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Study on the influence of the distance to shore for a wave energy farm operating in the central part of the Portuguese nearshore

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ABSTRACT

The objective of the present work is to assess the coastal impact induced by a generic wave farm operating in the central part of the Portuguese continental coastal environment, south of Lisbon. In order to identify better the most relevant wave patterns in the target area, two data sets were processed and analyzed. The first is represented by the 'in situ' measurements provided by the Sines buoy, which operates in the immediate vicinity south of the target area, and the second consists in the wave data coming from the European Centre for Medium-Range Weather Forecasts, in a point located offshore close to the target area. Three scenarios were considered for the numerical simulations that were carried out with a computational framework combining a wave and a circulation model. A generic wave farm was defined in the computational domain considering various distances from the shore: 1 km, 4 km and 7 km, respectively. In the first part of the work, the down-wave effect of the farm was evaluated taking into account the local wave characteristics in the target area and analyzing various wave parameters, as for example the wave power, wave height and mean wave direction. In the second part of the work, the influence of the farm on the nearshore circulation was also assessed. Based on the results of the present work it can be concluded that the nearshore impact of such a marine energy farm can be considered significant. This suggests that a project as this herewith considered, besides providing renewable energy, could assure an effective coastal protection.

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1. Introduction

From all the geographical environments, the marine areas can be considered to be more attractive in terms of the natural resources, especially in the vicinity of the coastal regions, where the water depth is suitable for the development of renewable energy projects [1,2]. At this moment it is feasible to obtain energy from the sea, as it can be noticed in the case of the state of the art wind and wave energy generators [3–5]. Moreover, it is considered more effective to develop hybrid projects, which will reduce the intermittency of the two resources at the same time being possible to provide a sheltering effect for some sensitive coastal sectors [6–8].

The Iberian Peninsula can be considered a hot spot in terms of the wave energy, especially as regards the western coast, which is under the influence of the North Atlantic waves [9]. From this perspective, Portugal has a long tradition in assessment and harnessing the wave power, and in fact this is the first country where a commercial wave farm was installed. Nevertheless, it has to be highlighted at this point that the three modules of Pelamis installed in 2008 were in the sea during only a few months and the project was abandoned because those machines (version P1) were sub-optimal and Pelamis company focused its efforts on the next generation machines (version P2) that were further tested in Scotland. However, although it is generally accepted that at present there is no commercial wave farm, only some pilot installations of technologies in a "pre-commercial" stage, a real commercial breakout is expected within the next decade.

As regards the wave climate in the Portuguese nearshore, during the winter time, wave heights of about 3 m and wave powers of 36 kW/m can be considered a representative sea state, while during the winter storms, the continental part of Portugal may face waves with significant wave heights of about 9.5 m or more [10]. Besides the continental Iberian nearshore, the islands and archipelagoes belonging to Portugal or Spain (as the: Azores, Madeira or Canary) increase the number of sites attractive for the development of the marine farms [6].

On the other hand, the high wave energy conditions may have a negative impact on the stability of the coastal sectors, since the sediments may be carried out further in the offshore areas throughout the combined action of the backwash process of waves

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and rip currents [11]. As a consequence, the coastal environment of Portugal is vulnerable to the coastal erosion, which represents an important issue for the local authorities since almost 76% of the population lives in these areas. According to the shore orientation, there are two protection schemes which involve shore-parallel approach (ex: seawalls) or shore-normal systems (ex: groins) which are frequently used in the Portuguese coastal environment. This type of protection is implemented in areas, such as: Praia da Rocha, Alvor, Cabanas Island or Cacela Peninsula [12]. The shortage of the sediment volume coming from the local rivers represents another issue, especially in the central part of Portugal where for example the Douro River has reduced his natural volume from 1.5–2 million m^3/year to a maximum 0.25 million m^3/year in the present. The local configuration of the shoreline is also influenced by the longshore sediment transport induced by the waves, which is estimated to be in the range of 1–2 million m^3/year [13]. Thus, the Portuguese coastal sectors are subjected to strong erosion, such processes being more important in the sector Lisbon–Algarve, which is also sensitive to tsunami events. That sector is critical, as also the central part of Portugal continental and some spots in the north. In this category can be also included some other coastal areas, such as Braga–Coimbra (in the north) or Faro–Tavira (in the south) [14]. From this perspective, the local wave conditions are considered very suitable for testing and development of various wave energy converters (WECs). In 2007 a full scale WaveRoller system (rated at 10–15 kW) was deployed in the Peniche region (north of Lisbon), the success of this prototype opening the door for an extended marine energy project.

Another important project is the Pico Power Plant, where an oscillating water column converter (rated at 400 kW) was installed on the shoreline of the Pico Island in Azores. Although the above project started in 1992 and the construction was concluded in 1999, the Pico Power Plant becomes operational only in 2005.

In the offshore areas, the flow concept can be mentioned, which is an attenuator capable to generate 1.5–2 MW throughout a hydraulic system. In order to reach the 0.3 GW from the wave power proposed by Portugal until 2020, various WECs are already considered for implementation in the Portuguese nearshore, such as WEGA, Ocean Plug, Wave Dragon or Pelamis [15]. Since the Atlantic coasts are promising areas in terms of the wave energy and at this moment various WECs are taken into account, the current research is focused mainly on the assessment of the performances reported by these systems [16,17] and especially on the impact of the wave farms on the nearshore dynamics [18,19].

In order to be more efficient, several WEC arrays should be deployed in the same coastal location defining the so called wave farms, with configurations depending on the type of the systems considered and on the water depth. The expected impact of a wave farm on the coastal environment can be assessed based on scenarios which involve in general numerical simulations capable to estimate the evolution of the most relevant environmental parameters. From this perspective, the evaluation carried out in the nearshore of Cornwall, SW of England [20], can be mentioned, where the impact on the beach profile was assessed by considering 11 WaveCat WECs deployed on two rows covering 1.5 km^2. In this case, the influence of the farm on the waves and on the beach profile was evaluated considering the SWAN spectral wave model [21] together with the XBeach morphodynamic model [22]. A similar approach was considered to assess the coastal protection that would be provided to the Perranporth Beach, which is located near the Wave Hub Project, developed to test the WECs in the North Atlantic conditions [23]. The impact of the devices may significantly vary according to the distance to the coastline, this aspect being investigated for the same region considering a wave farm defined gradually at 2 km, 4 km and 6 km, respectively from the shore [24]. Some other representative works were focused on the Portuguese coastal environment, as in the case of the São Pedro de Moel area (one of the two Portuguese maritime pilot zones), in which 5 groups of devices were considered at a 17 km distance from the shoreline, by using transmissions coefficients starting from 0 (total absorption) to 1 (no farm) [19]. Another area located in the Portuguese nearshore, north of the city of Peniche, was considered to define a case study which involved 5 Pelamis devices oriented along the wave direction. In this case, two wave farm configurations have been designed consisting in one and two lines, respectively, and using transmission coefficients in the range 0.45–0.55 [25]. Another relevant study in relationship with the present work is focused on the Bay of Santander in Spain and also on Las Glorias beach in Mexico. The particularity of this work is that in the numerical simulations different convertors were considered, among them being the Wave Dragon, Dexa and Seabreath [26]. Nevertheless, although the focus is in general on the coasts facing the ocean, it can be mentioned that there is also some interest to cover this topic in enclosed seas, such as the Black and Mediterranean seas, where the marine energy farms can become an effective mean for providing coastal protection [10,27,28].

In this context, the main objective of the present work is to estimate the influence of a generic wave farm on the wave and nearshore currents in a representative Portuguese coastal area. The possible influences are assessed for different distances of the marine farm from the shore, in order to establish the possible impact on the coastal dynamics.

2. Methods and materials

2.1. Target area and wave data

The target area, Pinheiro da Cruz, is located south of Lisbon in the central part of Portugal continental, as illustrated in Fig. 1. In this sector, the shoreline is aligned along the north–south line between the city of Setubal and Sines harbor, being characterized by a curved configuration with a total length of 3.6 km [29,30]. The local bathymetry is regular, with isolines aligned almost parallel to the coast in the nearshore and bounded by the Setubal Canyon, offshore [31]. In the case of extreme events, involving strong winds coming from the northwestern sector, the entire area is naturally protected against the wave action. The moderate climate of the European region controls the ocean circulation in the vicinity of the Portuguese coasts, being under the influence of the air masses generated close to the Azores area. In general, the circulation is dominated by the current of Portugal and deep cold waters can be frequently observed near this coastal environment.

In order to identify some relevant wave patterns in the target area, two data sources were considered. The first is represented by the ‘in situ’ measurements performed at the Sines buoy (37°92′N, 8°93′W) which operates close to the target are in its southern vicinity. In the present work the wave characteristics were processed for the 16-year interval January 1988–December 2003, more details about this dataset are provided in [10]. Offshore the target area, a deep water point (denoted as DW) was defined. Corresponding to this location, data coming from the European Centre for Medium-Range Weather Forecasts (ECMWF) were processed for the 15-year time interval January 2000–December 2014. The ECMWF wave data (denoted also as ERA-Interim) are validated against altimeter measurements or/and data coming from buoys, platforms or research ships [32].

Corresponding to a spatial grid of $0.75^\circ \times 0.75^\circ$ and a 6-h time step (00-06-12-18 UTC) the following parameters were processed: (a) significant wave height (H_s), (b) wave period ($T_{m-1,0}$) and (c) mean wave direction (*Dir*). Regarding the wave period, this is evaluated by the ECMWF model as follows [33]:

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