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Economic viability of floating wave power farms considering the energy generated in the near future

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ABSTRACT

This article aims to analyse the economic viability of floating wave energy farms for the present and the next twenty years. The energy potential of the waves mainly depends on the climate, so the current and near future analysis is crucial to determine the economic viability of wave energy farms in a particular location. Current and near future wave resources were considered to assess the main parameters (Net Present Value (NPV), Internal Rate of Return (IRR) and Levelized Cost of Energy (LCOE)) that allow to know the economic feasibility of wave energy farms. This study takes one step forward in determining the economic evaluation of wave energy farms located in deep waters using their future energy projections. The case of study in this paper is the Atlantic coast of the Iberian Peninsula. Results indicate that the future wave energy reduction principally affects the NPV and LCOE of the wave farm.

1. Introduction

The last IPCC (Intergovernmental Panel on Climate Change) report [1] indicates that the emission of greenhouse gases has caused a global temperature increase of 1.1 °C in the period 2011–2020 compared to 1850–1900. The United Nations reaffirmed its goal of limiting the global temperature rise of the planet to well below 2 °C above pre-industrial levels in the COP26 in Glasgow [2]. In this way, it was reported that it is necessary to reach net zero CO_2 emissions around 2050. In this sense, the European Commission has highlighted that increasing the installation of renewable energy systems and to diversifying them is necessary [3]. Marine renewable energy can be an important help in this diversification since the EU strategic roadmap considers that approximately 10 % (100 GW) of the electricity consumption in the EU can be produced by offshore renewables [4].

The concept of "offshore renewable energy" includes a series of less polluting energy technologies whose stage of maturity is different [5]. The most important marine renewable energies are offshore wind energy and wave energy [6]. Current commercial offshore renewable energy projects are operating in shallow European waters using fixed offshore wind structures. By the year 2022, Europe had installed a total offshore wind capacity of 30 GW [7]. This placed Europe slightly behind the Asia-Pacific region, which had reached 34 GW in offshore wind capacity. Nevertheless, Europe maintained its status as the foremost region in the world for installed floating offshore wind energy, boasting a capacity of 171 MW (GWEC, 2023). Furthermore, the European Union (EU) also held a global leadership position in ocean energy (tidal and wave energy), with an installed tidal stream energy capacity of approximately 30 MW, far surpassing the rest of the world, which had a capacity of around 10 MW [8]. In the realm of wave energy, Europe contributed an installed capacity of approximately 13 MW, a figure comparable to the rest of the world's capacity [8].

Wave energy presents the advantage of being more predictable than offshore wind and solar [9]. Researchers have two outlooks on wave energy: designing and testing Wave Energy Converters (WECs) [10,11] and studying the wave energy resource to find the best regions to install the WECs [12,13]. The wave energy is extracted using different types of WECs according to their operating principle [14,15]: using an air

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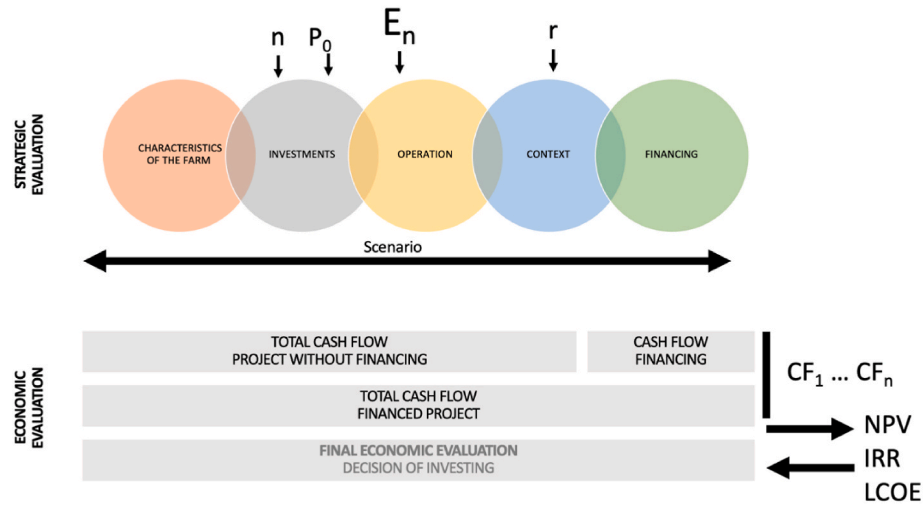

Fig. 1. The general methodology followed. Source: Own elaboration.

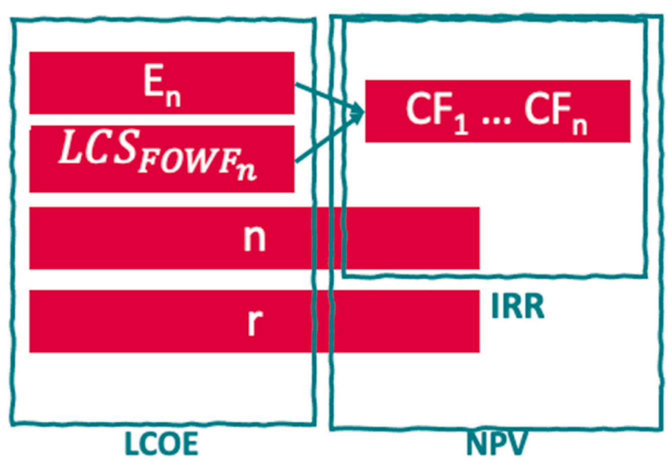

Fig. 2. Relationship between economic viability parameters. Source: Own elaboration.

turbine [16,17], oscillating systems [18,19] or an overflow structure with a low height hydraulic turbine [20,21]. On the other hand, regarding the study of the resource obtained from waves, the prediction of waves for deep and shallow water [22,23] on long-term time scales is significant to analyse the energy produced. Lin et al. [24] determined the distribution of wave energy resources over a great area and used an algorithm to choose critical points for locating wave energy farms in China.

However, these two approaches need a new vision: the economic analysis of wave energy farms. In this sense, some authors [25] analysed the suitable location index to select wave energy locations, and others carried out a decision-making process to use a wave energy converter [26]. Veigas et al. analysed the optimal location for a coastal WEC [21]. Nobre et al. developed a multicriteria geospatial analysis for the deployment of the wave energy conversion system [27]. Carballo et al. [11] developed a method to calculate the energy performance of WECs at a particular coastal location. However, all these authors do not consider the economic aspects of wave energy farms.

One of the main parameters to determine the economic feasibility of a wave energy farm is the calculation of the wave energy resource at the place of its installation [21,22]. Some researchers contemplated the wave resource in diverse locations: Spain [] [28], USA [] [29], United Kingdom [30], Atlantic Coast [31] and Cavo Verde Islands [32]. Others analysed some general economics of wave energy in several parts of the European Union [33]. Nevertheless, estimating the data for all the costs involved in a floating wave farm is very complicated because there is no data on actual places in real farms. On the other hand, Castro-Santos et al. [34] carried out a method to calculate the costs related to floating offshore wind power, hybrid systems (waves and wind) [35] and the comparison of floating offshore wind power, as well as the combined wind and wave systems. Furthermore, Castro-Santos et al. (2020) [36] studied the economic viability of wave energy farms in northern Spain, considering some WECs such as Pelamis and AquaBuoy. However, in this study, the energy produced was analysed considering only the historical values of wave height and wave period.

This study aims to calculate the economic feasibility of floating wave energy farms considering the wave resource of the near future along the west Iberia Peninsula and the Bay of Biscay. The rapid growth of wave energy farms in these areas is expected due to the technical progress of this offshore renewable energy and the necessity of increasing renewable energy to achieve the global commitments of reducing greenhouse gas emissions. Consequently, an advance in defining the economic viability of floating wave farms was developed considering present and near-future wave resources by evaluating the main factors for calculating the economic evaluation of a wave energy farm: Net Present Value (NPV), Internal Rate of Return (IRR) and Levelized Cost of Energy (LCOE). In this regard, high-resolution wave data obtained through a downscaling simulation of the RCP8.5 of MIROC5 GCM was used for the periods 1986–2005 (historical) and 2026–2045 (near future). Different scenarios were analysed considering the historical and future wave climate to assess the variances in terms of economic feasibility. The results are shown as maps, a valuable and useful tool for entrepreneurs and investors to locate the most profitable spots considering both wave resource and economic terms to install a wave energy farm. The results show the importance of future wave energy predictions in the economic viability of a floating wave farm.

2. Methodology

2.1. *Calculation of indicators*

The economic viability of the wave energy farm was developed considering the main economic parameters when an investment project is analysed: Levelized Cost of Energy (LCOE), Net Present Value (NPV) and Internal Rate of Return (IRR). The general methodology is shown in Fig. 1.

The Scenario will be composed of the following data (see Fig. 2): characteristics of the wave energy farm, investments, operation, context and financing. All of them will determine the strategic evaluation of the

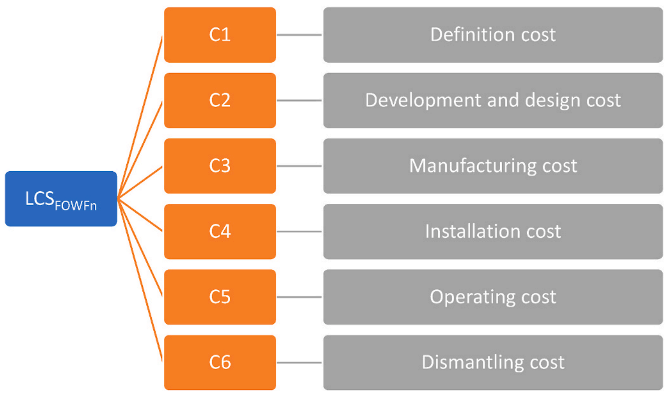

Fig. 3. Main cost components. Source: own elaboration.

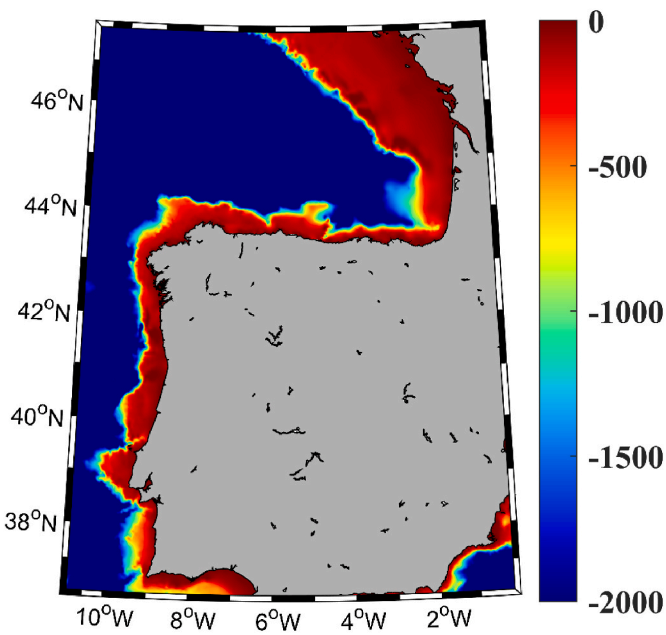

Fig. 4. Bathymetry (m) of the area under scope.

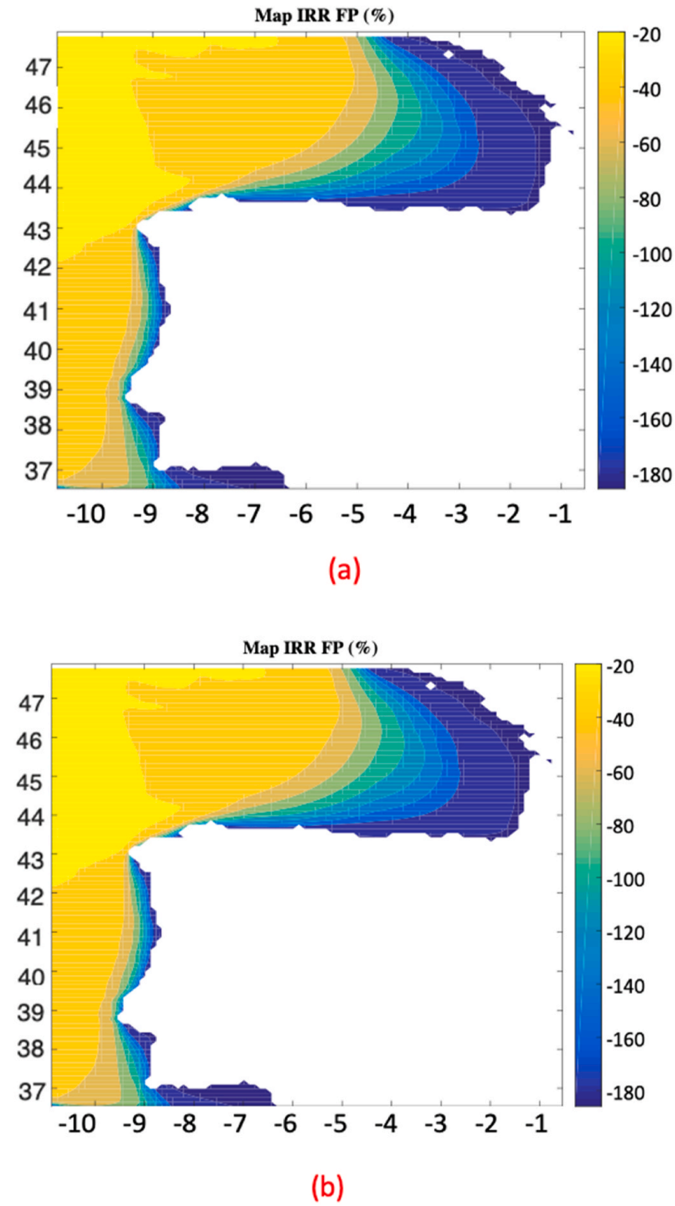

Fig. 5. IRR (in %) for the wave energy farm with Method 1 for 8 % of the cost of capital (a) and for 10 % of the cost of capital (b). Source: Own elaboration.

wave energy farm, which will allow to calculate the total cash flow of the financed project (composed by the total cash flow without financing and the total cash flow of financing).

NPV is the "*net value of the cash flows of the farm studying its discount from the beginning of the investment*" [37]. It depends on the cash flow in year n (CF_n), the cost of capital or discount rate (r) and the initial investment (I_0), as equation (1) shows:

$$NPV = -I_0 + \sum_{n=1}^{N_{farm}} \frac{CF_n}{(1+r)^n} \tag{1}$$

The IRR is the "discount rate when the NPV is equal to zero" (equation (2)) [37,38].

$$0 = -I_0 + \sum_{n=1}^{N_{farm}} \frac{CF_n}{(1+IRR)^n} \tag{2}$$

In addition, the LCOE considers the total costs of the farm (LCS_{FOWF_n}) in €, the capital cost (r), the total service life of the farm (N_{farm}) and the energy generated by the wave farm (E_n) in MWh/year (see equation (3)).

$$LCOE = \frac{\sum_{n=0}^{N_{farm}} \frac{LCS_{FOWF_n}}{(1+r)^n}}{\sum_{n=0}^{N_{farm}} \frac{E_n}{(1+r)^n}} \tag{3}$$

The annual cash flow in year n (CF_n) is calculated considering the energy produced by the farm in such year n. Consequently, NPV, IRR and LCOE depend on the energy generated (see Fig. 2). Thus, it is important to calculate the energy generated by the WECs (E_{1WEC}). In this context, there are two methods to calculate the energy:

(a) OPTION 1: considering the WEC's power matrix and the probability matrix of the sea conditions of the place chosen, as Equation (4) shows; where p_{ij} is the probability of occurrence of a given sea state (Hs, Tp) in percentage; and P_{ij} is the electrical power associated to the identical power point for the studied wave power converter [39], dependent on wave height (H_s) and wave period (T_p).

Table 1
Power matrix of Aquabuoy [53].

Tp (s)	Power Matrix (in kW)												
Hs **(m)**	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0	0	8	11	12	11	10	8	7	0	0	0	0
1.5	0	13	17	25	27	26	23	19	15	12	12	12	7
2	0	24	30	44	49	47	41	34	28	23	23	23	12
2.5	0	37	47	69	77	73	64	54	43	36	36	36	19
3	0	54	68	99	111	106	92	77	63	51	51	51	27
3.5	0	0	93	135	152	144	126	105	86	70	70	70	38
4	0	0	0	122	176	198	188	164	137	112	91	91	49
4.5	0	0	0	223	250	239	208	173	142	115	115	115	62
5	0	0	0	250	250	250	250	214	175	142	142	142	77
5.5	0	0	0	250	250	250	250	250	211	172	172	172	92

Table 2
Main features of the farm.

Variable	Value	Units
Total farm power	500	MW
Electric rate	300	€/MWh
Capital cost	8 %, 10 %	–
Maximum bathymetry	500	m

(b) OPTION 2: considering the water density (ρ), gravity (g), T_p, H_s and % efficiency ($\eta_{efficiency}$), D as the main dimension, as Equation (5) shows [40].

$$P_{WEC} = \frac{1}{100} \bullet \sum_{i=1}^{n_T} \sum_{j=1}^{n_H} p_{ij} \bullet P_{ij} \tag{4}$$

$$P_{WEC} = \frac{2}{64 \bullet \pi} \bullet \frac{\rho}{1000} \bullet g^2 \bullet T_p \bullet H_s \bullet D \bullet \eta_{efficiency} \tag{5}$$

Subsequently, the energy produced by the WEC is calculated, as indicated by Equation (6). It is dependent on the annual hours ($NHAT$), the power produced ((P_{WEC}), the availability ($\eta_{availability}$) and the electric losses ($\eta_{transmissionlosses}$), as shown in equation (6).

$$E_{1WEC} = NHAT \bullet P_{WEC} \bullet \eta_{availability} \bullet \eta_{transmissionlosses} \tag{6}$$

This work will apply the second method to simplify the calculations.

2.2. Cost calculation

The life-cycle cost of the floating wave energy farm (Life-Cycle CoSt (LCS) of the Floating Offshore Wave energy Farm (FOWF) (LCS_{FOWF_n})) is calculated considering each phase of its life cycle [41], as shown in equation (7) and Fig. 3: definition (C1), development and design (C2), manufacturing (C3), installation (C4), exploitation (C5) and dismantling (C6).

$$LCS_{FOWF_n} = C1 + C2 + C3 + C4 + C5 + C6 \tag{7}$$

The Definition Cost (*C1*) reflects all the initial studies to develop the wave energy farm, for example, the spatial and temporal distribution of offshore energy resources to identify the best location to install the farm and the economic viability of the same, among others. Definition cost is composed by: market study (*C11*), legislative factors (*C12*) and farm design (*C13*), as shown in equation (8).

$$C1 = C11 + C12 + C13 \tag{8}$$

The design and development cost (*C2*) analyses the costs of the detailed engineering of the farm and its management. The total cost of design and development varies depending on the unit cost of design and development (C_{ga}), the number of WECs (NA) and their power per unit (PA), in MW, as shown in equation (9).

$$C2 = C_{ga} \times NA \times PA \tag{9}$$

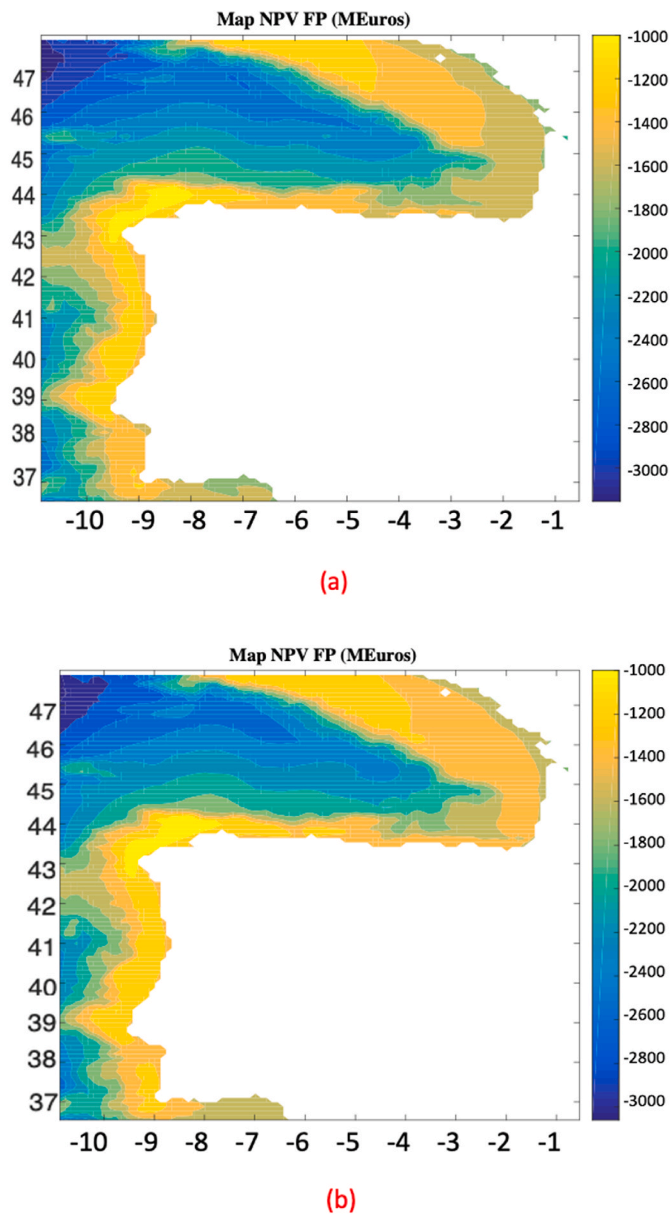

Fig. 6. NPV (in M€) for the wave energy farm with Method 1 for 8 % of the cost of capital (a) and for 10 % of the cost of capital (b). Source: own elaboration.

The Manufacturing cost (*C3*) considers the manufacturing costs of the generators (*C31*), floating platforms (*C32*), moorings (*C33*), anchors (*C34*) and electrical systems (*C35*), as shown in equation (10). The

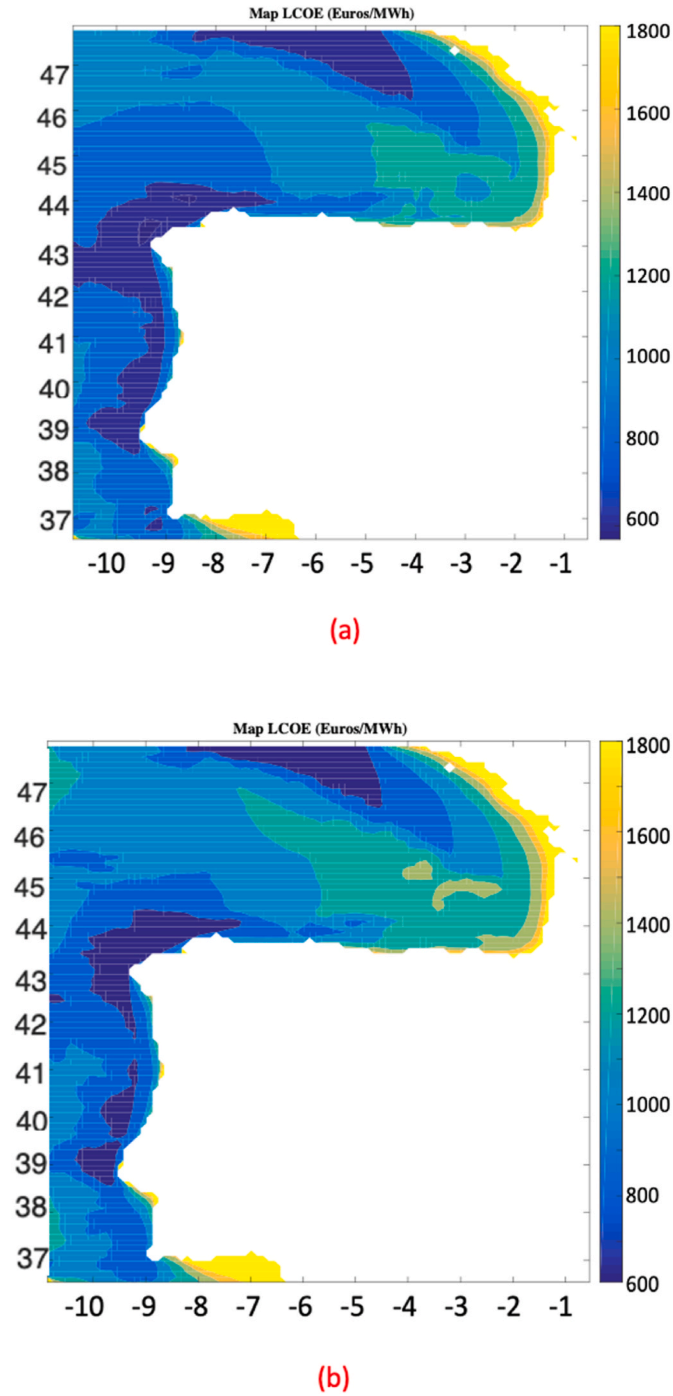

Fig. 7. LCOE (in €/MWh) for the wave energy farm with Method 1 for 8 % of the cost of capital (a) and for 10 % of the cost of capital (b). Source: Own elaboration.

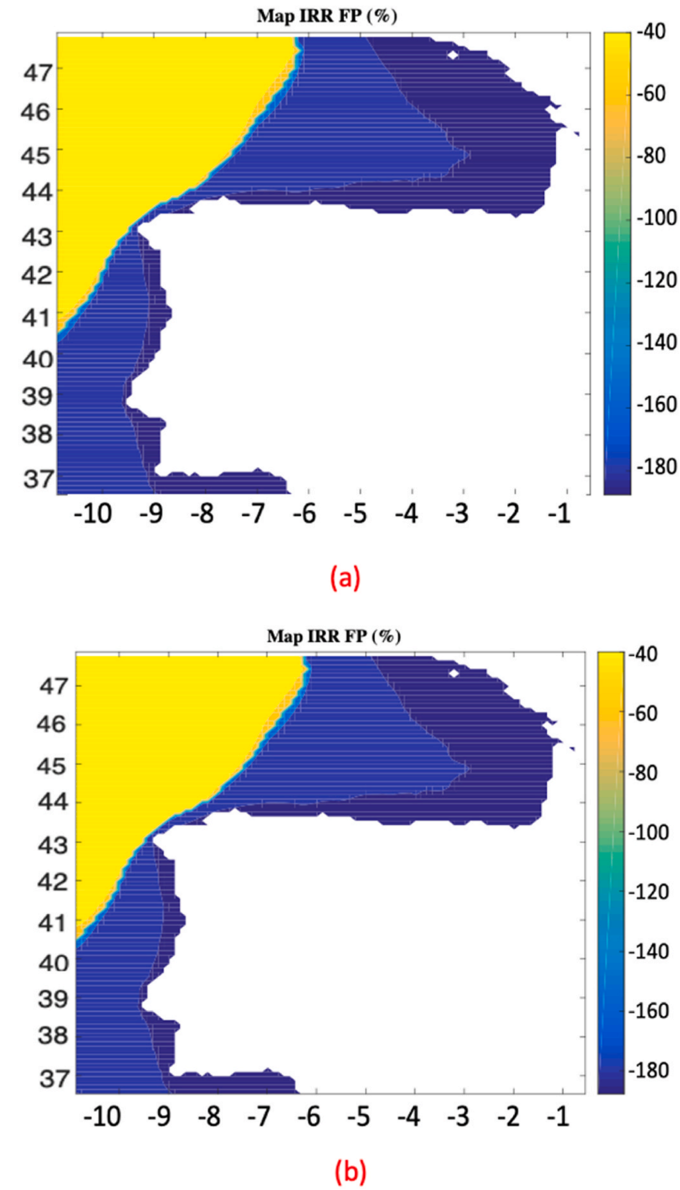

Fig. 8. IRR (in %) for the wave energy farm with Method 2 for 8 % of the cost of capital (a) and for 10 % of the cost of capital (b). Source: Own elaboration.

electrical systems costs include both the cable cost and the substation cost.

$$C3 = C31 + C32 + C33 + C34 + C35 \quad (10)$$

The Installation Cost (*C4*) includes the installation cost of the generating device (*C41*), the floating platforms (*C42*), the moorings and anchors (*C43*) and the electrical system (*C44*). It also includes the start-up cost (*C45*), as shown in equation (11).

$$C4 = C41 + C42 + C43 + C44 + C45 \quad (11)$$

The Cost of exploitation (*C5*) is made up of several subcosts: insurance *(C51)*, management and administration (*C52*) and operation and maintenance (O&M) (*C53*), as shown in equation (12) [42].

$$C5 = C51 + C52 + C53 \quad (12)$$

The wave farm must be disassembled at the end of its life-cycle to leave the offshore location as it was initially. First, the farm is dismantled, and then the material obtained (steel, copper, etc.) is sold (considering it a negative cost). Therefore, the Dismantling Cost *(C6)* depends on the dismantling cost of the generating devices *(C61*), the floating platforms (*C62*), the mooring and anchoring systems (*C63*) and the electrical system (*C64*). It also comprises the cost of cleaning the area (*C65*) and the cost of removing the materials (*C66)*, as shown in equation (13).

$$C6 = C61 + C62 + C63 + C64 + C65 + C66 \quad (13)$$

2.3. Definition of energy calculation methods

Usually energy is calculated based on historical or past wind resource data available for the study region. However, the feasibility studies show

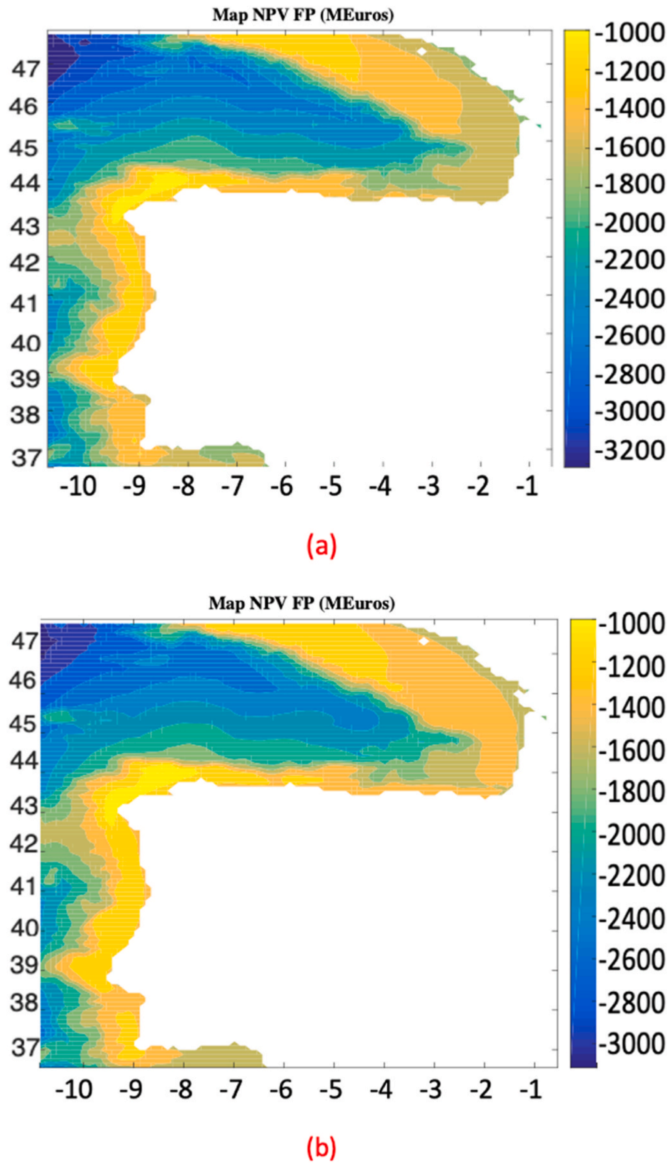

Fig. 9. NPV (in M€) for the wave energy farm with Method 2 for 8 % of the cost of capital (a) and for 10 % of the cost of capital (b). Source: Own elaboration.

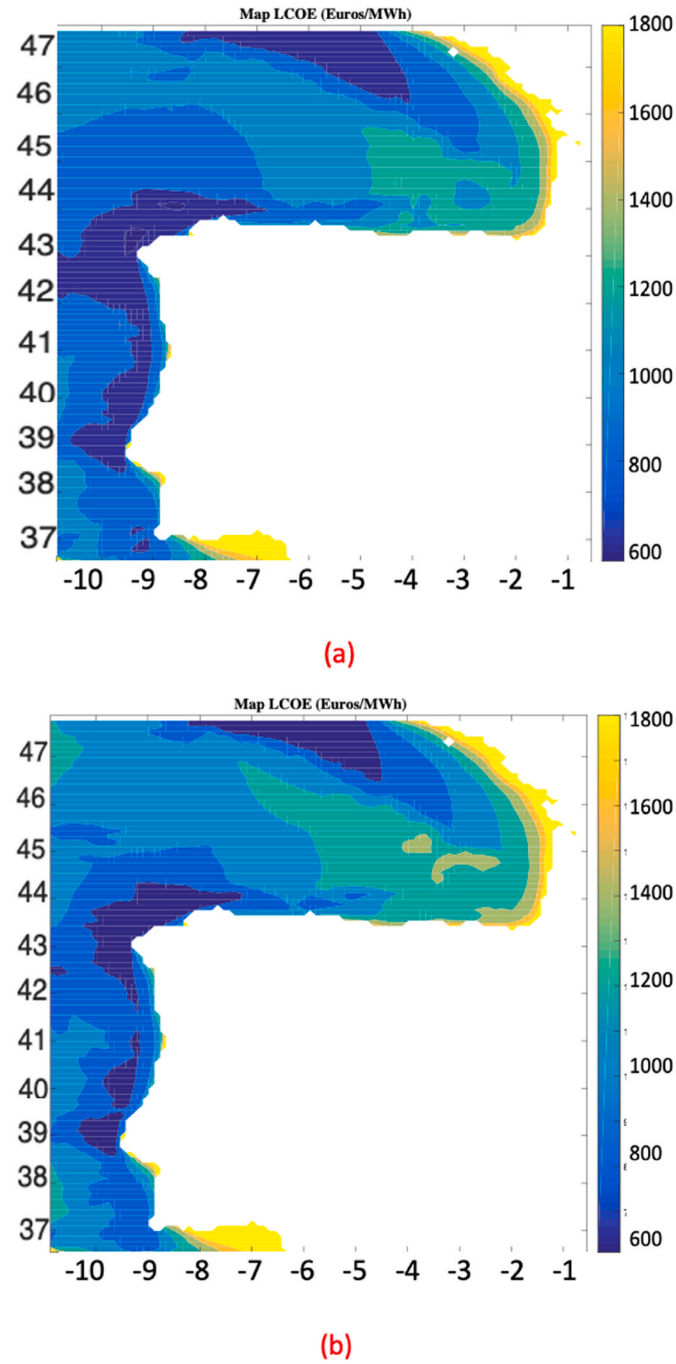

Fig. 10. LCOE (in €/MWh) for the wave energy farm with Method 2 for 8 % of the cost of capital (a) and for 10 % of the cost of capital (b). Source: Own elaboration.

predictions of how the farm will perform. So, the energy used for calculating NPV, IRR and the LCOE must be the energy calculated for the future, as conducted in this article and achieving greater accuracy.

In this context, four methods have been developed to study the type of calculation of the energy generated by the farm. These four methods have been considered in a previous study about offshore wind [43]. However, the objective of this study is a step forward by acknowledging if considering these methods change the economic feasibility of wave energy farms. The methods are the following [43]:

- “Method 1: average future prediction for all years. E_n constant with future data.
- Method 2: future prediction for each year. E_n variable with future data.
- Method 3: average of the past prediction for all years. E_n constant with past data.
- Method 4: past data of each year. E_n variable with past data.”

2.4. Wave data

Significant wave height (H_s) and wave peak period (T_p) are the wave parameters necessary for the wave energy calculation in this study, notwithstanding that the wave power is commonly determined with the wave energy period (T_e). *It* can be estimated by the T_p: $T_e = \alpha T_p$, where α depends on the shape of the wave spectrum [44]. A dynamical downscaling with the SWAN (*Simulating Waves Nearshore*) model [45] was performed to obtain high-resolution wave data in the area under scope. These simulations were previously validated in Ribeiro et al. [40]. In addition, this data was also used to carry out a wave energy classification on the north-western coast of the Iberian Peninsula [44] and to

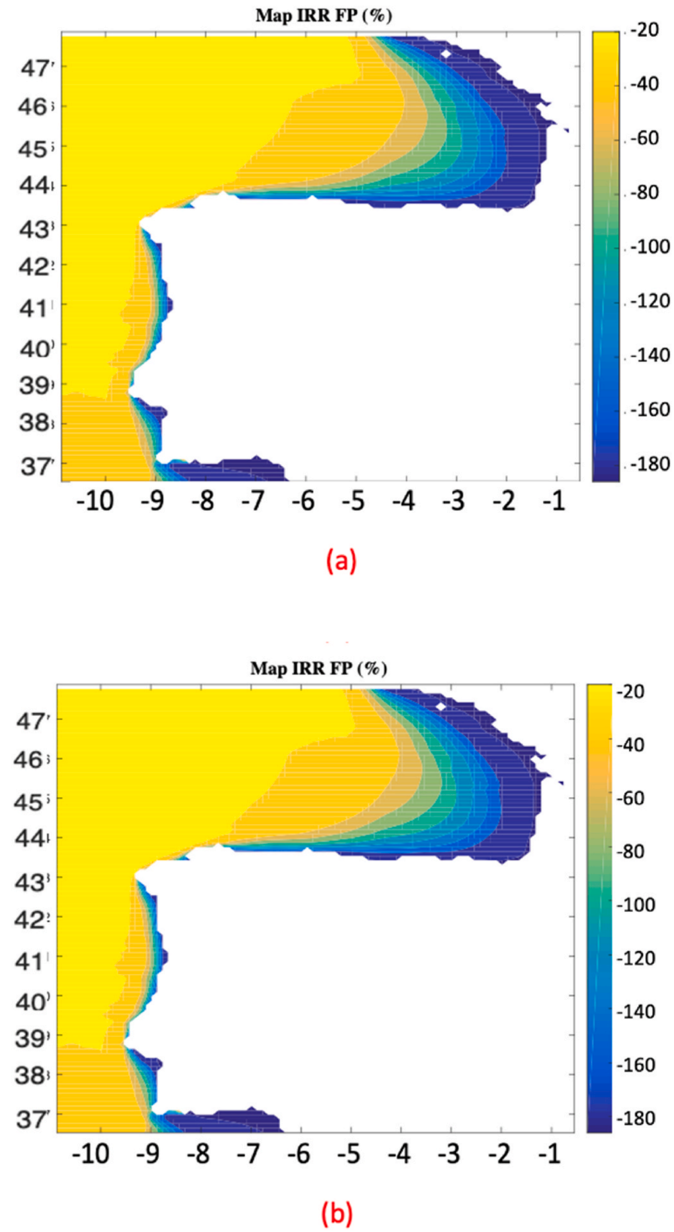

Fig. 11. IRR(in %) for the wave energy farm with Method 3 for 8 % cost of capital (a) and for 10 % cost of capital (b). Source: Own elaboration.

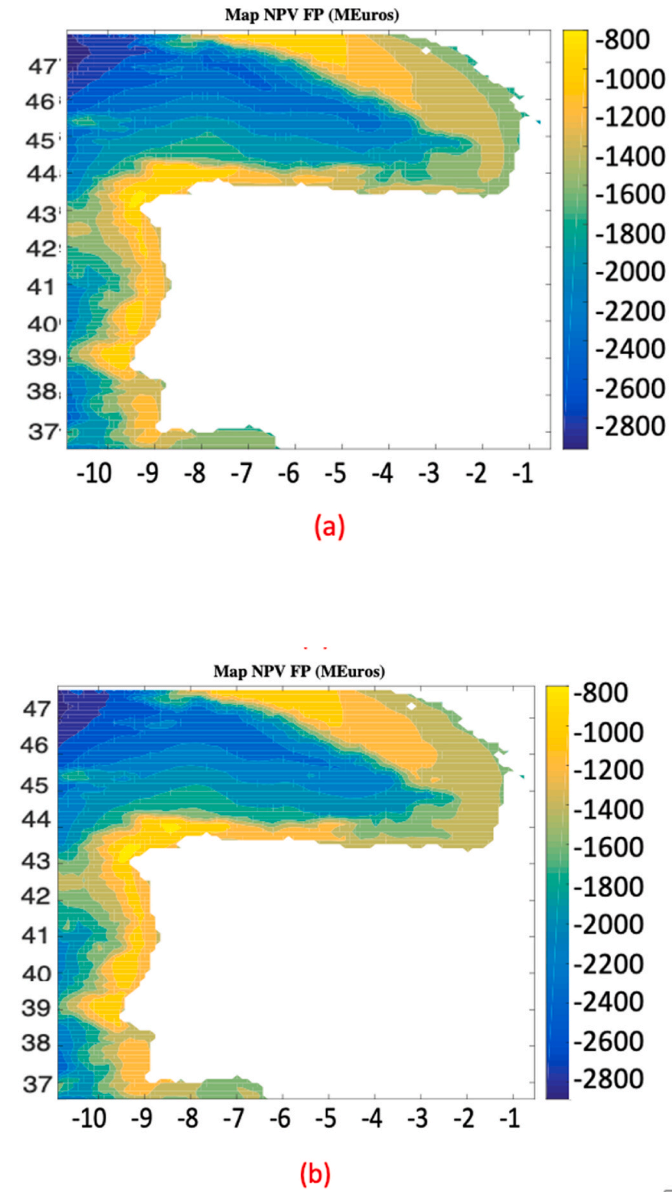

Fig. 12. NPV (in M€) for the wave energy farm with Method 3 for 8 % cost of capital (a) and for 10 % cost of capital (b). Source: Own elaboration.

study the hybrid wind-wave energy resource in the same area [46].

In brief, the initial and boundary wave conditions for running the SWAN model were provided by the global climate model (GCM) MIROC5 because this GCM was the most accurate when compared to other 8 GCMs [40] from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) database [47,48]. This data has a spatial resolution of $1^\circ \times 1^\circ$ both in latitude and longitude. To be coherent, the initial and boundary conditions of wind data were provided by the regional climate model MIROC5-CCLM4-8-17 from EURO-CORDEX database [49]. This downscaling process allows to obtain significant wave height (H_s) and wave peak period (T_p) parameters with a spatial resolution of 0.11° both in latitude and longitude in the west Iberian Peninsula and the Bay of Biscay. This high spatial resolution allows to carry out a detailed economic analysis. Wave parameters were obtained for historical (1986–2005) and near future (2026–2045). Detailed information regarding the downscaling process can be found in Ribeiro et al. [40].

3. Case study

The study zone to analyse the feasibility of floating wave energy farms is the Atlantic Ocean covering the Iberian Peninsula and the Bay of Biscay (which includes the European countries of Spain, Portugal and France) (see Fig. 4). The recent technical advances in floating structures applied to marine energies allow the installation of wave and wind farms at higher depths [50]. This is of special interest in the region under scope because the continental shelf is narrow, especially in the Atlantic arc around the Iberian Peninsula, as can be seen in Fig. 5. This fact suggests a rapid increase in the number of marine energy farms in the upcoming decades. In addition, other factors will favour this increase. An example is the advance in the legal framework regarding marine energy in Spain [51] and Portugal [52] or the necessity of increasing the installation of marine energy farms in these countries to achieve the commitments regarding the reduction of greenhouse gasses. Due to these factors, conducting an economic future analysis of wave farms in this area is of special interest.

The calculations have been carried out considering the AquaBuoy

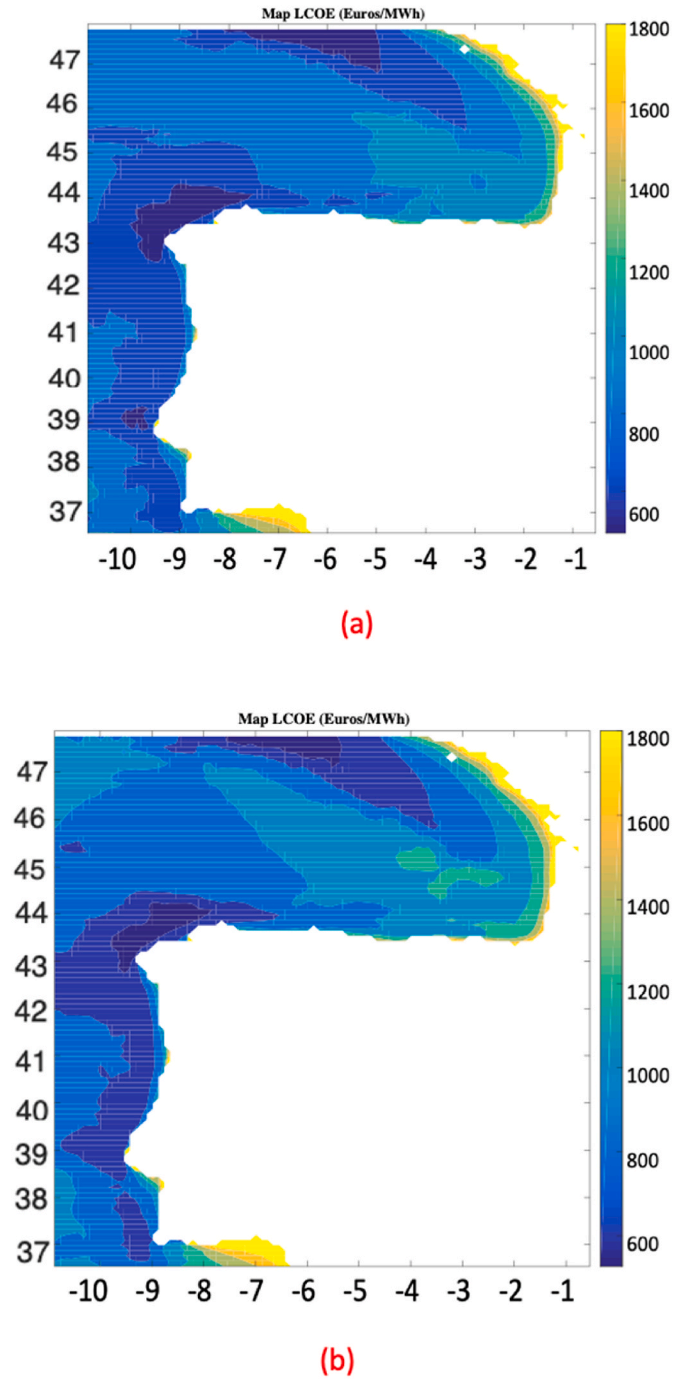

Fig. 13. LCOE (in €/MWh) for the wave energy farm with Method 3 for 8 % cost of capital (a) and for 10 % cost of capital (b). Source: Own elaboration.

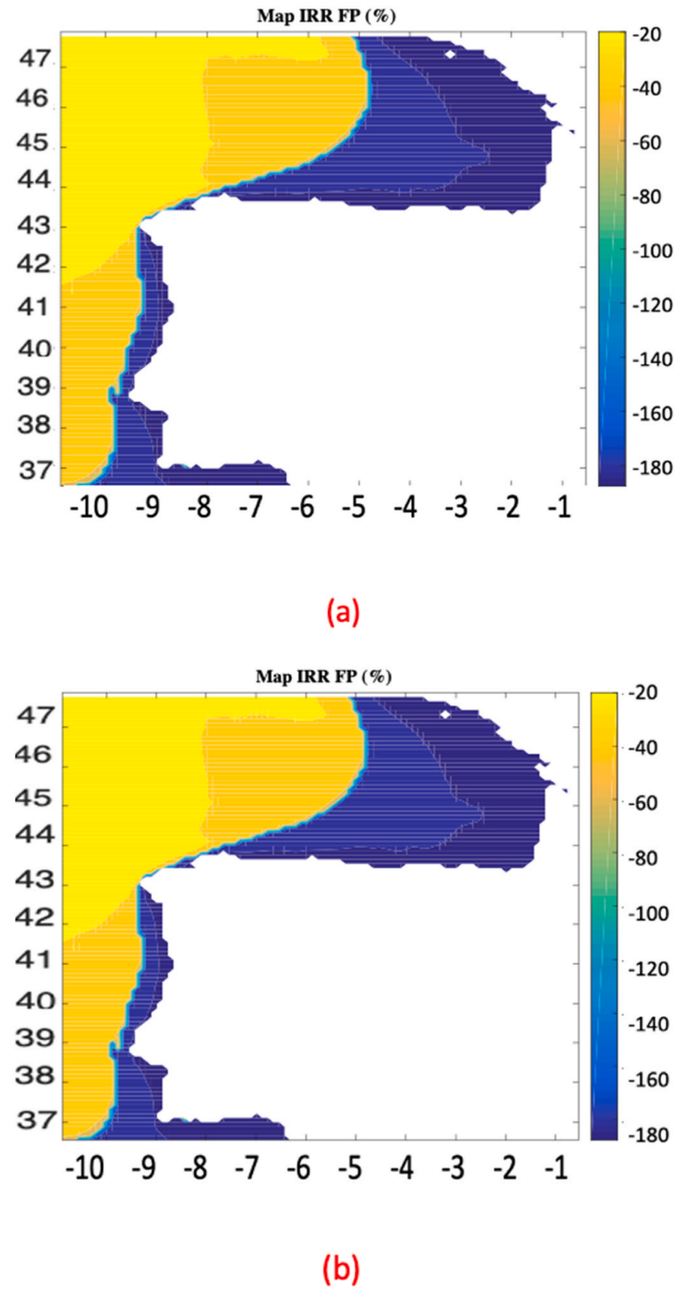

Fig. 14. IRR (in %) for the wave energy farm with Method 4 for 8 % of the cost of capital (a) and for 10 % of the cost of capital (b). Source: Own elaboration.

floating wave platform, whose power matrix is shown in Table 1 [53]. It can be seen that its maximum generated power is 250 kW. AquaBuoy is a WEC device of type point absorber that operates at intermediate/deep waters.

The principal features of the defined farm are presented in Table 2 [54,55].

4. Results

Considering Method 1 and 8 % of the cost of capital, the IRR, NPV and LCOE maps are shown in Figs. 5a–s. 6a and 7a, respectively. The IRR oscillates between −185.8248 % and −16.5465 %, and the NPV has values varying from −3154M€ to −903 M€. So, in terms of economic viability, there are no areas of economic feasibility because the IRR is less than the Weighted Average Cost of Capital (WACC), and the NPV is less than zero. In addition, the LCOE (Fig. 7a) has a minimum value of €568.7717/MWh for the analysed region.

Assuming the Method 1 and 10 % of the cost of capital, the IRR, NPV and LCOE maps are shown in Figs. 5b–s. 6b and 7b, respectively. The IRR has the same value as in the previous case because it does not depend on the cost of capital, and the NPV has values varying from €3059.6 M to €875.5 M. Therefore, considering economic viability, there are no areas of economic feasibility because the IRR is less than the Weighted Average Cost of Capital (WACC) and the NPV is less than zero. On the other hand, the LCOE (see Fig. 7b) presents a minimum value of €609.4739/MWh for the studied region.

Considering Method 2 and 8 % of the cost of capital, the IRR, NPV and LCOE maps are shown in Fig. 8a, Figs. 9a and 10a, respectively. The

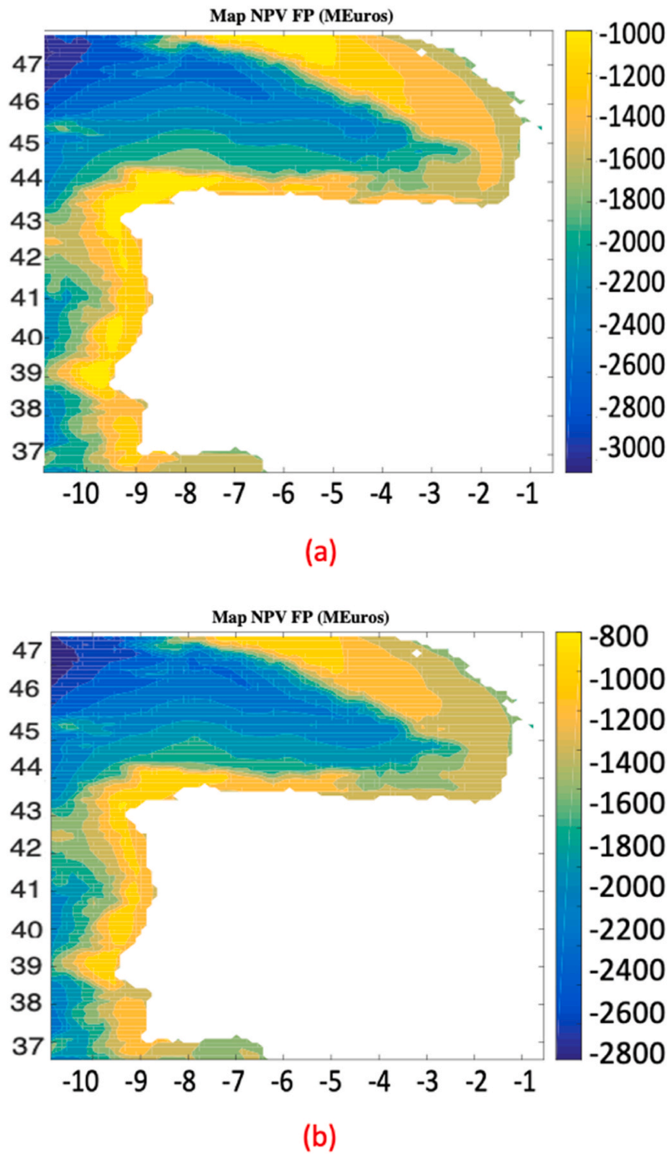

Fig. 15. NPV (in M€) for the wave energy farm with Method 4 for 8 % of the cost of capital (a) and for 10 % of the cost of capital (b). Source: Own elaboration.

IRR goes from −187.5173 % to −21.5948 % and the NPV goes from −3215 M€ to −917.9 M€. Thus, studying the economic feasibility, there are no areas where the FOWF considered for the electricity rate is economically feasible because the IRR is less than the WACC and the NPV is less than zero. Otherwise, the LCOE (see Fig. 10a) shows values for the Galician area (Northwest of the Iberian Peninsula), with a minimum value of €568.7714/MWh.

Regarding Method 2 and 10 % of the cost of capital, the IRR, NPV and LCOE maps are shown in Figs. 8b–s. 9b and 10b, respectively. The IRR has the same value as in the previous case because it does not depend on the cost of capital and the NPV ranges between −3112.5 M€ and −886.6 M€. Consequently, considering the economic feasibility, there are no areas of economic feasibility because the IRR is less than the WACC and the NPV is less than zero. Regarding LCOE (see Fig. 10b), it presents values for the Galician region with a minimum value of €609.4738/MWh.

Taking into account the Method 3 and 8 % of the cost of capital, the IRR, NPV and LCOE maps are shown in Fig. 11a, Figs. 12a and 13a, respectively. The IRR oscillates from −185.8238 % to −10.1976 % and the NPV from −2957.5 M€ to −750.3 M€. Subsequently, bearing in mind the economic feasibility, there are no areas of economic feasibility because the IRR is less than the WACC and the NPV is less than zero. On the other hand, the LCOE (see Fig. 13a) presents values for the Galician area, with a minimum value of €492.9337/MWh.

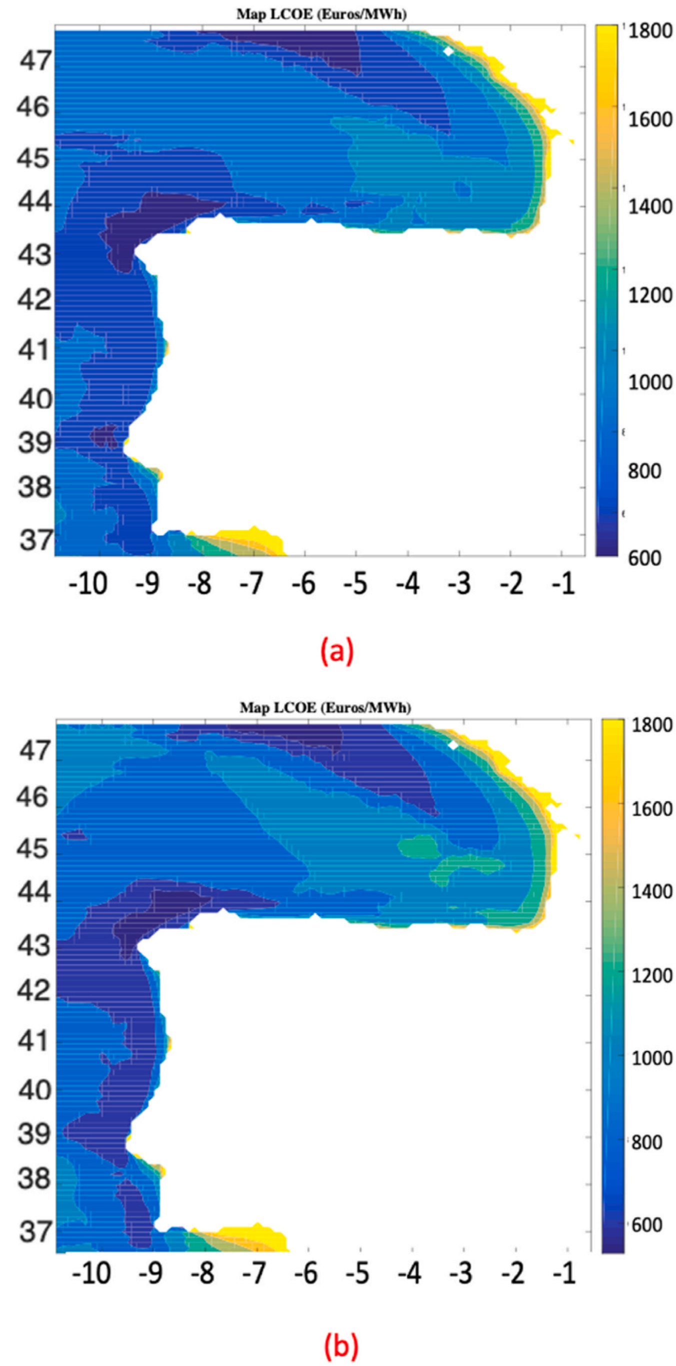

Fig. 16. LCOE (in €/MWh) for the wave energy farm with Method 4 for 8 % of the cost of capital (a) and for 10 % of the cost of capital (b). Source: Own elaboration.

Considering Method 3 and 10 % of the cost of capital, the IRR, NPV and LCOE maps are shown in Figs. 11b and 12b, respectively. The IRR has the same value as in the previous case because it does not depend on the cost of capital and varies from −2885.7 M€ to −740.9 M€. Subsequently, contemplating the economic feasibility, there are no areas of economic feasibility because the IRR is less than the WACC and the NPV is less than zero. Regarding the LCOE (see Fig. 13b), it presents values

Table 3
Comparison considering the method and Method 2.

Method		IRR		NPV		LCOE
	r	MIN	MAX	MIN	MAX	MIN
Method 1	8 %	0,90 %	23,38 %	1,90 %	1,62 %	0,00 %
	10 %	0,91 %	23,38 %	1,70 %	1,25 %	0,00 %
Method 2	8 %	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %
	10 %	0,00 %	0,00 %	0,00 %	0,00 %	0,00 %
Method 3	8 %	0,90 %	52,78 %	8,01 %	18,26 %	−13,33 %
	10 %	0,90 %	52,78 %	7,29 %	16,44 %	−1,85 %
Method 4	8 %	0,00 %	36,53 %	4,57 %	12,09 %	−13,33 %
	10 %	0,00 %	36,53 %	4,16 %	11,06 %	−13,33 %

for the Galician area, with a minimum value of €598.2198/MWh.

Considering Method 4 and 8 % of the cost of capital, the IRR, NPV and LCOE maps are shown in Fig. 14a, Figs. 15a and 16a, respectively. The IRR oscillates between −187.5166 % and −13.7071 %, and the NPV ranges from −3068.1 M€ to −806.9 M€. Therefore, studying the economic viability, there are no areas of economic feasibility due to the IRR being less than the WACC and the NPV being less than zero. Considering LCOE (see Fig. 16a), it presents minimum values for the Galician of €492.9338/MWh.

Contemplating the Method 4 and 10 % of the cost of capital, the IRR, NPV and LCOE maps are shown in Figs. 14b–s. 15b and 16b, respectively. The IRR has the same value as in the previous case because it does not depend on the cost of capital and goes from −2982.9 M€ to −788.5 M€. Therefore, taking into account the economic viability, there are no areas of economic feasibility. In addition, LCOE (see Fig. 16b) presents values for the Galician area, with a minimum value of €528.2200/MWh.

5. Discussion

The primary phase in evaluating the viability of a wave energy farm at a particular location is to analyse its wave energy resource. Therefore, it is very significant to define how climate change may influence that wave resource in the near future. Therefore, studying future wave resource projections under different greenhouse gas emission scenarios is essential [43].

Table 3 displays the evaluation of the greatest results of the methodologies calculated, comparing them with Method 2, which is theoretically the most appropriate because it symbolises the real energy of future years. According to Table 3, the main differences between the results of the four methods are in the NPV, with a maximum alteration of 52.78 % for Method 3 with respect to Method 2. This result is much higher than that obtained previously for floating offshore wind, whose maximum variation was 13.09 % [43]. In addition, the LCOE value in the case of wave energy also has a large difference for Method 3 and Method 4 (−13.33 %), which differs from the results obtained for offshore wind energy (with a maximum variation of 1.84 %) [43]. This LCOE increase indicates that energy production will be lower for the selected region in the future. Therefore, the economic viability of floating offshore wave power farms will decrease in southern Europe.

6. Conclusions

This study analysed the economic viability of wave energy farms along the Atlantic coast of the Iberian Peninsula. Data from historical and projected waves have been considered to examine their impact on the main economic parameters (NPV, TIR and LCOE) that control this type of wave energy farm's viability. Therefore, various cases were studied considering the historical and future wave climate to evaluate the variances in terms of economic feasibility. This study considered the economic aspects in addition to the previous assessments, which considered only the resource from a physical point of view. The analysis presented in this study shows a step forward in the viability of exploiting the wave energy to be produced in wave farms. This analysis can be considered a decision support toolkit in identifying the most profitable locations for wave farms, or in the management, adaptation, and resilience of projected and ongoing plans since it considers a projection of the near future.

Projections of the wave resources in the near future are crucial to define the feasibility of a wave energy farm in particular locations. Considering the results obtained, the predicted wave energy reduction mainly affects the operation's NPV and LCOE.

This work provides a valuable methodology, however, it should be mentioned that the results should be considered as an estimation and decision support toolkit due to some limitations. These limitations are linked to economic constraints such as the interdependence between services, spatial and temporal issues that affect the cost and benefits of present values and generate uncertainty as we look further into the future. This validation of this study is also constrained by the inexistence of floating offshore wave energy farms in the world. However, the proposed method offers a good approximation of the economic feasibility of a floating wave energy farm since it also considers the possible decreases in the wave resource due to climate change during the total service life of the farm.

CRediT authorship contribution statement

Laura Castro-Santos: Conceptualization, Methodology, Software, Writing – original draft, Supervision. **Almudena Filgueira-Vizoso:** Conceptualization, Methodology, Software, Writing – original draft. **Xurxo Costoya:** Conceptualization, Methodology, Software, Writing – original draft, Supervision. **Beatriz Arguilé-Pérez:** Data curation, Methodology, Writing – original draft. **Américo Soares Ribeiro:** Data curation, Methodology, Writing – original draft.

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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