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Floating vs. bottom-fixed turbines for tidal stream energy: A comparative impact assessment

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ABSTRACT

Tidal currents represent a promising energy source for electrical supply in Europe; however, nowadays there still exist important aspects to address regarding their exploitation prior to becoming a fully-fledged renewable energy. The accurate assessment of the available resource and the development of TECs (Tidal Energy Converters) are challenges which have been partially solved, but it is necessary to go further in the investigation of other aspects such as the impacts on the estuarine circulation. In this work, the impacts caused on the estuarine circulation in Ria de Ortigueira by the operation of two different tidal stream plants, one composed of floating and the other of bottom-fixed TSTs (Tidal Stream Turbines), were analysed by means of a three-dimensional model. Prior to using the model for assessing the impacts, it was validated based on field data at two measuring stations. Then, the tidal farms were implemented in the model as a momentum sink. The results show that there are no significant differences between the impacts caused on the general circulation by floating and bottom-fixed TSTs with slight reductions of the flow being apparent up to some km away the plant. Then again, strong differences were found in the vicinity of the plant.

1. Introduction

The interest of marine energy resources in Europe has been widely demonstrated over the last decades e.g. [1–7]. In particular, the exploitation of tidal energy was considered for the first time for energy supply in the 60's [8]. Since then, lots of studies have dealt with this issue and several projects have been developed [8,9]. Initially, the exploitation of tidal energy was based on the construction of tidal barrages but soon this system was abandoned due to its aggressiveness with the environment – large effects caused on the seabed, marine ecosystems, hydrodynamics, shipping, etc [10]. The efforts were then focused in the study of the exploitation of tidal currents. In this vein, two main lines of research dealing with the investigation of this new energy source can be distinguished: the assessment of the energy resource, e.g. Refs. [8,11–13], and the development of new technologies capable of converting the kinetic energy into electric energy [14,15]. Both tasks constitute one of the major scientific challenges over the last decades and much work in these fields has been required to get successful results. Nevertheless, as a result of the large effort made, several regions with important tidal stream energy potential have been identified around the world and some TECs (Tidal Energy Converters) have achieved a commercial or pre-commercial stage (although a lot TECs are still in development stage). Overall, these TECs can be classified, according to its principle of operation, into reciprocating [16] or rotating [17,18] devices. The latter, also known as TSTs (Tidal Stream Turbines), are the most popular and can be install with two different configurations: (i) floating beneath the surface and anchored to the bottom (floating TSTs), or (ii) rigidly attached to the bottom by means of a structure (bottom-fixed TSTs).

Despite both challenges being partially solved, there still exist important issues to be addressed and additional work is necessary. In this vein, it is important to note that tidal currents are almost negligible in the open ocean or along straight coasts, with the greatest tidal resource being usually located in estuaries, bays, and other coastal indentations [12,19,20] presenting complex hydrodynamics. Therefore, given the environmental importance that these coastal areas usually boast, the potential effects resulting from their exploitation should be carefully analysed before installing a tidal stream energy plant. With this aim, recent works have begun to study part of these potential effects [21–27].

In order to go further in the investigation of the impacts of tidal stream plants on the estuarine circulation, this work studies the effects resulting by the operation of two tidal stream plants in a

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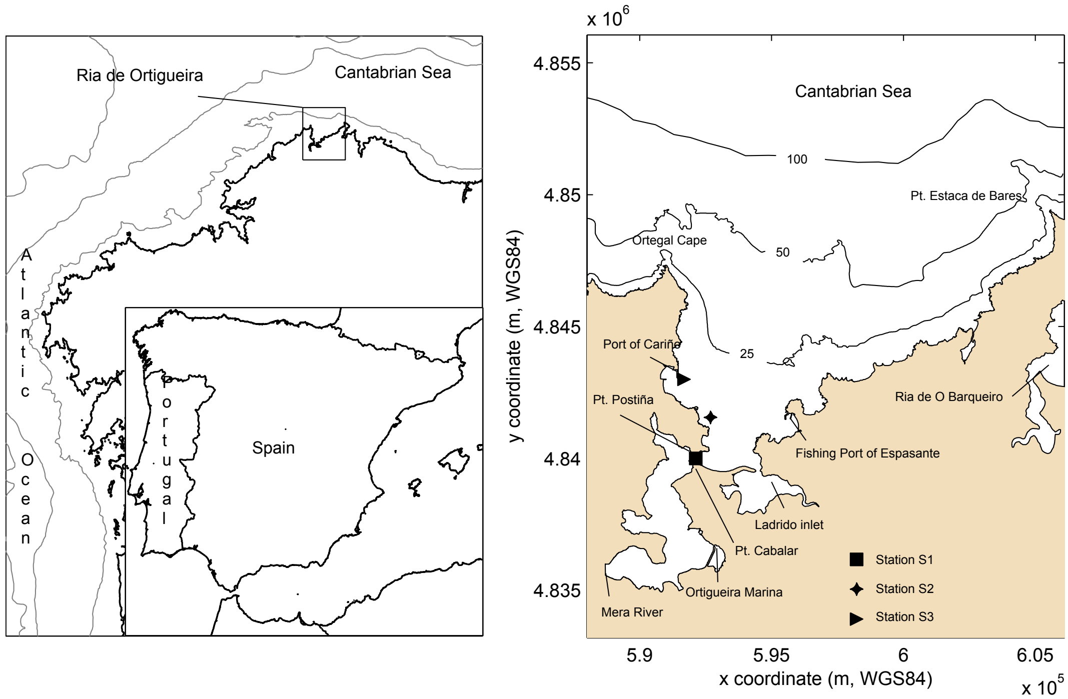

Fig. 1. Location of Ria the Ortigueira (left-hand site). Detailed map of Ria the Ortigueira showing singular points and measuring stations (right-hand site).

specific region, Ria de Ortigueria (NW Spain), by means of a three-dimensional high resolution numerical model. Both plants have the same plan view layout but present a different vertical configuration: one is composed of floating and the other of bottom-fixed TSTs. As a result of their different configuration, despite them being installed at the same coastal site, the impacts caused by their operation may widely differ due to the varying hydrodynamic conditions throughout the water column (each type of TST is located at a different position within the water column). Clearly, the differences in their impacts on the estuarine hydrodynamics may be a major issue in the selection of the most appropriated TST for a specific area. Far beyond the interest of the results obtained for the coastal region herein studied, the final aim of this investigation is to establish a methodology which can be used in the analysis of the potential impacts on the estuarine circulation in other rias or estuaries with similar hydrodynamic conditions.

The structure of this article is as follows. In Section 2, information about the area of study is provided. In Section 3, the numerical model implemented for the simulation of the operation conditions of the tidal plants considered is described. Next, Section 4 deals about the impacts caused on the estuarine circulation by the proposed plants. Finally, in Section 5 the most relevant conclusions are drawn, stating the interest of determining the impacts caused on the estuarine hydrodynamics by different TSTs for the selection of the most appropriated turbine.

2. Study area

The most characteristic feature of the Atlantic Region of the Iberian Peninsula is the presence of large drowned river valleys, a specific type of primary estuary [28], generally known as rias, developed in high relief coasts drowned by the rise of sea level during Holocene. Although the use of the term ria is more popular in this region, there exist estuaries with similar geomorphology conditions in other areas around the world such as Brittany in France, Devon and Cornwall in the British Isles, Korea, certain regions of the Chinese and the Argentina coasts. It is important to note that the morphology of the rias have not any Pleistocene glacial influence which makes them quite different from fjords [29].

The ria herein analysed, Ria the Ortigueira (Fig. 1), is characterised by its irregular geomorphology. Flanked to the West by Cape Ortegal and to the East by Pt. Estaca de Bares, the northernmost point of the Iberian Peninsula, Ria the Ortigueira has an intricate main lobe presenting several curves and narrowings, and a secondary lobe, the Ladrido Inlet. The area occupied by the water mass covers 85 km^2 with its main axis extending approx. 18 km. Furthermore, there exist several streams flowing into the ria, but only one of them presents a significant discharge, River Mera, with an average flow rate of 5.45 $m^3\ s^{-1}$. Regarding the tide, the main component of the astronomical tide is the M2 (Table 1), as in the rest of Europe. However, there are other semidiurnal relevant components in the area such as S2, N2 and K2 which results in a region with a semidiurnal tidal regime as it is stated by its *Form Factor* ($F = 0.082$) [30].

The narrowings of the main lobe together with the high tidal range (up to 4.5 m during spring tides) make tidal currents increase significantly; this causes Ria de Ortigueira being a promising region for tidal stream energy exploitation. According to previous works in this ria [6,31], tidal currents reach values up to 2.5 ms^{-1} in the narrow between Pt. Postiña and Pt. Cabalar. This strong current and

Table 1
Main tidal constituents in the Ria de Ortigueira

Constituent	Amplitude (cm)	Phase (°)
M2	122.79	90.15
S2	42.91	121.08
N2	25.98	70.39
K2	12.03	118.76
K1	7.35	73.49
O1	6.22	324.62
P1	2.22	65.15
Q1	2.11	271.31
M4	1.45	334.80