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The Levelized Cost of Energy (LCOE) of wave energy using GIS based analysis: The case study of Portugal

Laura Castro-Santos *, Geuffer Prado Garcia, Ana Estanqueiro, Paulo A.P.S. Justino

National Energy Laboratory (LNEG), Solar, Wind and Ocean Energy Unit (UESEO), Estrada do Paço do Lumiar, 22, 1649-038 Lisbon, Portugal

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ABSTRACT

The main objective of this paper is to establish an economic modelling of wave energy through a Geographical Information System (GIS). Furthermore, this method has been tested for the particular case of the Portuguese coast. It determines the best sea areas to install wave energy converters in this region, using spatial analysis of the Levelized Cost of Energy (LCOE). Several economic parameters, as capital or O&M costs, have been considered. In addition, a sensitivity analysis has been performed by varying the discount rate in three different scenarios. Several types of physical restrictions have been taken into account: bathymetry, submarine electrical cables, seabed geology, environmental conditions, protected areas in terms of heritage, navigation areas, seismic fault lines, etc. Spatial operations have been carried out to complete the procedure, using Model Builder of GIS software. Results indicate the most suitable areas in economic terms in Portugal to install wave energy devices.

Introduction

Nowadays, one of the most important problems all over the world is generating enough clean energy to guarantee human consumption without harming the environment [1]. In this context, offshore renewable energies can help to achieve this purpose.

Portugal has many kilometres of coast which could be exploited in terms of wave energy [2]. Furthermore, the Portuguese government is aiming to achieve 60% of produced electricity by RES in 2020, following the European path. Nevertheless, renewable resources for electricity production should be diversified to achieve this objective.

According to different renewable resources for electricity production, marine energies, such as wave, tide or offshore wind, have a large potential of application in Portugal [3–5]. In fact, over the last 30 years, Portugal has been on the front edge of marine renewable energy field. In this sense, several examples could be quoted: wave power plant of 400 kW was connected to the grid in 1999, in Pico (Açores) [6]; the research wave power plant, Pelamis [7,8], with 2.25 MW, has been in operation in 2009 in Aguçadoura [9]; or the second floating offshore wind turbine in the world, WindFloat [10], which has also been installed in 2009 in Aguçadoura.

In the last decade, many research projects of wave energy converters (WECs) have been developed all over the world [14,15], especially in Europe. They can be used to obtain some of the huge amounts of energy which can theoretically be exploited from the oceans [16,17]. Most of the designs convert the wave energy to electrical energy [18,19], but wave energy can also be used for the desalination of salt water by reverse osmosis, which has vital importance for many societies and countries situated in arid climates [20].

Wave energy development is being considered by the Portuguese Government for the accomplishment of its goal respecting renewable energy sources [5]. One example is the pilot zone in Pedro de Moel (Decree-Law 5/2008), created in early 2008 [21].

Although waves resource has been previously studied in several papers [11–13], the economic path [22] is the most important perspective for developers [23]. In this context, the aim of this article will be to determine the best economic areas in Portugal where wave energy can be developed. In this sense, the economic index of the Levelized Cost of Energy (LCOE) will be analysed. In addition, a sensitivity analysis will be performed by varying the discount rate in three different scenarios. Furthermore, several types of physical restrictions will be taken into account: bathymetry, submarine electrical cables, seabed geology, environmental conditions, protected areas in terms of heritage, navigation areas, seismic fault lines, etc. Spatial operations have been carried out to complete the procedure, using Model Builder of GIS (Geographic Information System) software [24]. Results will indicate the most suitable areas in economic terms in Portugal to install wave energy devices.

* Corresponding author.
E-mail address: laura.castro.santos@udc.es (L. Castro-Santos).

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Methodology

Economic procedure

Using the wave resource map as reference, it is possible to calculate the average annual energy of the wave farm assuming that devices are largely spaced and no interaction between them is considered. Through the energy values and using all the input data, the results of economics evaluations (Levelized Cost of Energy (LCOE)) are calculated for each point of the reference maps. These results are saved in the coordinates of each origin point in distinct grids/matrix, each with one type of economic evaluation. The resulting grids are saved as grids compatible with Surfer™ and ArcGIS™ software [25]. They will be the economic maps. The relation between the economic tool, which calculates de LCOE, and the GIS tool, which determines the area selected is shown in Fig. 1:

The Levelized Cost of Energy (LCOE), in €/MW h, evaluates the economic cost of a power generation system throughout its life cycle [26]. There are several approaches of defining the LCOE [26–28]. However, the definition given by the International Energy Agency (IEA) and the Nuclear Energy Agency (NEA) has been considered. It defines the costs as a sum of the total cost of the initial investment, annual operating and maintenance costs, annual fuel and carbon costs and the cost of decommissioning. This model does not take into account extremely volatile values, like interest rates and tax rates which differ depending on the country or region selected. It is very useful to compare normalized costs of energy production from different sources, regardless of the floating parameters.

Since a clean renewable energy source is being analysed, the parameters "fuel costs" and "cost of carbon" were considered to be zero. The "decommissioning cost" was also considered to be zero since the site could usually be used in the future for repowering, taking advantage of the groundwork and construction already carried out. The LCOE depends on the following variables: initial investment costs (C_0), operation and maintenance costs in the year k ($C_{0\&M}$), inflation rate (Inf), discount rate (d) and energy output on year k (ECR_k), as Eq. (1) shows:

$$LCOE = f(C_0, C_{0\&M_k}, Inf, d, ECR_k) \quad (1)$$

The annual wave resource (kW/m) will be used in the calculation of the annual energy output. Using the specific parameters for the wave energy technology considered, the annual energy output for one unit will be calculated in Eq. (2). It will be dependent on: Atlas of Annual Wave Resource [kW/m] (AR), if AR is higher them 35 kW/m, then its value becomes 35 kW/m; capture width ratio (CR), depends on device technology and available sea states; hours per year [h/year] (h_{year}); main dimension [m] (d_{dim}); power Take-Off (η_{PTO}), mechanical efficiency, 0.6 in this study; distinct wave technology type (k).

$$ECRu_k = AR \times CR_k \times d_{dim_k} \times \eta_{PTO} \times h_{year} \times (1 - DegP) \quad (2)$$

In addition, it will be necessary to estimate the nominal power of each device, essential to obtain the initial investment when multiplied by the capital cost (€/kW). To determine the nominal power (Pn), in kW, of each power group is required to absorb the available power on the area of Peniche will be used Eq. (3), which is dependent on: annual offshore resource available in a particular location [kW/m] (MAR) and the capacity factor (C_f), among others:

$$Pn = f(MAR, CR_k, d_{dim}, \eta_{PTO}, C_f) \quad (3)$$

The resulting maps have the format (coordinates and size) of the wave resource reference maps, and illustrate the spatial analysis of the wave farm economics evaluation with all technical and economic parameters introduced as input data at the beginning of the tool. The illustration of this procedure is shown in a simplified form in Fig. 2:

Fig. 1. Relation between economic and GIS procedures.

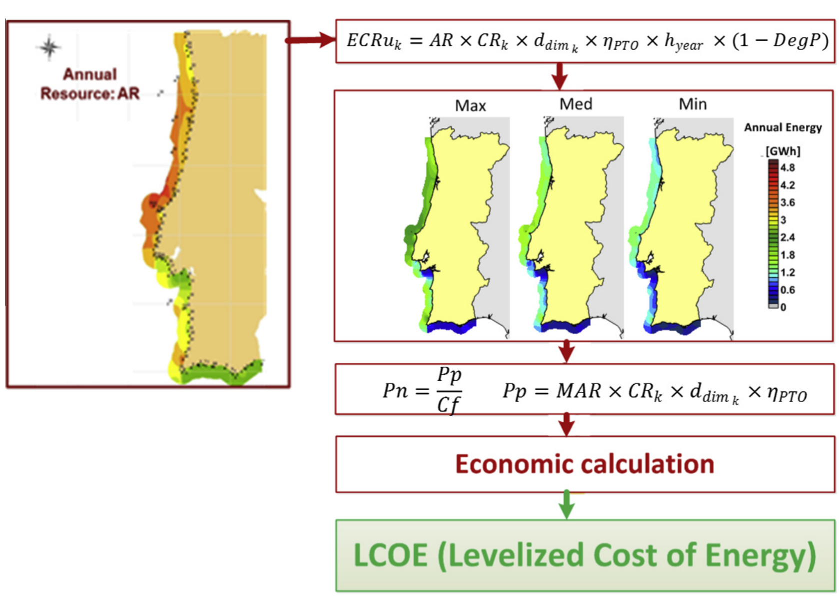

Fig. 2. Economic procedure.