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Evaluation of potential tidal impoundment energy systems in Ria de Aveiro, Portugal

João Rocha[a], Tiago Abreu[a,b,*], Carlos Felgueiras[a,c]

[a] *School of Engineering, Polytechnic of Porto (ISEP-IPP), Rua Dr. António Bernardino de Almeida, 431, 4249-015 Porto, Portugal*
[b] *CESAM-Centre for Environmental and Marine Studies, University of Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal*
[c] *CIETI/ISEP, School of Engineering, Polytechnic of Porto, 4249-015 Porto, Portugal*

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Abstract

The shelving of the seabed and funneling of the water by the estuaries is favorable for tidal impoundment technologies. In this work, the estimation of the tidal potential energy for Ria de Aveiro lagoon was achieved through the application of a model developed in the Delft3D software. This software can reproduce the hydrodynamics of this complex system and simulations were run to identify hot spots to retrieve gravitational potential energy. For the selected places, both power and annual energy were calculated. It was concluded that the tidal energy that can be extracted from Ria de Aveiro is considerable, justifying further studies to consider the accommodation of some type of tidal exploitation, in the foreseeable future.

Keywords: Potential energy; Tidal barrages; Tidal energy; Tidal impoundment

1. Introduction

Concerns about reducing conventional energy sources forced researchers to explore alternative energy sources. The ocean offers a wide range of renewable energy sources. The energy of the seas has high energy density, high predictability, and low environmental impact [1]. Tidal energy can be obtained through kinetic or potential energy.

Tidal barrages and lagoons use the gravitational potential energy produced by the different elevations obtained between high and low tides. Tidal impoundment installations are essentially composed of a dam structure with gates that control the sea water flow. The main difference between the mechanism of hydroelectric power plants and the

* Corresponding author at: School of Engineering, Polytechnic of Porto (ISEP-IPP), Rua Dr. António Bernardino de Almeida, 431, 4249-015 Porto, Portugal.
E-mail address: taa@isep.ipp.pt (T. Abreu).

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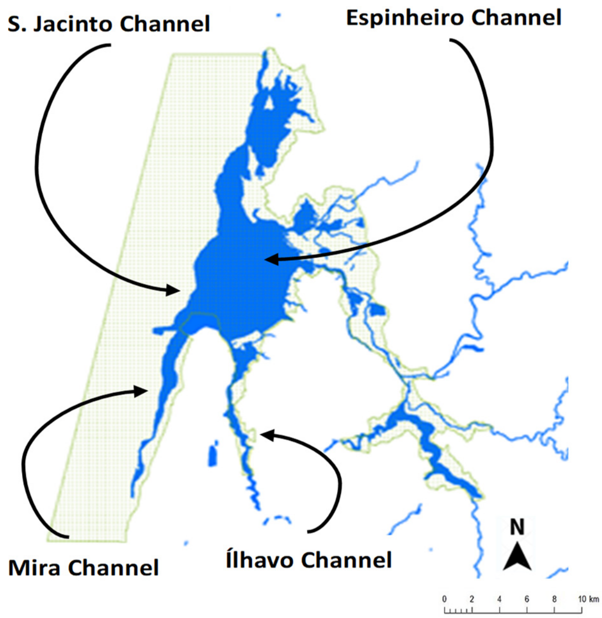

Fig. 1. Scheme of Ria de Aveiro.
Source: Adapted from [4].

mechanism of harnessing energy through the amplitude of the tides is that the water flows in both directions, that is, the flow is bidirectional.

Tidal stream systems extract kinetic energy from moving waters in a similar way to windmills that extract energy from air. However, it can be noted that water is approximately 800 times denser than air. Horizontal axis turbines are the most common mean of extracting energy from streams and are quite similar, in terms of design, to wind turbines. The vertical axis turbines extract energy from the tides in a similar way to the horizontal ones. However, in this last case, the turbine is mounted on a vertical axis and the tidal flow causes the rotors to rotate around the vertical axis, generating energy.

This work aims to assess the energy that can be produced in Ria de Aveiro, located in the Norwest coast of Portugal, through tidal impoundment technologies.

2. Methods

2.1. Study area

Ria de Aveiro, shown in Fig. 1, is located on the north coast of Portugal (40°38′N, 8°45′W). Here, a shallow lagoon is separated from the Atlantic Ocean by a dune barrier. It has an irregular geometry and its only connection to the ocean is through an artificial channel known as Barra de Aveiro. Four main branches, identified in Fig. 1, radiate from Barra de Aveiro: Mira, S. Jacinto, Ílhavo and Espinheiro channels.

The tidal prism of the lagoon for the maximum spring tide and for the minimum neap tide is estimated to be 136.7 $\times$ 10^6 m^3 and 34.9 $\times$ 10^6 m^3, respectively. The tides are predominantly semidiurnal, with an average amplitude of about 2.0 m, influenced mainly by the semidiurnal lunar constituent, M_2, corresponding to 88% of the total tidal energy and by the semidiurnal solar constituent, S_2, corresponding to 10%. The minimum tidal amplitude is 0.6 m, in neap tides, and the maximum tidal amplitude is about 3.2 m, in spring tides, corresponding to maximum and minimum water levels of 3.5 and 0.3 m, respectively [2,3].

2.2. Numerical model

The Delft3D numerical model was used to model this study area, allowing to simulate the hydrodynamics with an adjusted grid. All necessary data for the model's performance and calibration were extracted and processed by

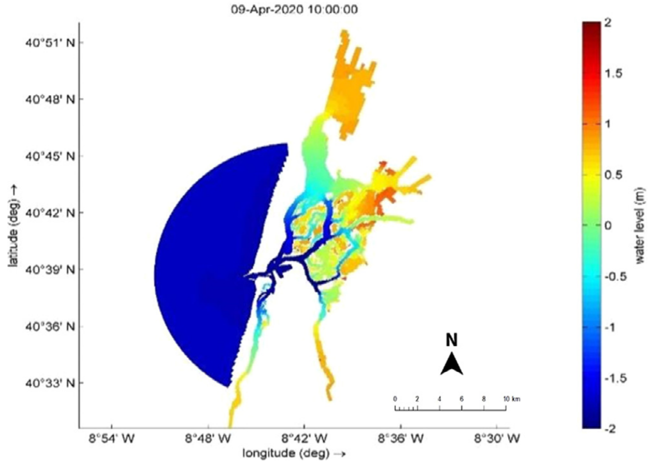

Fig. 2. Example of a water level map for a spring tide.

the Estuarine and Coastal Modeling Center of the University of Aveiro. The bathymetry was obtained through a compilation of topo-hydrographic surveys from the Instituto Hidrográfico in 1988, from Polis Litoral in 2011 and, also, from the Aveiro Port Administration in 2012. The dominant tidal constituents were introduced and interpolated for several border points. Using the Delft3D model, one year of simulation was performed using a 2-minute time step.

To identify hot places for energy use, a series of steps were taken. Annual time series of water elevations were obtained from the model. The tides of high amplitude and tidal ranges were compared with local previous measurements, showing the ability of the model to reproduce expected results. Subsequently, water level maps for the most energetic tide were analyzed (Fig. 2), identifying the most interesting places for exploitation.

2.3. Numerical model

The technologies used to extract energy from the tidal range take advantage of the potential energy. The power can be obtained from Eq. (1):

$$P = \rho g Q H \tag{1}$$

where ρ is the water density ($\rho = 1025$ kg/m^3), g the gravitational acceleration ($g = 9,81$ m/s^2), Q the flow rate and H the gross head.

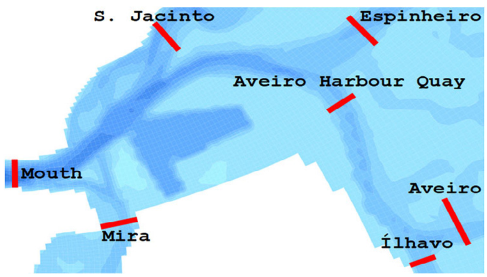

Fig. 3. Interesting places for harnessing potential energy from Ria de Aveiro tidal ranges.

Through this equation, maximum theoretical powers were obtained during a tidal cycle for seven places of interest identified in Fig. 3. They were selected regarding both mean flows and mean differences between maximum and minimum water levels. The adopted operating mode of the barrage was bidirectional, constituting an operating mode that leads to a greater factor of utilization of the plant (Fig. 4). Assuming that the height of the gross head would

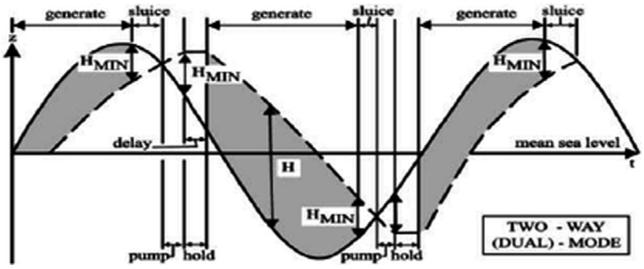

Fig. 4. Two-way operation mode [5].

Table 1. Nominal flow, minimum flow, affluent mean flow, available power head, maximum power and maximum annual energy for the identified areas.

	Mouth	Mira	S. Jacinto	Espinheiro	Harbour Quay	Ílhavo	Aveiro
Nominal flow [m^3/s]	6074	419	1997	1751	909	316	369
Minimum flow [m^3/s]	3948	272	1298	1138	591	206	240
Mean flow [m^3/s]	5393	374	1763	1554	803	280	325
Available head [m]	0.81	0.83	0.82	0.84	0.85	0.86	0.86
Power [MW]	30.0	2.1	9.8	9.0	4.7	1.7	1.9
Annual Energy [GWh]	199	15	63	59	27	11	12
Nominal flow [m^3/s]	6074	419	1997	1751	909	316	369

be 40% of the mean water levels difference, the available powers were estimated from such exploitations. Other losses, as for example, resulting from hydraulic circuits or due to the efficiency of the turbine (Bulb type turbine), were also considered, reducing the theoretical power values of Eq. (1).

This work considers a nominal flow equal to the existing flow that is exceeded in at least three months of the year. With minimum and nominal flows established, the mean affluent flow between these values was calculated for each identified location. Thereafter, the powers were calculated over the various tidal cycles, resulting in maximum annual energies.

3. Results and discussion

For the identified locations, Table 1 lists the maximum powers obtained during a tidal cycle, as well as the maximum annual energies, considering a minimum flow rate, a nominal flow rate, the system performance and the available power heads. The values of both mean affluent flow and maximum power during a tidal cycle are higher at the inlet (Mouth), followed by S. Jacinto and Espinheiro channels. Consequently, the annual energy is also higher for these channels.

The highest power is obtained for the Mouth section, which corresponds to the hypothesis of totally enclosing the inlet of Ria de Aveiro. This is clearly due to the high flow rate values at that location. Other damming hypotheses could be considered, resulting from a combination of different tidal impoundments. For example, a second hypothesis could be to incarcerate the channels of S. Jacinto, Espinheiro, Mira and the channel that passes to the Port of Aveiro. Another hypothesis could consist in damming the channels of S. Jacinto, Espinheiro, Mira, Ílhavo and the channel that goes to the central channels of the city of Aveiro.

Table 2. Maximum power and annual energy for each damming scenario.

	1st scenario	2nd scenario	3rd scenario
Power [MW]	30.0	25.7	24.5
Annual Energy [GWh]	199	166	160

The power estimations for these three hypotheses are listed in Table 2. The values were calculated assuming the entire affluent flow would be turbined, disregarding changes in the hydrodynamics associated to the introduction of the dams. The greatest energy production still occurs in the first hypothesis. It appears that the greater the number of exploitations, the lower the energy produced. Nevertheless, the obtained values are not negligible, and these hypotheses would create different impacts (e.g., environment, navigation, etc.), regarding the obstruction of the channels. Comparing with other operational tidal exploitations, such as La Rance, Annapolis Royal and Sihwa, with annual energy outputs of 540 GWh, 30 GWh and 553 GWh, respectively, we find that the Ria de Aveiro, for the tidal impoundment technology, presents interesting potential energy values.

4. Conclusion

This work seeks to evaluate the energy that can be extracted from Ria de Aveiro through tidal exploitation. For this purpose, the study area was modeled using the Delft3D software.

The simulations allowed to assess power extraction for tidal impoundment at different locations of this shallow lagoon. Some assumptions have been made to obtain the presented estimates that are indicative approximations of the maximum power values.

This study indicates that the most energetic channels are located at the inlet, S. Jacinto and Espinheiro channels. Focusing only on the potential energy, it is concluded that damming the entire lagoon at the inlet, drives to higher values of annual energy.

It is noted this study only focus on power extraction for electrical generation, lacking on studies of environmental impact, as well as studies on technical, economic and financial feasibilities. Nevertheless, the annual energy achieved at Ria de Aveiro denotes a relevant predictable renewable potential energy, justifying further studies.

CRediT authorship contribution statement

João Rocha: Data curation, Investigation, Validation, Writing - review & editing. **Tiago Abreu:** Conceptualization, Supervision, Formal analysis, Writing - original draft. **Carlos Felgueiras:** Writing - review & editing, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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