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Uncertainty analysis of wave energy farms financial indicators

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ABSTRACT

In this work, an analysis of the uncertainty that influences wave energy farm financial returns is carried out. Firstly, a methodology to analyze the financial uncertainty through cash flow analysis is developed. A reconstruction of a set of power production life-cycles is made based on the methodology proposed in Ref. [1] using a selection and an interpolation technique. This set of lifecycles allowed to obtain the statistical distributions of the main financial indicators (IRR, NPV and PBP). The high variability of these parameters is explained by the climate variability. Therefore, for the economic study of a wave energy project the influence of the climate conditions is demonstrated and for this purpose a long climate data series is needed. Finally, a second uncertainty source related with the political and legislation environment is studied, focusing on the effect of feed in tariff. This sensitivity analysis of the feed in tariffs is made based on cash-flow algorithm. Current feed in tariffs seemed insufficient in order to get profitable wave energy projects and also an increase in feed in tariff resulted in an increase of variability of financial indicators. Therefore an increase in feed in tariff is not recommended for early stage technologies. Finally, learning curve was also included in this investigation and it appeared as a key parameter in order to get cost effective financial returns.

1. Introduction

Nowadays wave energy is still in the prototype testing stage. However, the ocean wave energy sector has significant potential to contribute substantially to the global electricity generation if sufficient investment is provided (see Ref. [2]). Furthermore, wave energy represents a good alternative as a renewable source due to the low environmental impacts (see Ref. [3]) and the extensive sites available for the placement of wave farms. Current wave energy targets for 2020 are quite ambitious (e.g. 1000 MW for 2020 in the UK or 500 MW for Ireland) making economic assessment of wave energy farms a key issue in the search of financial resources (see Ref. [4]).

A methodology for economic analysis of wave energy projects is therefore required and it is an essential tool for assessing the potential profitability of wave energy projects from the perspective of developers, local administration and investors. Beside costs, developers, investors and public administration's major concern is the assessment of project uncertainties. According to Ref. [5] there are three major sources of uncertainty that can affect the profitability of an investment projects.

The first one is related to the high internal variability of the data: met-ocean historical records show a highly variable behavior (see Ref. [6]) which origins uncertainty about how seasonal, interannual and long term variability of wave energy flux may affect production over the farm's expected life.

The second source of uncertainty has to do with the fact that most technologies have rarely been tested under real conditions; consequently only simulations of future response and efficiency are possible. Future estimates should consider the reduction in uncertainties thanks to the experience acquired through the learning processes associated with the deployment of WECs.

The last source of uncertainty considered is linked to socioeconomic issues including, among others: institutional support, availability of subsidies for emerging green technologies, future social acceptance or commercial conditions under which energy will be supplied to users. Therefore, a study of the uncertainties that affect wave energy development is required in order to provide investors a guide to the potential risks assumed on wave energy development.

Several authors have carried out studies regarding the economic performance of wave energy projects ([4,7,8]), almost all of them

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concerning a specific type of technology. Ref. [4] was one of the first to study several arrangements for the Wave Dragon device taking into account the operational and maintenance costs as a function of the marine climate.

In Ref. [4], studied the economical performance of a generic wave energy device through operational simulations. However, in general all the studies published to date base their cash flow analysis on the power matrix. However Ref. [1], showed that the power matrix is not accurate enough to study the long term behavior of a WEC and neither its economic performance due to the absence of a power production series.

Several authors have studied the economic feasibility of wave energy projects reaching the same conclusion, namely that current feed in tariffs are not sufficient to make the development of wave energy farms cost-effective. A sensitivity analysis of the inputs of the economic analysis was performed and optimal locations for specific technologies are suggested as a function of these parameters ([9]).

Ref. [8] also studied the implications of operational costs on the economic analysis taking into account the concepts of accessibility and availability of a specific location. Finally Ref. [7] performed a case study sensitivity analysis taking into account the impact of the learning curve, supply and demand curves and future cost of cash. The conclusion of this study was that the current feed in tariffs for wave energy in countries such as Ireland are insufficient to develop cost-effective projects. Ireland feed in tariff, available until 2015, has been set to 0.22 Euros/kWh and spans a 15 year project. However this tariff has been shown to be insufficient for currently available devices, specifically for the Pelamis Device studied by Ref. [7]. A feed in tariff of 0.45 Euros/kWh was found to be more realistic in order to reach an attractive internal rate of return.

The goal of this paper is to carry out an uncertainty analysis of the most relevant financial indicators to be considered in wave energy farm developments and focus on the aspects that had not been studied previously by other authors. The three sources of uncertainty considered are treated differently:

- Introducing parametric scenarios for prices and feed in tariffs. A sensitivity analysis to different socioeconomic scenarios is carried out.
- Uncertainties regarding technological evolution are addressed considering a learning coefficient as is usually done in other energy economic analysis.
  •Much emphasis is put in this work in assessing uncertainties stemming from inter-annual variability of wave climate, one of the most unpredictable sources of uncertainty to date.

Without loss of generality a case study is presented and then the uncertainty analysis is carried out for a specific wave energy converter technology based on a two body heave converter as described in Ref. [1].

2. Methodology

2.1. Technology selection

The first step consists of the selection of the technology. The WEC selected is a two body heave converter which extracts energy from the relative motion of both bodies in the heave mode (see Fig. 1). This WEC extracts energy with a linear generator with 1 MW of nominal power. The device is based on Ref. [10]. This type of technology is currently under development by two different companies. It should be highlighted that although the methodology is applied to this converter, this methodology can be generalized to any WEC technology.

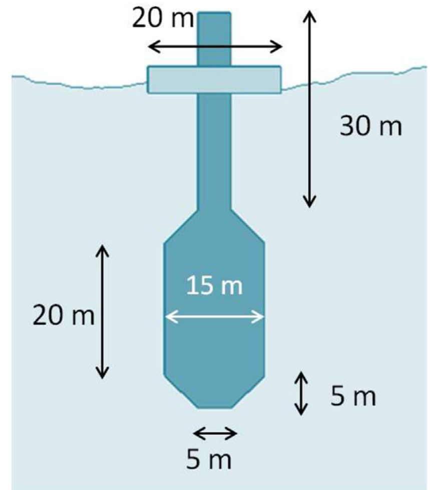

Fig. 1. Two body heave converter analyzed.

2.2. Wave farm location

The second step in the methodology is the design of a wave energy farm consisting of a number of these devices. Wave energy is an expensive option when compared with other renewable sources. However, under some specific conditions this cost could be admissible. For instance, isolated electrical systems are highly dependent on fossil fuel resulting in high energy costs due to long distances from mainland or developed areas.

In this context, renewable energy sources are very useful in order to achieve self-sufficiency and avoid over expenses of transportation of fossil fuels. A wave energy resource assessment around La Palma (Canary Islands, Spain) island has been carried out in Ref. [11], reaching the conclusion that the northwest coast of La Palma is the most suitable place for the farm [12] (see Fig. 2). The selected area is located at a point in La Palma Island with coordinates 28.81 N and 18.01 W for its accessibility and clean exposure to wave energy flux (due to the incidence of the Atlantic swell). This site is 1500 m from the shoreline, at a 150 m depth and has a yearly mean resource of 22 kW/m (see Ref. [11]). The wave climate data of this point has been provided by Ref. [13] from a reanalysis database, including the wave height, peak period and wave direction from 1948 to 2008. In Fig. 3 the occurrence matrix of this location is shown.

2.3. Wave farm production

The methodology to obtain the long-term power production is explained on Fig. 4, based on Ref. [1]. This method provides a way to obtain the life cycle power production of a device with the same computational effort than the classical method based on the multiplication of the power matrix and the occurrence matrix, being able to estimate long-term power production time series. Firstly, the climate data is taken from a global reanalysis database, GOW, with 60 year climate data (see Ref. [13]). A sea state selection technique is applied to this set of data. The MaxDiss selection technique is used from Ref. [14] in order to select the power of the most representative sea states only (Fig. 3). These selected sea states are the input for the time domain model assuming a Jonswap spectra with gamma 3.3.

Numerically, in order to compute the power production two steps are needed, firstly, the floating converter is analyzed with [15], a Boundary Element Model (BEM), that obtains the added mass, damping and excitation force coefficients. These coefficients