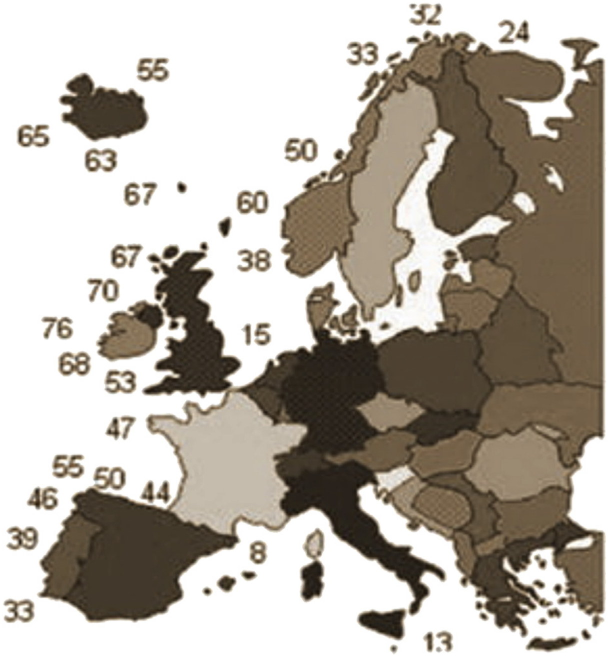

Fig. 1. European wave power atlas (Adapted from Pontes et al., 1998).

The Portuguese coast receives fair amounts of wave energy, reaching an average wave power density around 30 kW/m at the north and central part of the offshore Portuguese west coast [11,12]. Pontes et al., developed an Internet access atlas of the nearshore Portuguese wave energy resource, using a third-generation wind-wave model coupled with an inverse-ray model to compute the directional spectra transformation from open ocean to the nearshore [11]. They have considered 85 nearshore sites along the coast (20 m depth) founding a typical value of 25 kW/m at unsheltered west coast sites with a moderate gradient decreasing from north to south. Rusu et al., by coupling a nearshore spectral wave model to a ocean wind-wave model, simulated the spatial pattern of the wave power density associated to four case studies representing the most average energetic situations, from which they concluded that some nearshore locations, mainly in the vicinity of capes and in the coastal environment close to Viana do Castelo, have higher wave energy resource [12].

For the exploitation of this wave energy resource, various technological solutions exist, and the later years have seen a significant increase on the development of WEC. Although multiple solutions for the conversion of wave energy to electricity exist, the major difference between different WEC's, is their ability, or inability, to orientate themselves with the incoming waves. Moreover, because some of these technologies are installed in fixed positions, the orientation of a line of such devices could influence the amount of energy available for each WEC.

Another aspect to take into account is the nearshore vs. offshore issue. Although the wave energy potential is generally greater at offshore locations, the economical advantages in terms of maintenance and installation of deploying WEC on nearshore sites are easy to understand. Yet, the deployment of such devices in those locations is often dismissed without considering the complexities between offshore to nearshore conditions. Interaction with the seabed or the surrounding landmasses as well as the coastline orientation may turn a seemingly unfit site into an optimal location for wave energy production [13]. In fact, the wave direction should also be considered through wave energy flux estimates, in order to obtain a proper evaluation of the available wave energy for fixed linear array of point absorber wave energy devices or isolate devices that not have the ability to orientate themselves with the incoming waves. This alternative measure for determining the productivity of a wave farm, denominated by exploitable wave energy resource, reveals that the nearshore energy resource losses are not so significant as suggested by an omni-directional wave energy resource analysis [13]. This approach was used by Electric Power Research Institute Group to determinate the available and recoverable wave energy resource on the United States coastline, considering wave energy flux crossing a linear feature as a complement to wave power density [14].

2. Methodology

The wave power density P is the rate at which the wave energy by unit length of wave crest is transmitted along the water column in the direction of wave propagation. Following the deep water approximation one has

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

where ρ is the sea water 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 readily computed through the wave spectral variance S:

$$H_s = 4\sqrt{m_0} \quad T_e = \frac{m_{-1}}{m_0}, \tag{2}$$

where the nth order spectral moments are defined as

$$m_n = \int_0^{+\infty} f^n S(f) df \tag{3}$$

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 [14]. Just like planet Earth, in which more solar energy is available along the equator than on the poles, due to the angle at which solar radiance hits the surface, the same is valid for ocean wave energy along a linear feature. Wave energy flux across a linear feature is then given by

$$P_\alpha = P \cos(\alpha) \tag{4}$$

in which P is the incoming wave power density given by eq. (1) and α is the angle between the wave direction and some specific direction. This study considers two different line references; the shoreline normal and the annual mean wave direction to which correspond the angles α_s and α_ω, respectively.

It is recognized that there is a threshold depending on significant wave height and wave period from which WEC devices lose efficiency or enters survival mode. Discarding this feature in evaluating the energy resource leads to overestimate the wave power available in some situations [15]. In order to consider this issue the concept of exploitable power P_{exp} is introduced [13], defined as four times the annual average wave power $\overline{P}$,

$$P_{exp} = 4\,\overline{P} \tag{5}$$

Thus, sea states with wave power greater than the exploitable power are excluded in the calculation of available wave energy. Despite the exploitable wave power cut-off criteria given by eq. (5)