22nd International Conference on Renewable Energies and Power Quality (ICREPQ'24)
Bilbao (Spain), 26th to 28th June 2024

ISBN: 978-84-09-60656-6

Potential of offshore photovoltaic solar technology in the north of Chile

T.I.Guillén-Diaz [1], P. Rubial-Yáñez [2], D. Jara[3] , I. Lamas-Galdo [4], D. Cordal Iglesias [5], F. Puime-Guillén[6], A. Filgueira-Vizoso[7], I. Robalo-Cabrera[8] L. Castro-Santos [9]

1 Universidad Adolfo Ibáñez, Facultad de Ingeniería y Ciencias, Chile

2 Universidade da Coruña, Campus Industrial de Ferrol, Escola Politécnica de Enxeñaría de Ferrol, Esteiro, 15471 Ferrol, Spain

3 Universidad Adolfo Ibáñez, Facultad de Ingeniería y Ciencias, Chile

4 Universidade da Coruña, Campus Industrial de Ferrol, Departamento de Ciencias da Navegación e Enxeñaría Mariña, Escola Politécnica de Enxeñaría de Ferrol, Esteiro, 15471 Ferrol, Spain

5 Universidade da Coruña, Campus Industrial de Ferrol, Escola Politécnica de Enxeñaría de Ferrol, Esteiro, 15471 Ferrol, Spain

6 Universidade da Coruña, Campus Industrial de Ferrol, Centro de Investigación en Tecnoloxías Navais e Industriais (CITENI), Departamento de Empresa, Facultade de Economía e Empresa, Elviña, 15071 A Coruña, Spain

7 Universidade da Coruña, Campus Industrial de Ferrol, Departamento de Química, Escola Politécnica de Enxeñaría de Ferrol, Esteiro, 15471 Ferrol, Spain

8 Universidad de Almería, Escuela Superior de Ingeniería, La Cañada de San Urbano, 04120, Almería, Spain

9 Universidade da Coruña, Campus Industrial de Ferrol, Departamento de Enxeñaría Naval e Industrial, Escola Politécnica de Enxeñaría de Ferrol, Esteiro, 15471 Ferrol, Spain

Abstract. The main objective of this study is to know the generation potential in Chile through marine solar technology, in terms of generated energy, exploitable area and delimiting factors for its installation using georeferencing tools for the application of restrictions, as well as economic tools for sensitivity analysis and the study of the economic feasibility of these projects on the Chilean coast. Concluding that the chosen configuration is economically viable at high levels of installed capacity, primarily subject to the variability of the energy selling price as the most significant factor contributing to the sensitivity of the NPV (Net Present Value).

Key words. NPV (Net Present Value), Solar offshore energy, LCOE (Levelized cost of energy).

1. Introduction

The northern region of Chile, with its high solar irradiance and extensive coastline, emerges as a favorable setting for solar energy generation. However, the lack of knowledge regarding the potential of photovoltaic solar energy over the sea poses challenges in terms of suitable locations, regulations, environmental impact, and costs. Internationally, this technology offers benefits such as lower module operating temperatures [1] and weather conditions that reduce soiling [2]. While the installation of these plants presents technical and environmental challenges, the internship focuses on assessing their technical, economic, and environmental viability. In the long term, the implementation of this technology could significantly contribute to decarbonization and the diversification of the energy matrix.

2. Methodology

The temperature of a photovoltaic module can be stated by comparing the ambient temperature and radiation with the stc situation (standard test condition).

$$T_m = T_{env_i} + \left(\frac{TONC - T_{env}}{G}\right)_{stc} G_i$$

Fig.1 Photovoltaic module temperature.

For its part, the monthly energy generation can be expressed as the product of the performance ratio, efficiency, area and incident radiation.

$$E_{pv_i} = PR \cdot \eta \cdot A \cdot G_i ; i\epsilon[1, ..., 12]$$

Fig.2 Energy generation.

Based on Figure 1 and 2, the expression that considers the lower temperature operation factor of the photovoltaic panels in the sea can be developed.

$$E_{pvi} = [\frac{(1 + \gamma(T_m - 25) + 100)}{100}](PR \cdot \eta \cdot A \cdot G_i); i\epsilon[1, ..., 12]$$

Fig.3 Mathematical Model.

Where PR is the performance ratio, a value that discount all the loses in the system, the efficiency (Ƞ), array area (A) , radiation (G), Temperature of module (Tm), and gamma as a thermal coefficient. Were the left part of the equation is a correction based on the operation temperature of the solar panels.

Select and technically evaluate a suitable structure for different locations based on climate and geography. Based on factors such as wave height, wind, and bathymetry, the implementation of galvanized steel structures used in the salmon industry is technically viable, as detailed below in Fig.4.

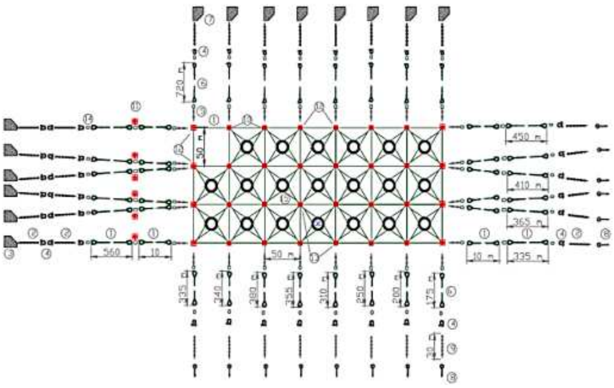

Fig.4 Steel platform

Calculate economic metrics based on a technical-economic assessment as the NPV and LCOE, comparing costs and generation potential between onshore and offshore installations to conclude on the viability of offshore generation in Chile.

3. Case of study:

The considered location in the case of study is the area of the North of Chile, between the region of Arica and Parinacota and the region of Antofagasta, shown in the Fig.5.

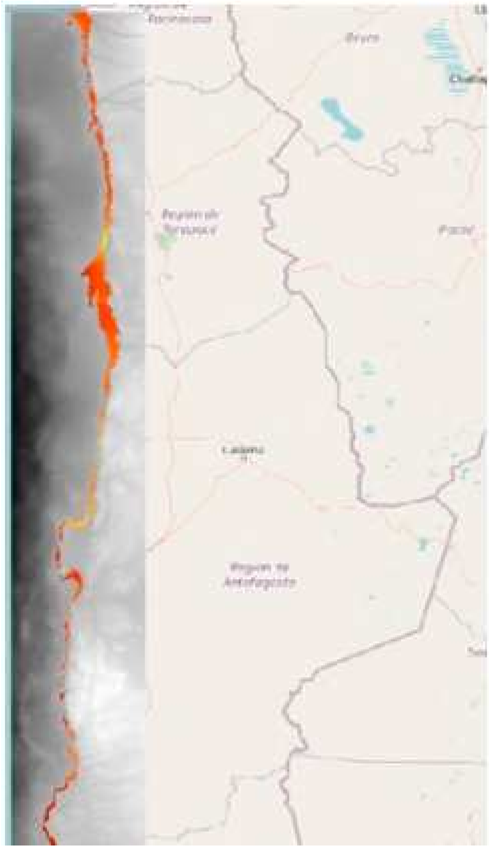

Fig.5 Area considered

4. Results:

In summary, the study results are as follows:

A) Validation of the generation model:

A photovoltaic generation model is proposed, enhancing it by considering the reduction in solar panel temperature. When comparing a mathematical model with one based on environmental data, it is found that the mathematical model underestimates the cooling capacity of solar panels by 54%. This translates to a 9% increase in energy generation capacity.

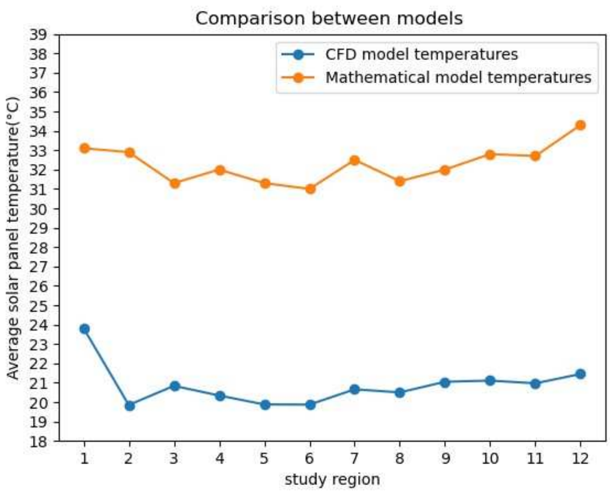

Fig. 6 Comparison between mathematical model and Machine learning model.

Based on the constraints analysis, the only limiting restriction for the implementation of offshore solar plants is bathymetry. Both wave height and current fall within suitable ranges for installation, with a wave height less than 4 meters and a current less than 1.5 [m/s] based on Copernicus information. From the above, it is inferred that the total potential of this technology is determined by the feasible area corresponding to the bathymetric profile. The total potential of this technology is estimated at 67 GW, surpassing the geothermal and onshore wind potential of the country [3][4].

B) Comparative analysis of generation compared to onshore plants:

Energy generation is compared in different locations, including the sea, land near the coast, and the desert. The sea-based plant shows a 7% increase in generation compared to the coastal plant, while the desert plant has a 14% increase, albeit with associated challenges.

C) Analysis of CAPEX based on installed capacity:

For this case, the CAPEX value of offshore solar power plants is considered based on the installed capacity. This is because the composition of CAPEX allocates a larger portion of its costs to those variables dependent on the power level, such as the quantity of modules, moorings, and solar panels. However, factors like the distance from the coast or the distance to the connection point, which contribute directly to the cost of onshore and offshore cabling, are not considered.

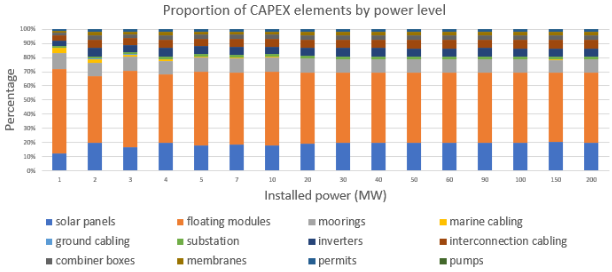

Fig.7 Proportion of CAPEX elements by power level.

From the previous graph (Fig.7), it can be appreciated that the investment cost is strongly influenced by the cost of floating modules, followed by the number of panels, and finally, by the quantity of required moorings.

D) OPEX analysis based on project operation year:

It is important to note that for different power levels, the proportion of components comprising the OPEX does not change significantly. OPEX components include variable and fixed costs. On the other hand, depreciation and interest on the credit are not considered as they are treated as financing costs. Regarding depreciation, it is also not considered since it is not related to the core operational activity. In terms of costs, fixed costs remain constant throughout the lifecycle, while variable costs related to structure maintenance and part replacement are spread across the materials lifecycle. It is noteworthy that the variable cost increases in year 20 due to the inclusion of decommissioning costs in this parameter.

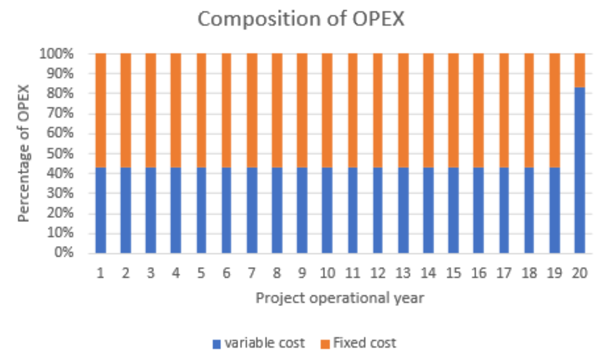

Fig.8 Composition of OPEX.

E) LCOE analysis for different levels of installed capacity:

The Levelized Cost of Energy (LCOE) is evaluated for different levels of capacity, showing a decrease in LCOE with an increase in installed capacity.

For low levels of capacity the behaviour is showed in Fig.9.

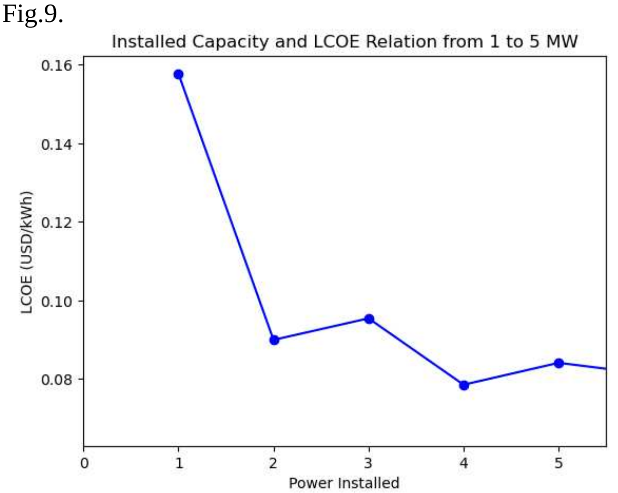

Fig.9 Installed capacity and LCOE relation from 1 to 5 MW.

For higher levels of installed capacity, the behavior is detailed in Figure 10.

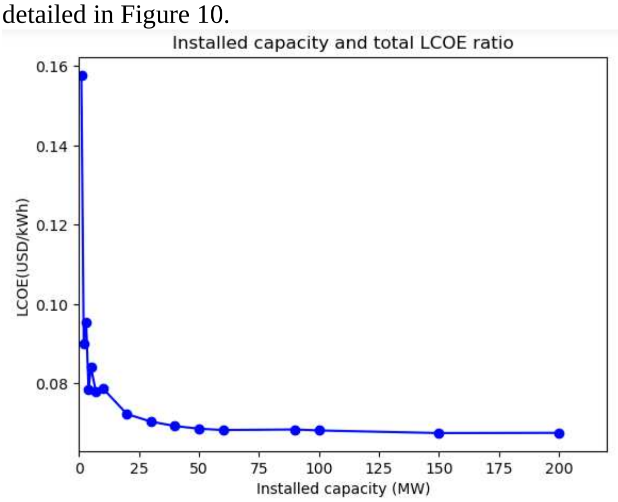

Fig.10 Installed capacity and total LCOE ratio.

In Figure 10, the behavior of the LCOE for higher levels of power from 1 MW to 200 MW is shown. In this case, the lowest levelized cost is achieved with an installed capacity of 200 MW, with a value of 0.0674 USD/kWh

F) Comparative analysis with other technologies:

To carry out this analysis, cost information for onshore power plants is used, obtained from the IRENA report of 2019. This report provides a breakdown of costs in USD per installed capacity, allowing the modelling of CAPEX costs for different power levels. Based on this analysis, it is found that for power levels below 20 MW, onshore technology has lower installation costs, while for higher installed capacities, the CAPEX is lower for the proposed offshore power plants as shown in Figure 11.

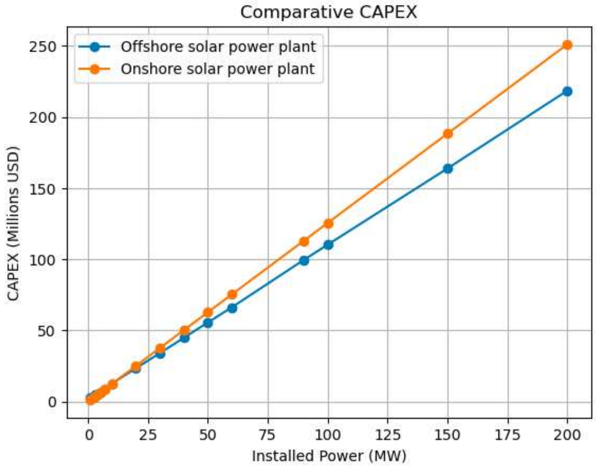

Fig.11 Comparative CAPEX.

G) Analysis of results NPV, IRR, and Payback:

To obtain the NPV of different projects based on the installed power level, the distance to the coast is set at 10 km, the distance to the onshore connection point is set at 10 km, and the selling price of energy is set at 0.05 USD/kWh, assuming a PPA contract, so that the NPV depends only on the installed power level. The following results are obtained with this approach.

It can be observed in Figure 12 that for power levels between 1 and 7 MW, the NPV result is negative.

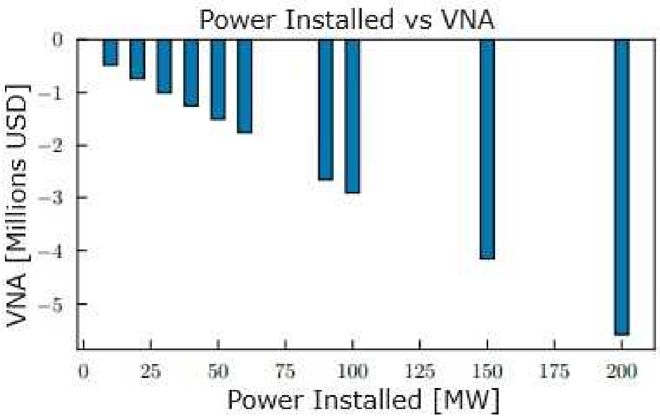

Fig.12 Power installed vs VNA.

This is supported by the assumed PPA price being below the LCOE, so the project returns are not sufficient to cover the expenses. On the other hand, the NPV decrease is not constant due to the significant impact of the number of modules on the investment cost. For example, 1 MW and 2 MW plants use a single module; the difference is that the 1 MW plant completes half of the structure, while the 2 MW plant completes its entirety, resulting in higher generation, which reflects in a less negative NPV. It should be noted that it is not viable to analyse the IRR for this scenario, given that the NPV results are negative, as well as the payback period, as the investment is not recovered.

H) Sensitivity analysis:

For the sensitivity analysis, conducted through Crystal Ball, the probability of positive NPV results is provided by adjusting certainty to consider positive values. Across 1,000 simulations under various scenarios of input variables, it is observed that the NPV is positive in 38.53% of the cases studied. Emphasizes that the mean is in an unprofitable NPV, while the average standard error is deemed plausible for the NPV magnitude.

The most significant correlation with NPV behaviour is associated with the selling price of energy, demonstrating a direct relation and a high correlation value of 0.94. It should be emphasized that the influence of generation and energy price has a considerably more substantial impact on variance compared to cost-related factors. This underscores that the profitability, in terms of NPV, is heavily contingent on both the set energy price and the approximation of the generation model.

4. Conclusion

Based on this study, the following conclusions can be drawn:

Regarding the development of the generation model, it demonstrates that a decrease in the panel temperature dependent on radiation and ambient temperature can improve generation by 7% compared to a panel under similar conditions but installed on land. Meanwhile, a solar panel with similar characteristics installed in the desert compensates for the temperature loss factor due to an increase in radiation levels. However, it is susceptible to failures due to inverter overheating, insulation melting, and greater losses due to soiling effects. Finally, comparing the model with the UDC's machine learning proposal shows a 54% decrease compared to the current study's model. This is a result of considering current, wave height, and wind in the temperature calculation, translating into a 9% improvement in generation.

In terms of economic indicators, it can be said that, in CAPEX terms, the most significant cost is that of the modules, while for OPEX, fixed costs and variable costs maintain approximately the same proportion for different levels of installed capacity. Compared to other technologies, CAPEX begins to be similar for power levels above 50 MW.

Regarding the economic indicators of NPV, IRR, and Payback, the NPV of projects at different power levels under the assumption of a PPA contract with an energy selling price of 0.05 USD/kWh presents negative results in all cases. Therefore, the analysis of IRR and payback does not provide meaningful information for the analysis.

With respect to the values obtained for NPV through the sensitivity analysis, it can be observed that the energy selling price is the main parameter affecting the NPV outcome, with a correlation of 0.94. Therefore, a significant portion of the NPV results can be explained based on the price variation. On the other hand, generation is the second parameter with the most significant impact on NPV. From this, it can be inferred that the economic profitability of a project of this nature depends more on the behaviour of revenue-generating variables than on the variation in investment and OPEX costs.
The energy production through offshore solar technology presents several advantages that can eventually make it competitive in the long term. These include environmental characteristics that improve generation, a decrease in soiling, and the ability to bring generation zones closer to consumption areas. Additionally, Chile has a competitive advantage in terms of both solar resources and technical expertise in floating module installation, thanks to the aquaculture industry.

Furthermore, this study demonstrates that at high levels of installed capacity, the LCOE is competitive with other renewable technologies, and installation costs can even be lower than those of wind and conventional solar technologies on land. In terms of installation potential, offshore solar technology shows promising figures compared to onshore wind and conventional solar. Ultimately, the proposed technology can be viable at high power levels due to its competitive levelized cost compared to other renewable technologies and the technical advantages it may offer.

Acknowledgement

This research was carried out within the framework of the professional internship at the Adolfo Ibáñez University, with the participation of the University of La Coruña.

This research is part of the Project TED2021-132534B–I00 “Characterization of a software to determine the roadmap of the offshore solar energy in the Spanish shore (SEASUN)”, financed by MCIN/AEI/10.13039/501100011033 and by the European Union “NextGenerationEU”/PRTR.

References

[1] Emma Woollacott. Could floating solar farms survive out at sea? BBC News, 2023. URL https://www.bbc.com/news/business-63728020. Consultado el 20 de julio de 2023.

[2] BOX. 30 • FLOATING SOLAR HANDBOOK FOR PRACTITIONERS 30 • FLOATING SOLAR HANDBOOK FOR PRACTITIONERS Module temperature simulation. 2016.

[3] José Ángel Lagos Conejo. Análisis Técnico, Económico y Medioambiental sobre Plantas Fotovoltaicas Flotantes y su Potencial Implementación. PhD thesis, ETSI_Diseno, 2021

[4] David Watts Casimis, N Oses, and R Pérez. Assessment of wind energy potential in chile: a project-based regional wind supply function approach. 2016.