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A methodology for the long-term simulation and uncertainty analysis of the operational lifetime performance of wave energy converter arrays

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ABSTRACT

This work presents a new methodology for the long-term simulation and uncertainty analysis of the performance of different alternatives of wave energy converter arrays. With it, we can analyze complete operational lifetime time-series of energy production for any type of wave energy converter. The methodology is based on the application of cutting edge methods, including complex wave climate simulations, downscaling techniques, numerical wave propagation and the application of Monte Carlo techniques for the uncertainty analysis of the results. The methodology was applied to arrays of 9 overtopping wave energy converters for which 9 different geometric alternatives were defined. Results of the mean energy available for the experiments carried out with Monte Carlo techniques indicate that the arrow-shaped array with a distance between devices of 6 times their diameter is the alternative in which more energy is produced. However, the results for some of the 500 experiments indicate that a different alternative is the one with the highest potential production, revealing that the most likely outcome of the experiments can be different from the hindcast results. These results highlight that simulations provide much more information for the decision-makers and that an uncertainty analysis is key towards optimizing energy production.

1. Introduction

Over the last decades, numerous studies have focused on the development of technologies related to the extraction of energy from gravity waves as a sustainable alternative to fossil fuels. This type of energy source has the potential to substantially contribute to global electricity generation if sufficient investment is provided [1], with 3 TWh as the best estimate for the worldwide energy available to this technology [2]. Its main strengths lie on its low environmental impacts [3], its high energy density and consistency of supply [2] and the availability of extensive places where wave energy extraction facilities can be located [4].

Several aspects must be considered in order to develop this renewable energy source, including not only the development of devices to extract energy from waves with enough efficiency (wave energy converters, WECs hereinafter), but also the creation of facilities containing several WECs (WEC arrays) to increase the efficiency of the investment [4]. This efficiency is key to assure the investments needed for further developments of this technology. Among the factors that potential investors analyze to asses the viability of this type of installations, the simulation of both wave conditions and available energy resource during the lifetime of the infrastructure are two of the most important [1,5,6]. The first determines the forces that the WECs should be able to withstand and the conditions for operation and maintenance works, whereas the latter is used to evaluate profitability [7].

For the simulation of wave and energy conditions, two time scales are generally considered: (1) a short-term forecasting (hours–days) of wave conditions to anticipate operational and maintenance tasks or immediate energy production [5]; and (2) a long-term simulation (years–lifetime) to analyze the financial viability of the different facility alternatives under study [8]. Significant advances have been achieved during recent years in short-

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term forecasting of wave energy resources [5,6,9,10]. However, despite its importance, long-term simulation presents some difficulties that make it more complicated to develop, such as the complexity of wave climate simulation, given its random nature, the associated uncertainty [11], and the computational efforts required to obtain results over the lifetime of the facilities [12].

Fortunately, the development of new statistical techniques for long-term wave climate simulations [13] and downscaling approaches [14,15], along with the application of Monte Carlo methods [16], have opened a new line of work for long-term simulation of wave energy resources. Despite recent advances, to our best knowledge, these techniques have been applied only to facilities of individual WECs [8], with the aim to obtain the best location for a single device. However, as shown by Thomas and Evans [17]; the presence of several devices triggers interactions between them that can critically affect the available wave energy resource. The effects of these interactions have been analyzed using both numerical [18,19] and experimental approaches [20,21]. The reader is referred to [22] for a more in-depth review.

The main objective of this work is to present a methodology that can be systematically applied to forecast the potential lifetime performance of different configurations of WEC arrays. The methodology, described throughout the manuscript and summarized in Fig. 1, includes the employment of cutting-edge methods to obtain the wave energy potential for every individual WEC during their lifetime, trying to minimize the computational costs and evaluating the uncertainty of the predictions. This study complements the recent work by López-Ruiz et al. [22] by using a forecast approach rather than hindcast, which gives to investors and managers more information about the performance of the different alternatives tested. The simulation method presented here generally yields more robust results than those obtained using only hindcasting, representing a step-forward in the current state of art of the performance assessment of WEC arrays.

An example of the applicability of the methodology is presented: it is used to evaluate 9 different configurations of a 9-WEC array in the southwestern coast of Spain. The methodology can be applied to any type of device or study zone, although for practical reasons a particular WEC model was used in this work.

2. Study zone

The proposed methodology was applied in a study zone located in the continental shelf of the Gulf of Cádiz, close to the Trafalgar Cape (Fig. 2). The area is characterized by relatively low depths and mild slopes [23]. This place was chosen despite the increase in the operational costs (which are out of the scope of this work) for two main reasons: (1) the elevated energy potential of the area [6]; and (2) the width of the continental shelf which allows for WEC arrays to operate at intermediate depths (approximately 34 m) and therefore assure a remarkable energy potential [2], whilst being at a considerable distance from the coast (≃10 km) reducing the environmental impact of the facility [24].

Tides are mesotidal with mean astronomical ranges of 2 m [23]. Hindcasted wave data provided by Puertos del Estado (SIMAR point 5034009, Spanish Ministry of Public Works) indicates that the prevailing waves come from the West and West-Northwest (Fig. 2), with deep-water significant wave heights (H_s) typically exceeding 3.5 m during storms and averaged values between 0.5 and 1 m. Peak wave periods (T_p) are usually between 4 and 5 s for easterly waves, and range between 10 and 12 s for westerly waves (Fig. 3).

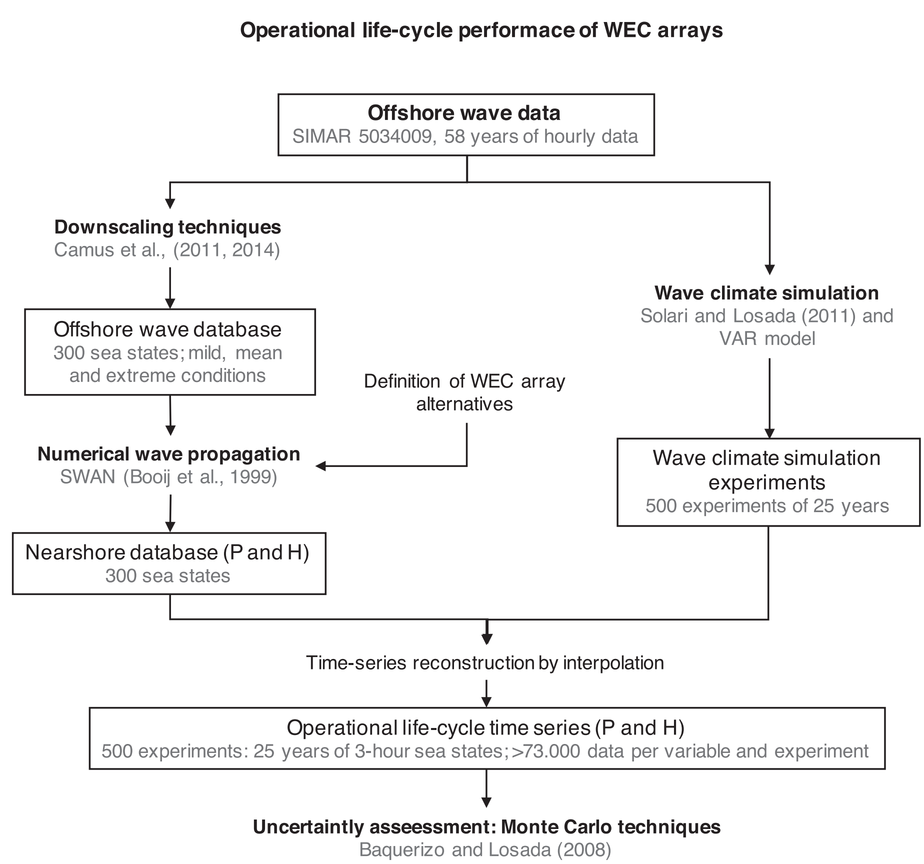

Fig. 1. Diagram of the methodological framework defined.