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Reconversion of the shipbuilding sector: from production by project to mass production. What is its effect on the LCOE of a wave energy farm?

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Abstract. The objective of this work has been to analyze the variation of different economic parameters (Levelized Cost Of Energy and Internal Rate of Return) for two possible ways of manufacturing: production by project to mass production. For this, 6 possible scenarios have been considered, taking into account the number of equipment manufactured and the economic parameters have been calculated in order to know which alternative provides greater economic viability, thus making the project more profitable.

Key words.
Platforms, LCOE, mass production, offshore wave energy farm

1. Introduction

Currently, the use of renewable energies is growing exponentially [1] due, among others, to two main factors that make them advantageous with respect to fossil fuels:

- They do not emit greenhouse gases [2–4]. The use of fossil fuels has been causing significant damage to the environment for many years. Among these damages, the main ones are those caused to the atmosphere through the emission of gases such as sulfur oxides, nitrogen oxides, etc., which are the main causes of acid rain [5], the destruction of the planet's ozone layer and causing, therefore, its heating [6,7].
- Allow energy independence from other countries. The use of fossil fuels has caused the energy dependence of those countries that possess these resources, which has made dependent countries vulnerable energetically speaking [9]. This has become clearer to a greater extent with the war between Russia and Ukraine [10], at which time a significant number of countries have found themselves deprived of the fossil resources necessary for electricity generation.

Within renewable energies there are many types, the most used at present is wind energy [11], but there are many others that are not yet so profitable but that it is necessary to study to make them equally or more profitable than wind, such as: wave energy [12,13], solar energy [14], tidal energy [15], etc. All of them located in the sea, since the planet has 70% sea and 30% land, locations on land are already more exploited, and because types of energy such as tides or waves are exclusively marine. That is why this study focuses on wave energy.

Mainly due to these problems, the growth of renewable energies is a fact and in order to have this type of energy, facilities are necessary that can manufacture, assemble, store and, where appropriate, maintain it. At this point, the shipyards play an important role, which although initially dedicated to building ships, currently have to be converted to manufacture renewable energy structures. A clear example of this transformation can be found in the NAVANTIA FENE shipyard [16] (one of the largest shipyards in Europe), located in Galicia (Northwestern

Spain) and where numerous offshore wind platform construction projects are being carried out. and is being a benchmark in this sector. To make these types of technologies more profitable, it is necessary to optimize the costs associated with them and for this it is necessary to analyze values such as the LCOE (Levelized Cost Of Energy) [17–20] taking into account different forms of production.

1. Methodology

Wave Energy Converters (WECs) will be built in the future in shipyards. Shipbuilding is an industrial sector whose main way of working is "*production by project*", building usually one or two products (ships) at the same time. However, the future of shipbuilding will be transformed to work similarly to "*mass production*", which involves producing a great quantity of products. The main reason is that shipyards should adapt their production system to the offshore renewable energy demand, both offshore wind and wave energy.

In this context, the present study will analyse the influence that the number of wave energy platforms built has on the LCOE (Levelized Cost Of Energy).

In this sense, LCOE depends on the total life-cycle cost of the Floating Offshore Wave Energy Farm (FOWEF) in year n (LCS_{FOWEF_n}), the capital cost (r), the number of years of the project (N_{farm}) and the energy produced by the wave energy farm in year n (E_n). Equation (1) shows the way of calculating the LCOE.

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

The total life-cycle cost of the farm (LCS_{FOWEF_n}) depends on the cost of each phase of the life-cycle of the process: from manufacturing to installing, maintaining and dismantling the wave energy farm [21]. The energy produced by the farm (E_n) is calculated considering the wave energy resource of the location selected and the wave power matrix of the WEC (Wave Energy Converter) selected.

2. Case of study

The case of study will be the Cantabric Sea and the Atlantic Ocean of the Iberian Peninsula (Spain, Europe). Fig. 1 shows the selected are in green colour.

Fig. 1. Location selected [22].

The offshore wave energy converter selected is the Aquabuoy [23]. The size of the farm taken into account is 500 M and the capital cost will be 8%.

Lastly, regarding the cost of steel, three different scenarios will be considered, as

Table **I** is shown:

Table I. Scenarios taken into account regarding the number of platforms built by the shipyard by year.

Scenario	**Number of platforms built by year (platforms/year)**
1	5
2	10
3	20
4	30
5	40
6	50

3. Results

Taking into account LCOE, it goes from 484.35 €/MWh to 3,560 €/MWh for Scenario 1 (see Fig. 2), from 433.63 €/MWh to 3,164 €/MWh for Scenario 2 (see Fig. **3**), from 408.07 €/MWh to 2,966 €/MWh for Scenario 3 (see Fig. 4, from 399.54 €/MWh to 2,900 €/MWh for Scenario 4 (see Fig. 5), from 395.28 €/MWh to 2,867 €/MWh for Scenario 5 (see Fig. 6), from 392.73 €/MWh to 2,847 €/MWh for Scenario 6 (see Fig. 7).

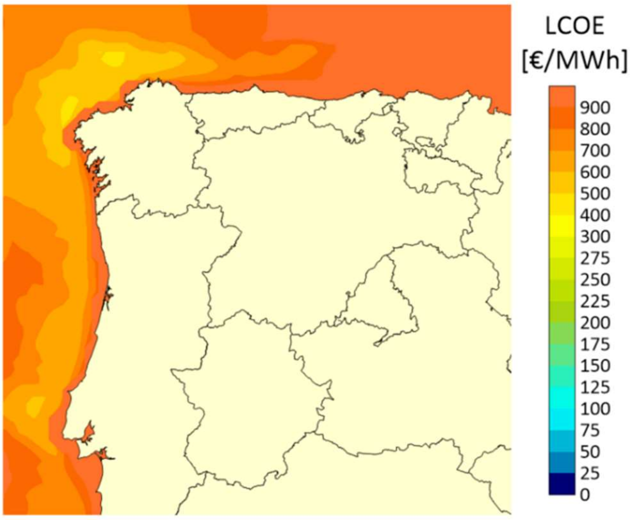

Fig. 2. LCOE (in €/MWh) for Scenario 1.

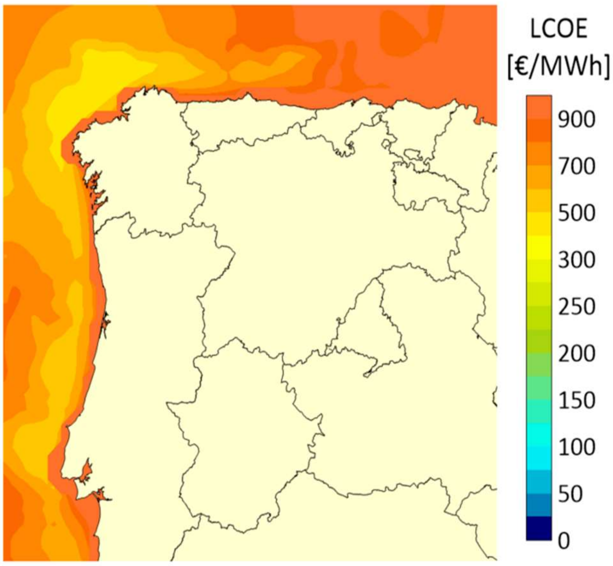

Fig. 3. LCOE (in €/MWh) for Scenario 2.

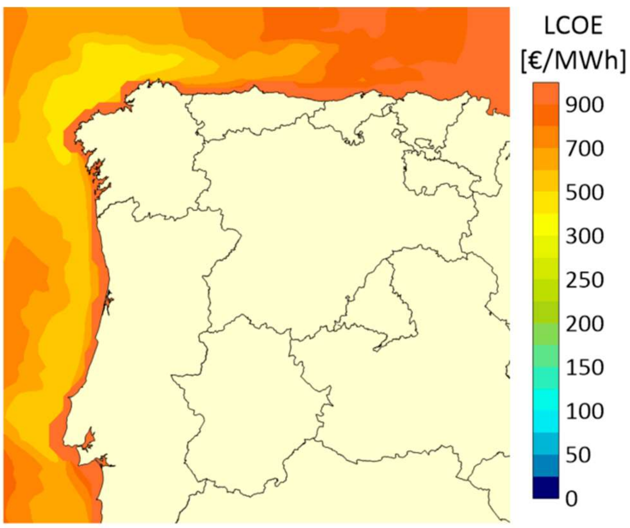

Fig. 4. LCOE (in €/MWh) for Scenario 3.

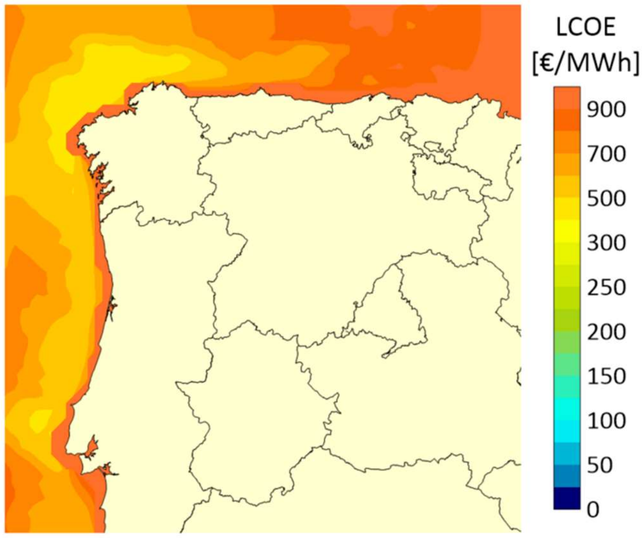

Fig. 5. LCOE (in €/MWh) for Scenario 4.

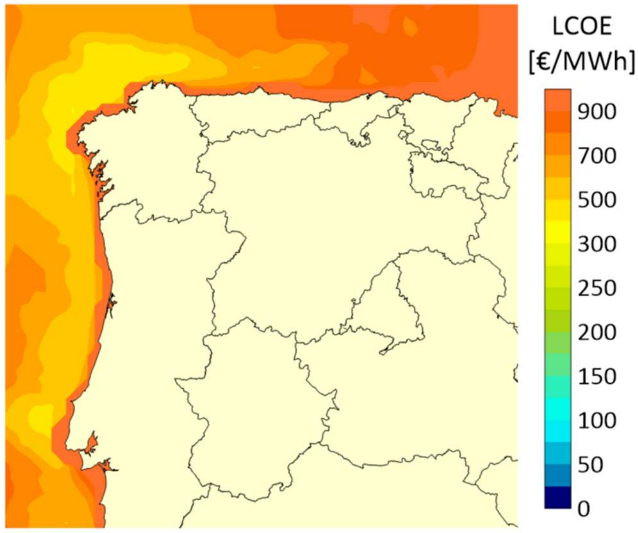

Fig. 6. LCOE (in €/MWh) for Scenario 5.

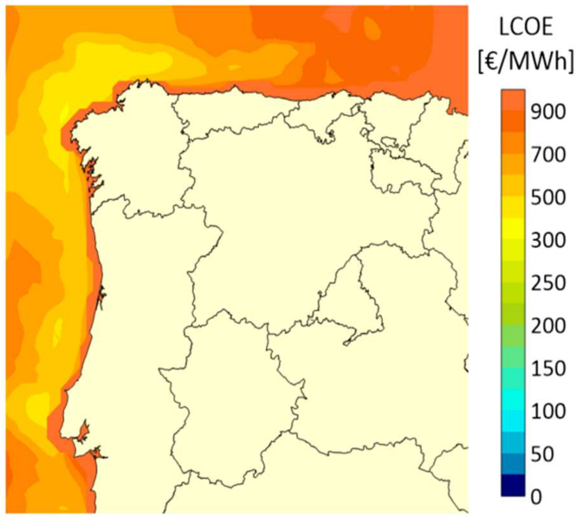

Fig. 7. LCOE (in €/MWh) for Scenario 6.

All these values for LCOE are very high at this moment. However, these results can vary in the future due to the

improvement of the maturity of the technology during the next twenty years.
Moreover, Fig. 8 shows the best areas in terms of LCOE for installing a wave energy farm:

- Area 1: Galician area.
- Area 2: Portugal area.

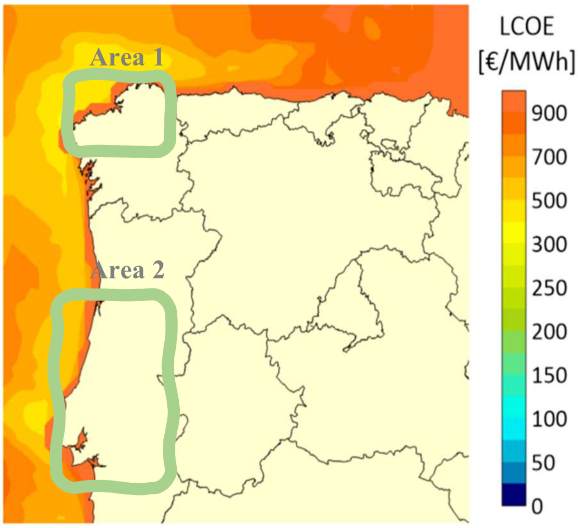

Fig. 8. Best areas for install a wave energy farm.

Considering the comparison between all the Scenarios, Fig. 9 shows that the highest economic variations are related to the IRR and LCOE, with values of -7.6% and 5.4% respectively.

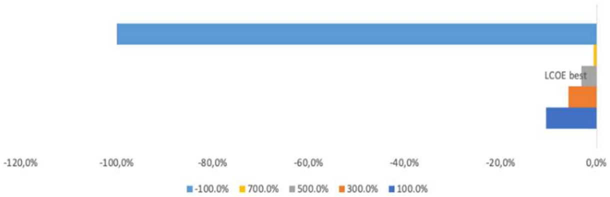

Fig. 9. Variation of the main economic parameters considering variations in the number of platforms built in the shipyard.

4. Conclusions

In this article, the Levelized Cost Of Energy (LCOE) of wave energy have been calculated taking into account two possible manufacturing alternatives, production by project and to mass production.
The case of study was located in the Atlantic region of the Iberian Peninsula (Spain and Portugal) and the WEC taken into account was the Aquabuoy platform.
For this, 6 possible scenarios have been analyzed depending on the number of platforms manufactured and it has been observed that the highest economic variations are related to the IRR and LCOE, with values of -7.6% and 5.4% respectively.
It indicates that the number of wave energy platforms built by a shipyard per year is a very important factor that affects to the future of shipbuilding industry.

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