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CAPEX and OPEX of floating offshore photovoltaic farms. The case of study of the Mediterranean area of the Iberian Peninsula

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Abstract. The objective of this work is to determine the CAPEX and OPEX of a floating offshore photovoltaic farm. The case of study will analyse a particular floating offshore photovoltaic platform called Merganser and a possible location in the Mediterranean area of the Iberian Peninsula. Results will denote the best areas where this type of energy can be installed in relation to its costs. It will bring help to future investors of this type of technology to do a preliminary analysis of offshore solar energy in this region.

Key words. Floating offshore photovoltaic, offshore renewable energy, solar, LCOE, economics

1. Introduction

Renewable energies are clean, inexhaustible and increasingly competitive sources of energy. They differ from fossil fuels mainly in their diversity, abundance and potential for use anywhere on the planet, and one of their main advantages is that they do not produce greenhouse gases or polluting emissions. Although the costs are not yet very low, it is true that the trend is downward, thanks to research and progress in the technology that carries them out [1].

Therefore, the growth of renewable energies is unstoppable, as shown by the International Energy Agency (IEA), the participation of renewables in the global electricity supply will go from 26% in 2018 to 44% in 2040, which It will provide 2/3 of the increase in electricity demand in that period, the main renewable energy sources involved will be wind, hydraulic and solar [1].

Spain ranks 11th out of 35 belonging to ENTSO-E (European Association for the Cooperation of the Transmission System Operation for Electricity) in 2020, with 46.8% generation of renewable energy out of total energy generation [2].

Nowadays, the Spanish energy system is closing the main coal power stations, for instance, the Coal Power Station of As Pontes (A Coruña) of 1,4 GW, that is the highest installation in Spain, and the Coal Power Station Litoral de Carboneras (Almería) of 1,2 GW of power. Therefore, the future Spanish energy roadmap should replace their electricity production. It is motivated by the fact that the present energy consumption is increasing continuously due to the electric cars, the home automation devices, etc.

In this context, renewable energies will have a great development in the future of the humanity. There are two main types of renewable energies: onshore renewable energies and offshore renewable energies. During the last thirty years onshore renewable energies, such as onshore wind, solar energy and hydro energy, had achieved a great development. Nowadays, certain onshore areas are occupied by wind farms or repowered wind farms. Moreover, onshore wind locations produce less electricity than the offshore ones due to their high roughness and their low wind speed. Therefore, offshore locations will represent the future of the clean energy that the society need.

There are several types of offshore renewable energies: offshore photovoltaic solar (PV), offshore wind, wave energy, tides, currents, salinity gradient energy and ocean thermal energy. Although the state of the technology is more developed in offshore wind and wave energy, the SEASUN project will consider the offshore PV because it has a great energy resource in Spain and it needs more impulse in terms of its technology development. In fact, the European Commission aims to complement the 300 GW of offshore wind capacity for 2050 with 40 GW of ocean energy and other emerging technologies such as floating wind and solar by 2050 [3].

Offshore solar energy is an alternative that has been little explored in the marine environment. To harvest this resource in the oceans and seas, floating photovoltaic (FPV) systems are required. Although applying this technology in the marine environment is new, FPV farms have been deployed worldwide in freshwater, including lakes and reservoirs [4]. The main advantage of FPV systems against land-based ones is the water cooling on the solar cells [5]. This effect results in a higher energy conversion efficiency of the floating panels, which can generate up to 10% more electricity [5]. Other advantages of offshore FPV systems include: the availability of abundant water for cleaning the panels, the scalability of the systems from microwatt to megawatt, and the reduction in the growth of algae by the shading effect of the panels.

The aim of the present paper is to calculate the CAPEX and OPEx of a floating offshore photovoltaic farm. The case of study will analyse a particular floating offshore photovoltaic platform installed in the Mediterranean area of the Iberian Peninsula. Results will indicate the best areas where this type of energy can be installed in economic terms. It will bring help to future investors of this type of technology to do a preliminary analysis of offshore solar energy in this region.

2. Methodology

According to the UNE-EN 60300-3-3 standard on "Reliability Management. Part 3-3: Application guide. Life cycle cost calculation" [6], the life cycle cost calculation is "the economic analysis process to determine the total cost of acquisition, ownership and disposal of a product. It can be applied to the complete life cycle of the product or to parts or combinations of different phases of its life cycle.

The main objective of calculating the life cycle cost is to provide criteria for decision making in any or all phases of the life cycle of a product.

An important objective in the preparation of LCC models is to identify the costs that may have a greater influence on the LCC or may be of special interest for this specific

application. Equally, it is important to identify the costs that only have a small influence on the LCC".
The most common types of decisions in which the LCC process provides a contribution including, for example:

- evaluation and comparison of alternative design approaches and technological elimination options;
- valuation of the economic viability of projects/products;
- identification of cost contributors and effective cost improvements;
- evaluation and comparison of alternative strategies for use, operation, testing, inspection, maintenance, etc. of the product;
- evaluation and comparison of different approaches for the replacement, rehabilitation/life extension or removal of aged equipment;
- allocation of available resources between different priorities for developing or improving a product;
- assessment of product warranty criteria through verification tests and commitments;
- long-term financing planning.

The costs of a floating marine solar farm using PV platforms will be calculated considering costs throughout its life cycle. For him, it is important to define the main phases in the life cycle of a floating marine solar farm. In this sense, previous studies on marine wind [7], [8] and regulations have been considered, a technology in superior development today, to identify these phases. Therefore, the main phases of the life cycle of a floating marine solar farm are as follows (see
Fig. ***1***):

- Phase 1: Conception and definition.
- Phase 2: Design and development.
- Phase 3: Manufacturing.
- Phase 4: Installation.
- Phase 5: Operation and Maintenance.
- Phase 6: Dismantling.

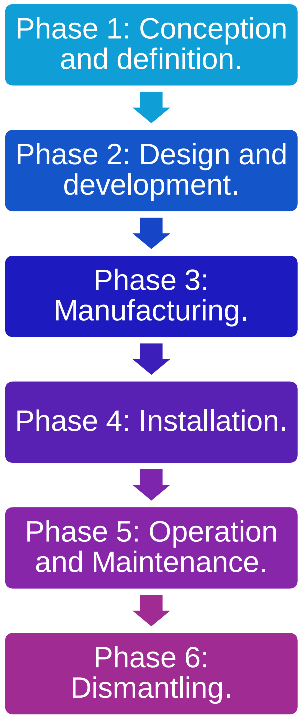

Fig. 1. Main phases of the life cycle of a floating marine solar farm with PV-bos technology. Source: Own elaboration.

Using these phases, the costs of the life cycle of the marine solar farm will be defined as demonstrated in the project (1): C_1 (Cost of conception and definition), C_2 (Cost of design and development), C_3 (Cost of manufacturing), C_4 (Installation cost), C_5 (Operating and maintenance cost) and C_6 (Dismantling cost).

$$LCC_{FOSF} = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 \qquad (1)$$

Therefore, CAPEX is shown in equation (2) and OPEX is shown is equation (3).

$$CAPEX = C_1 + C_2 + C_3 + C_4 + C_6 \qquad (2)$$

$$OPEX = C_5 \qquad (3)$$

3. Case of study

The case of study will analyse the Mediterranean area of the Iberian Peninsula, which is shown as the pink area in Fig. 2.

Fig. 2. Area considered. Source: [9].

The floating offshore solar photovoitaic platform considered is called MERGANSER. It is a heavy duty semisubmergible solar platform that is currently being developed by dutch company SolarDuck [10] (see Fig. 3) inside the context of the RWE project. It takes into account a unitary photovoltaic panel of 640 W, being 130 panels by platform (see Fig. 3) and, therefore, 0.0832 MW/platform.

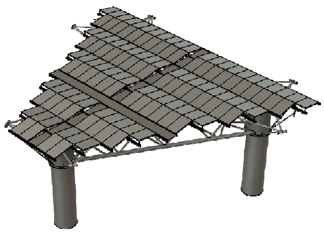

Fig. 3. Merganser platform. Source: own elaboration considering the data from [10].

The farm taken into account has a total power of 500 MW, considering the future development of the reference of the offshore wind in Spain given by offshore wind projects under processing.

4. Results

Results for costs C1 and C2 are independent of the area where the farm is located. Therefore, they are general costs and their value for the total farm considered are constant, being 253.62 M€ and 3.66 M€ respectively.

In addition, although C5 should be a cost dependent on the location, for this first approximation will be also considered as constant due to the lack of data about operation and maintenance of floating offshore photovoltaic farms. In this context, its value for the total farm is 544.13 M€.

Regarding C3, its medium value for the total farm is 22,907.16 M€, its minimum value is 2,044.16 M€ and its maximum value is 73,505.29 M€. The values of C3 depending on the location are shown in Fig. *4*.

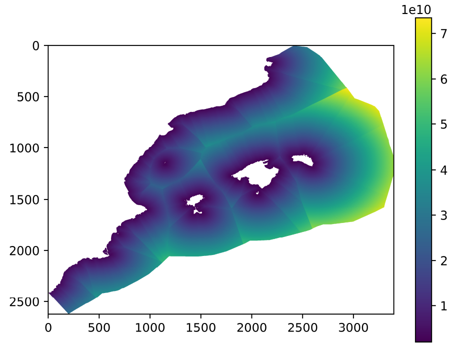

Fig. 4. Costs of manufacturing (C3). Units in €. Source: own elaboration.

Regarding C4, its medium value for the total farm is 3,018.80 M€, its minimum value is 1,190.53 M€ and its maximum value is 5,793.77 M€. The values of C3 depending on the location are shown in Fig. *5*.

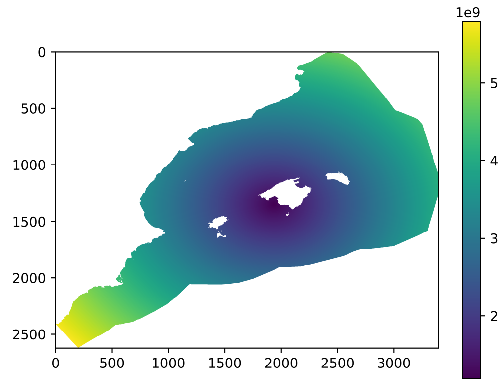

Fig. 5. Costs of installing (C4). Units in €. Source: own elaboration.

Regarding C6, its medium value for the total farm is 301.88 M€, its minimum value is 119.05 M€ and its maximum value is 579.37 M€. The values of C3 depending on the location are shown in Fig. *6*.

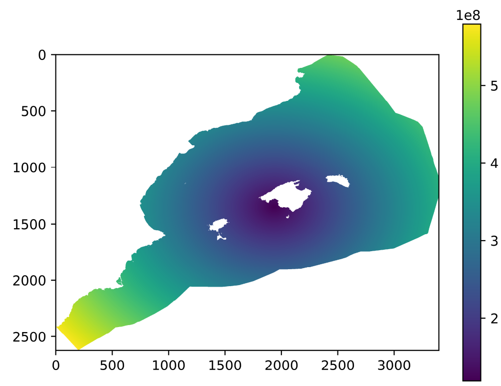

Fig. 6. Costs of dismantling (C6). Units in €. Source: own elaboration.

Regarding the total costs of the floating photovoltaic farm considered, its medium value for the total farm is 27,029.25 M€, its minimum value is 4,155.16 M€ and its maximum value is 80,679.85 M€. The values of the total cost depending on the location are shown in Fig. *7*.

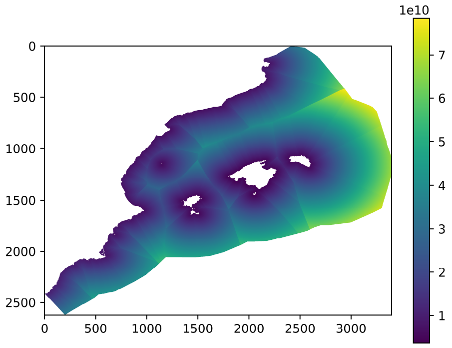

Fig. 7. Total life-cycle costs of a floating photovoltaic farm. Source: own elaboration.

It represents, for the case of the minimum costs a CAPEX of 7.22 M€/MW and an OPEX of 1.09 M€/MW.

Therefore, considering the minimum values of costs, the most important values of costs are the cost of manufacturing (49.20%), the cost of installing (28.65%) and the cost of maintenance (13.10%), as Fig. 8 is shown.

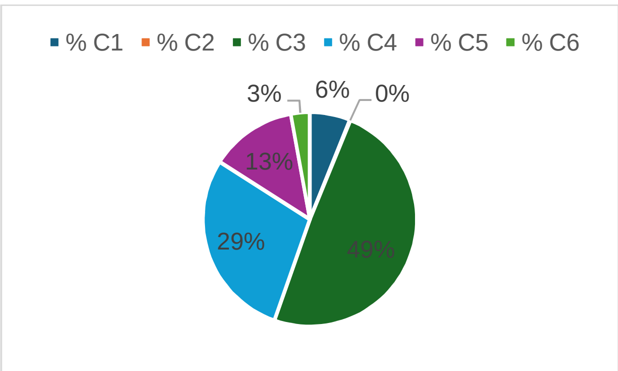

Fig. 8. Percentage of the total life-cycle costs of a floating photovoltaic farm. Source: own elaboration.

5. Conclusions

This paper has analyzed a new technology that can be useful for reducing the carbon emissions in the European Union: the floating offshore solar photovoltaic renewable energy, which combines the knowledge of offshore wind and oil&gas industry regarding the platform and the PV onshore industry, both of them well known.

In this context, a method to calculate the main life-cycle costs of a PV offshore farm has been developed considering all the phases of its life-cycle from the beginning (conception and definition) to the end of the process (dismantling).

A particular case of study has been analyzed considered Merganser prototype developed by SolarDuck and the Mediterranean area of the Iberian Peninsula in order to show the best areas where a farm of this characteristics can be installed.

The best areas where a solar floating offshore farm can be located are the closest to the Balearic Islands in the Mediterranean Sea.

The work carried out is helpful for considering the preliminary locations in a photovoltaic offshore farm in any location.

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