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A port towards energy self-sufficiency using tidal stream power

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ABSTRACT

During the last years the interest of supplying the energy needs by means of renewable energy sources has risen sharply. The objective of this work is to investigate the viability of the implementation of a tidal farm to fulfill the electricity demands of the Port of Ribadeo, which is located in a tide-driven estuary (Ria de Ribadeo, NW Spain). For this purpose a 3D hydrodynamic model of the estuary was implemented and successfully validated. Overall, Ria de Ribadeo presents a substantial tidal resource with annual energy densities close to 72.56 $MWhm^{-2}$. On these grounds, taking the Evopod tidal turbine as a reference, the viability and installation of a tidal farm are analyzed by means of four performance parameters (electric energy output, site-specific efficiency, capacity and availability factors), which are computed on a monthly basis according to the characteristics of the flow at the site. In addition, a momentum sink term was used to simulate the blockage effect caused by the turbine in the flow, and, therefore determine its performance with more accuracy. The results obtained prove that a tidal farm of 25 turbines with a rated power of 400 kW is capable of fulfilling the electricity needs of the port.

1. Introduction

In recent years, the rising worldwide energy demand has brought an increase in the use of carbon-free and renewable energy sources. In this context, the Spanish authorities following the EU's Directive 2009/28/EC [1], have elaborated the 2011–2020 Renewable Energy Plan with the aim of supplying the 20% of the electric demand from renewable sources by 2020 [2,3]. As a result of these policies during the last years several projects have been carried out in order to achieve the energetic self-sufficiency using renewable energy sources [4–6]. Among them, several Spanish port authorities have been developing initiatives with the aim of increasing its energetic sustainability by fulfilling part of their electric demands by means of renewable energies [7–9].

Within the wide variety of renewable energy sources, marine energies have been increasingly gaining interest during the last years [10,11]. Among them, tidal stream energy, which taps the kinetic energy contained in the tidal currents, is arising as an alternative energy source [12–14]. Tidal streams are generated in coastal regions by the tide-driven variation of the sea level and can be locally amplified by the coastline shape and bathymetry [15]. Among the main advantages of tidal stream energy in comparison with other renewable sources are: (i) the high predictability of the resource [16], (ii) absence of extreme flows (unlike wind energy), (iii) high load factors [17] and (iv) low visual and land occupation [18]. On the other hand, the main disadvantages are: (i) the possible disruptions that may be caused on the marine environment [19–23] and (ii) the technology of tidal energy converters is at the early stage of development, which is reflected in the fact that only a few tidal farms are in operation at present [12,24].

This work assesses the viability of fulfilling the electric demand of a port by means of tidal stream energy using as case study the Port of Ribadeo. Port of Ribadeo (NW Spain) is located inside of a small estuary, Ria de Ribadeo, in the lee of Pt. Pancha (Fig. 1), covering 8.6 ha of land surface and 25.1 ha of flotation surface. Following Ref. [25], the goods traffic in the year of 2012 reach a value up to 511,584 Tm, being the second most important port managed by the regional authority of Ports of Galicia (Portos de Galicia).

Ria de Ribadeo is a specific type of estuary [26] (Fig. 1), whose tidal range reaches values up to 4.6 m, which leads to a tidal prisms close to 20.6 Hm^3 in spring tides. This substantial tidal prism combines with the coastline shape to produce strong tidal flows in certain areas of the estuary; therefore, Ria de Ribadeo constitutes an excellent location for installing a tidal stream farm and to assess the viability of supplying totally or partially the electric demand of the Port of Ribadeo by means of tidal stream energy.

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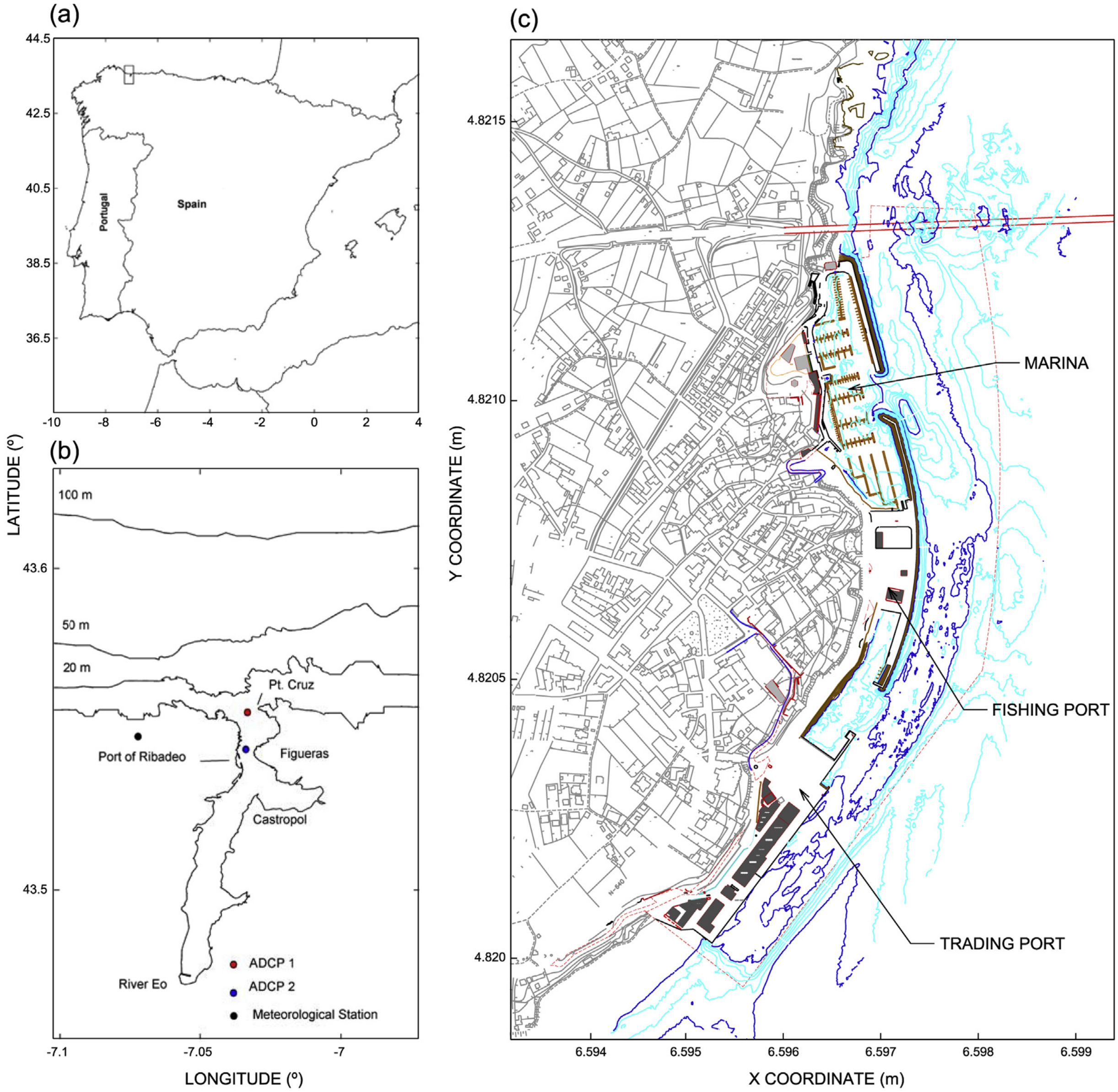

Fig. 1. Location of Ria de Ribadeo (b) and Port of Ribadeo (c) in NW of Spain (b).

2. Materials and methods

The estuarine dynamics can be best analyzed by means of a 3D model due to its complex spatial patterns [27]. For this reason, this research was carried out by means of a 3D numerical model of the Ria hydrodynamics, which was successfully validated based on field data of water levels and tidal currents. Upon validation, the model was then used to assess the tidal resource and to determine the most suitable tidal sites in combination with the TSE (Tidal Stream Exploitability) index, a tool developed for the selection of tidal stream sites in depth-limited areas [28]. Next, following Ref. [29], the performance of a tidal turbine was assessed in terms of the: electrical energy output, site-specific efficiency, capacity and availability factors. The operation of the tidal turbine was modeled by adding a retarding force term to the local momentum equations of the model. Finally, based on the performance assessment of the tidal turbine a pre-dimensioning of a prospective tidal farm was carried out to fulfill the electricity demand of the Port of Ribadeo.

2.1. Numerical model

The numerical model used for the present study, Delft3D-FLOW, is a finite difference code, which solves the 3D baroclinic Navier–Stokes and transport equations under the shallow-water and Boussinesq assumptions. Therefore, the equations solved by the model are:

(i) The continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=Q \tag{1}$$

where x, y and z represent the east, north and vertical axes, respectively; u, v and w are the velocity components on those directions and Q represents the intensity of mass sources per unit area.