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Wave and offshore wind energy on an island

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ABSTRACT

The island of Fuerteventura, a UNESCO Biosphere Reserve in the Atlantic Ocean, aims to develop renewable energy sources, in particular wave and offshore wind energy, to reduce its carbon footprint. In this context, the objectives of this work are: (i) to assess the wave and offshore wind resources around the island; and (ii) to determine the area or areas that are best suited for their exploitation, taking into account the resource assessment and other conditioning factors such as the bathymetry, distance to the coastline and ports, and offshore zoning prescribed by the authorities. To accomplish these objectives, hindcast wave and wind data obtained with numerical models are used alongside observations from meteorological stations. We identify two areas as having great potential for offshore wind farms; one of them is also very promising for a combined wave–wind farm (or a wave farm on its own). We characterise in detail the wind resource in both areas, and the wave resource in the latter: the wind resource, in terms of directions and velocities; and the wave resource, in terms of directions, significant wave heights and energy periods. In the case of the wind resource, most of the energy corresponds to NNE and NE winds with velocities between 8 and 14 m s^{-1}, which should be taken into account when selecting the offshore wind turbines. As for the wave resource, we find that most of the annual wave energy is provided by N and NNW waves with significant wave heights between 1.5 m and 3.0 m and energy periods between 10.5 s and 13.5 s. It follows that the Wave Energy Converters deployed in the area should have maximum efficiency in those ranges. In sum, Fuerteventura has a substantial wave and offshore wind resource, which is assessed in this work; two areas for their exploitation are proposed, and the ranges of wave and wind conditions for which the wave energy converters and offshore wind turbines to be installed should have maximum efficiency are determined.

Introduction

The Island of Fuerteventura, the second largest (1659 km^2) of the Canarian archipelago (Spain), is located in the Atlantic Ocean around (28°25′ N 14°0′ O) off the NW coast of Africa (Fig. 1). It is exposed to both the trade winds, which blow relatively constant throughout the year, and northwesterly winds. Exploiting its wave and offshore wind resource would contribute to the reduction of CO_2 emissions in Fuerteventura and, following the example of the neighbouring island of El Hierro (Iglesias and Carballo, 2011a), set the island on the path towards energy self-sufficiency (Bayer et al., 2013; Lund and Mathiesen, 2009).

Integrated offshore wave–wind farms present a number of advantages with respect to conventional (onshore) wind farms: (i) the reduction and, in some cases, virtual elimination of the visual and noise impact through distance from the shoreline; (ii) higher wind speeds (generally speaking, the wind speed is higher over the sea than over land); (iii) less turbulence, which leads to a greater efficiency of the windmills; and (iv) enhanced regularity in the power output due to the combination of the two resources, waves and wind. Some cases of integration of wave and wind power were studied (Babarit et al., 2006; Fusco et al., 2010; Lund, 2006); wave resource assessments include Beyene and Wilson (2007), Henfridsson et al. (2007), Iglesias et al. (2009) and Iglesias and Carballo (2009, 2010a, 2010b, 2010d); finally, the wind resource was analysed by, e.g., Hasslet and Kelledy (1997); Fagbenle and Karayiannis (1994); Celiktas and Kocar (2012), and Veigas and Iglesias (2012).

The objectives of this work are: (i) to assess the offshore wave and wind resource around the island using data from 11 study sites (Figs. 1, 2) (which correspond to the SIMAR-44 hindcast dataset based on atmospheric and oceanographic parameters obtained from numerical modelling); and (ii) to determine the optimum areas for hybrid wave–wind farms taking into account the results of the previous resource assessment alongside other relevant factors such as the bathymetry, the offshore zoning prescribed by the competent authorities, and the distance to ports.

Data were gathered on wave height, period and prevailing wave direction, on the one hand, and wind speed and direction, on the other. In addition to the energy resource itself, three other factors were taken into account in determining the optimum areas: first, the bathymetry — floating windmills can be anchored in water depths of

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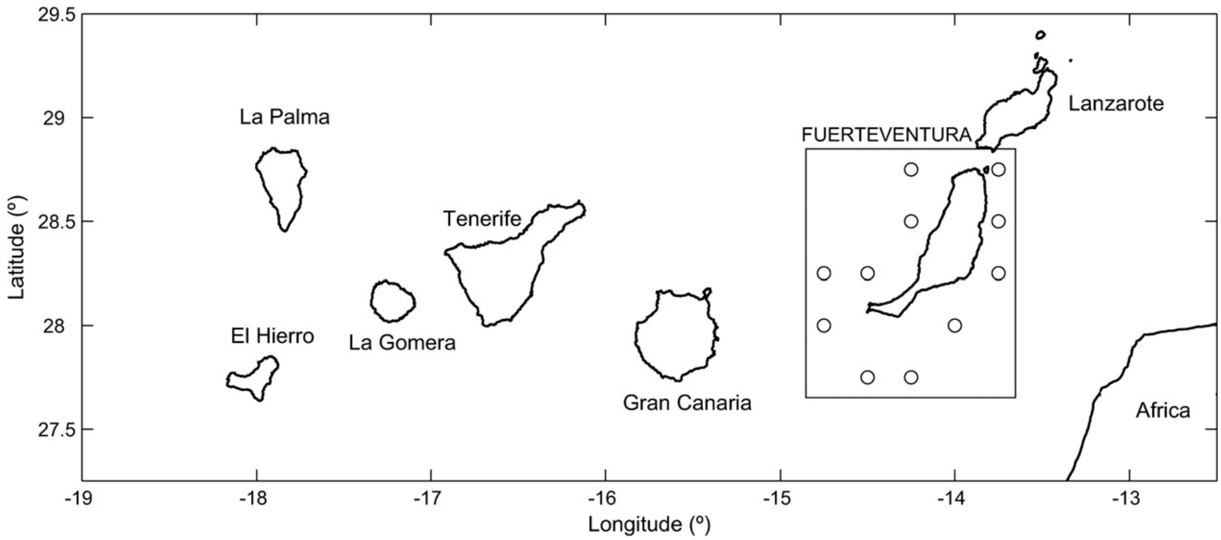

Fig. 1. Location of Fuerteventura in the Canary Islands and of the study sites around Fuerteventura (depicted by circles).

up to 1000 m (Sclavounos, 2010); and second, the zoning for purposes of offshore wind exploitation established by Spain's Ministry of Agriculture, Food and the Environment, which divides the offshore area into exclusion, conditioned and suitable areas.

The exclusion zones include shipping lanes, avian flyways and military zones (Dhanju et al., 2008). Finally, the distances to the shoreline and to a port, which have a significant economic impact since they influence the cost of the submarine cable and that of the maintenance, respectively.

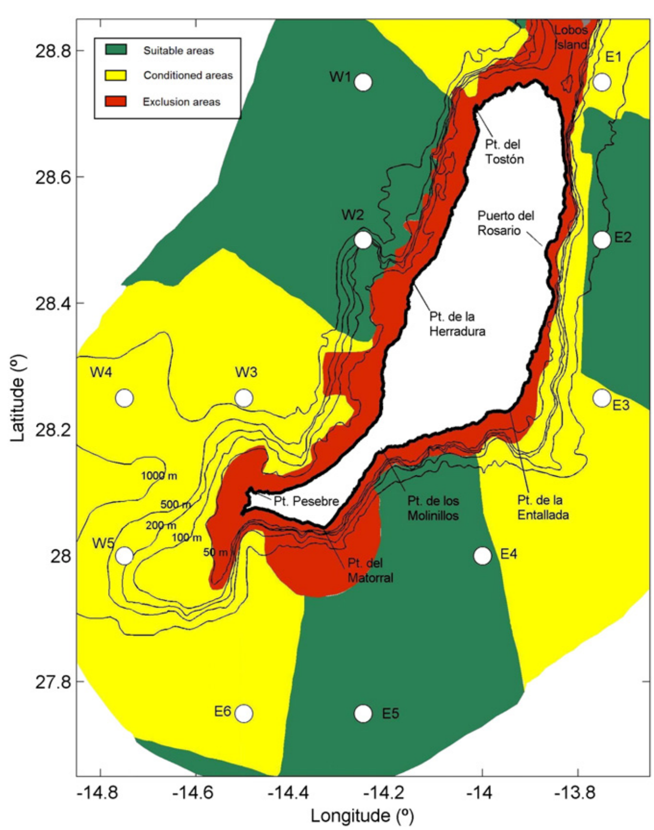

Fig. 2. Bathymetry and zoning for purposes of wind power exploitation. The circles mark the location of the study sites (E1 to E6, east and south of the island; W1 to W5, west of the island).

This article is structured as follows. Section 2 presents the material and methods, including the wave and wind data (2.1) and the procedure to determine the wave and wind resource (2.2). The results are explained and discussed in Section 3. Finally, conclusions are drawn in Section 4.

Material and methods

Wave and wind data

The assessment of the wave resource was carried out based on results from the numerical model WAM, a third generation spectral model where the wave energy equation is solved without setting any a priori hypothesis about the shape of the wave spectrum. It computes spectra of random short-crested wind-generated waves, and is one of the most popular and well-tested wave models. It is the first model that solves the complete action density equation, including non-linear wave–wave interactions (Holthuijsen, 2007; Komen et al., 1994; Wamdi Group, 1988) The model results are stored in a hindcast wave database covering a 44-year period (from 1.1.1958 to 31.12.2001) with a three-hourly frequency. The model grid had a resolution of 5′ Lon × 5′ Lat; the grid points relevant to this work correspond to the aforementioned study sites (Fig. 1).

The offshore wind power analysis was carried out by means of the regional atmospheric model REMO (Guedes Soares, 2008; Pilar et al., 2008; Von Storch et al., 2000) forced with global reanalysis data from the National Center for Environmental Prediction (NCEP) integrating instrumental observations and satellite data (Kalnay et al., 1996). The input variables are surface pressure, horizontal wind components, temperature, specific humidity and cloud water. The boundary conditions are specified at the top and the bottom of the model atmosphere, where the vertical velocity vanishes. This model uses a grid with a resolution of 30′ Lon × 30′ Lat and a 5 s time step. The wind data obtained are, as in the case of wave data, three-hourly values at 10 m above the sea level, which are integrated into the above hindcast dataset (SIMAR-44) covering the same 44-year period as the wave data.

The most relevant wave and wind parameters are shown in Tables 1 and 2, respectively; study sites to the west and east of the island are indicated with the letters W and E, respectively, in their denomination. In addition to the 11 study sites, three onshore sites (designated *A*, *B* and *C*) were selected for comparison purposes; they correspond to the meteorological stations at the airport and the ports of Gran Tarajal (Tuineje) and Morro Jable (Pájara), respectively.