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A proposed wave farm on the Galician coast

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ABSTRACT

This work is focused on the analysis of the wave resource and its exploitation by means of a proposed 12 MW wave plant in Northwestern Spain. For this purpose, a total of four current technologies of wave conversion are analysed at three different sites located at different water depths, which correspond to one of the European areas with the greatest wave energy resource and where its electric production is still underdeveloped. To carry out the research, the wave data recorded at an offshore buoy near the area and the power matrices of the four selected wave energy technologies are used. The offshore wave conditions—representing 95% of the total energy of an average year—are propagated through spectral numerical modelling towards the coast. On the basis of the results, two of the four selected technologies forming the 12 MW power plants and one of the three considered points emerge as the ones allowing the greatest energy production and, at the same time, having a minimum area of occupation which, in turn, is crucial to reducing the visual impact. Finally, this research discusses the energy supply capacity of the proposed plants to satisfy the energy consumption required by nearby communities.

1. Introduction

The climate change and the alert related to the global warming pose a serious threat to the ecosystems on the planet. The chance of changing this trend is based on the reduction of CO_2 emissions to the atmosphere. Many countries, under international treaties, are playing an important role in this way by investing on renewable energies such as wind or solar energy. Nevertheless, there exists another group of renewables having a great potential and a promising future which are still underdeveloped. This corresponds to the marine energy group within which wave energy is called to emerge as one of the leading alternatives to mitigate the effects of fossil fuel use with a low environmental impact [1]. Compared with other renewable energies, this resource has a major advantage: its high energy density [2]. In addition, the wave energy resource presents a very good predictability [3]. The wave energy resource has been characterised in different worldwide coastal areas in the past (e.g. [4]). To achieve this, different methodologies have been used for characterising the wave conditions, being numerical modelling the most extended [5].

In addition, for conducting a proper wave resource assessment which allows the estimation of the electric power generation of a given wave energy converter (WEC) in a specific location, the device's power matrix (i.e. the electric production for different wave events) is required [6]. By combining the latter matrix with the probability of occurrence of the events (provided by the so-called wave resource matrix), an expected annual production can be obtained [7]. Moreover, with this methodology, not only the optimum location for a WEC can be assessed [8], but also the most efficient WEC for a given coastal area can be determined [9].

Nonetheless, apart from the estimated electric production, several aspects have shown to be of relevance in selecting the optimum wave energy conversion site. On the one hand, the cost of the technology itself and technical considerations such as the operation and maintenance (O&M) as well as the length of the underwater cable can be decisive in lowering the final cost of energy [10]. On the other hand, minimising the environmental impact is required, given that the operation of wave farm can produce changes in the coastal hydrodynamics, impacts on the biodiversity and possible interferences with shipping routes or other human activities [11]. All these aspects are extremely affected by the surface occupied by the farm, which determines to a great extent the probability of causing a negative impact on the environment, and, therefore, should be appropriately analysed prior to install a wave operation.

Although many wave energy resource assessments and technology comparison analyses can be found in literature, they lack of considering occupation. Only in [12] the characteristic surface area of different WEC units is calculated. However, instead of single

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units of WECs, wave energy is harnessed in farms or plants with different layouts. Therefore, to consider the surface area occupied by complete wave plant seems more appropriate. This work deals with the wave energy production of a proposed 12 MW wave plant in the vicinity of the San Cibrao Port, a remote zone of the Galician coast (Spain), which is known to have a high energy resource [13]. In this work the electric production of four WECs is evaluated and compared at three possible sites, located at different depths without any environmental restrictions [14]. Such assessment is carried out through, the implementation of the numerical model SWAN [15]. The latter is a widely validated spectral wave propagation model [16], which allows determining the wave energy conditions at the site of interest [17]. The inputs of the model are the wave parameters of a large number of wave cases obtained from an offshore buoy located in deepwater, representing 95% of total offshore wave energy of an average year. Once characterised the wave resource matrix for each of the three sites selected, they are combined with the power matrix of each wave technology to obtain the expected electric power production of each wave plant [8]. Finally, different plant configurations are proposed and, as novelty, the area occupied is considered along with the electric power production to discuss the best solution.

The structure of this work is as follows: Section 2 presents the material and methods used to carry out the assessment; subSections 2.1–2.4 contain deal with the analysis of the study sites, the energy conversion technology, the wave data and the numerical modelling implemented, respectively. Section 3 shows the results of the research, including the resource assessment in subSection 3.1, the electric production in subSection 3.2 and the farm configuration and area occupied in subSection 3.3. Finally, Section 4 presents, the conclusions of this work.

2. Materials and methods

2.1. Study sites

The area of interest is located in Galicia (NW Spain), which is known to have a high wave energy resource [8]. The area considered (Municipality of Cervo) has a population of 4369, according to the Spanish Statistical Office (INE [18]). On the other hand, the Galician Institute for Energy (INEGA [19]) estimated the annual electric power consumption per capita of the region at 5721 kW h. Therefore, the annual electric energy demand for the area is estimated at 25 GW h.

So as to satisfy this energy demand the installation of a wave energy plant in the vicinity of the Port of San Cibrao has been proposed, on the basis of the reduction of the installation and operation costs. If WECs are deployed far away from a port with suitable facilities for O&M, the costs and the downtime required may increase to a great extent. Thus, suitable local port infrastructure enables lower O&M costs. Other benefit of installing a plant at this location is the existence of an electric substation at the port, which provides the necessary grid connection minimising the length of electric lines [20].

Given that the wave resource changes with the water depth because of the different processes affecting the wave field during propagation, three different sites to install the plant have been proposed so as to compare the energy productions among them. These locations are aligned with the perpendicular to the shoreline and at different water depths: Points A, B and C (Fig. 1). Site A is located in the breakwater of the port, which has a water depth of about 20 m. Sites B and C correspond to a nearshore (50 m) and an offshore location (80 m), respectively (see Table 1).

Table 1
The three study sites considered in the vicinity of the Port of San Cibrao for installing a 12 MW wave power plant.

Site	Coordinates		Distance to the coast (km)	Water depth (m)
	Latitude	Longitude		
A	43°43′5.63″	−7°27′41.17″	0	20
B	43°43′58.34″	−7°27′17.96″	2.5	50
C	43°44′24.71″	−7°25′53.81″	3.4	80

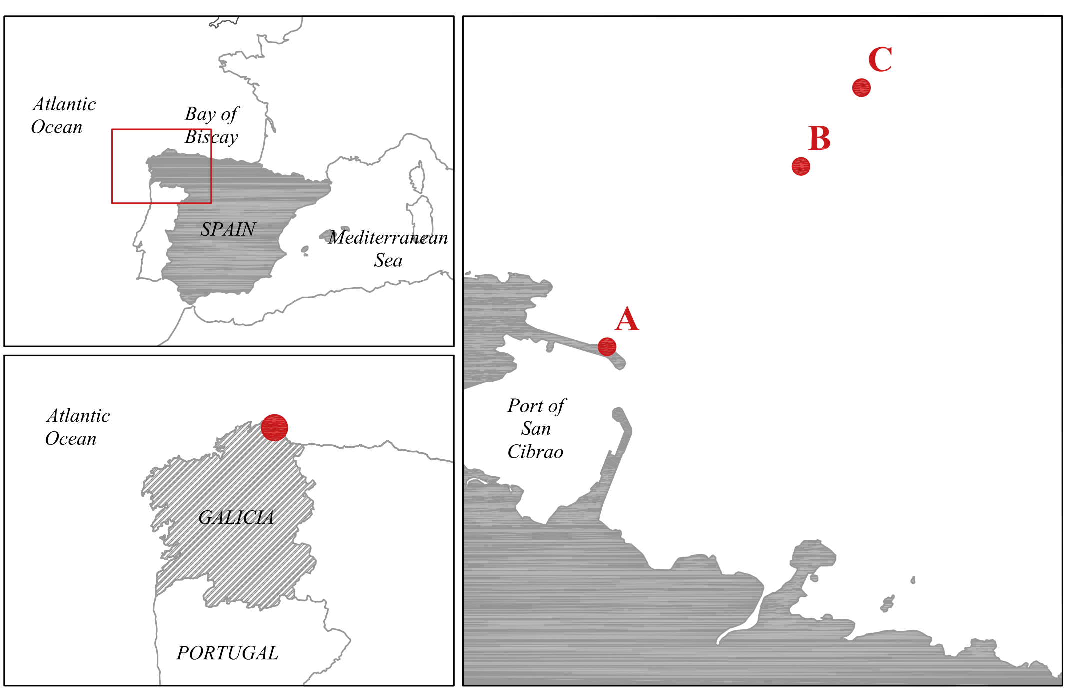

Fig. 1. Location and study sites.