Combining offshore wave and wind energy to supply a big size desalination plant

B. Del Rio-Gamero, Julieta Schallenberg Rodríguez, and Pedro Suarez Arocha

Abstract— **this research analyses the feasibility of supplying a large size desalination energy demand by marine renewables. The case study is Las Palmas III seawater desalination plant, the largest desalination plant in the Canary Islands (Spain), which is located in the northeast of the island of Gran Canaria. Its average daily water production is 62,614 m³/day, consuming a total of 90,670 MWh/year.**

A constant energy production is needed for the optimal plant operation which raises the possibility of using different renewable technologies in order to reduce the energy fluctuations. In this case, the sea and its wave and wind energy resources are key technologies for supplying desalination plants near the coast. For this reason, different configurations have been simulated combining wave farms and analyzing their possible pairing with wind energy to achieve a more stable energy production.

The proposed methodology contemplates the identification of the hotspot for the technologies location in terms of environmental constraints and resource assessment. The subsequent selection of the renewable energy technologies and the energy coverage evaluation.

Results tried to establish if the combination of offshore wind and wave energy improves the demand coverage.

Keywords—**Desalination plant, Marine renewable energy, Water-Energy Nexus.**

I. INTRODUCTION

ENSURING freshwater access is a global priority issue, particularly in regions suffering restricted freshwater resources [1]. Seawater desalination plants are a vital lifeline to address shortages of water by transforming seawater into fresh drinkable water [2]. The main challenge derived from desalination plants is their high-energy consumption [3]. In addition, a stable energy supply during the entire water treatment process is necessary to guarantee constant and optimal operation [4]. This situation results in the use of fossil fuels in the vast majority of this facility to securely support the energy supply of the plant. In other terms, desalination plants become an indirect, but important, stationary source of greenhouse gas emissions [5]. This Water-Energy nexus, so intrinsically linked in regions lacking or isolated from territorial water resources, must continue to move forward with the fulfilment of the new European, national and regional directives concerning the decarbonisation of the energy and water sector [6].

This is the case of the Canary Islands, where about 330 seawater desalination plants are currently operating, representing a significant percentage of the territory's energy mix [7]. All this, together with the fact that it is a territory completely surrounded by the Atlantic Ocean, makes marine renewable energies a cornerstone in the energy transition towards a more decarbonised and secure society [8, 9].

It will also contribute to the improvement of the island's electricity mix, which currently has a 17% penetration of renewable energy [10].

This percentage is supported by renewable energy sources, most of which is generated by wind (78.5%) and photovoltaic (18.2%) [10]. Therefore, the implementation of marine renewable energies will also be analysed in terms of complementarity with their land-based counterparts.

This paper focuses on analysing the possibilities of supplying the energy needs of a large-scale desalination plant through the use of marine renewable energies, specifically wave and wind energy. Particularly, the Las Palmas III seawater desalination plant, which is the largest desalination plant in the Canary Islands, will be the scenario under study.

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II. METHODOLOGY

This section details the methodology applied to assess the feasibility of energy self-supplying water treatment plants (precisely desalination plants) with marine renewable energies.

The Las Palmas III seawater desalination plant is the scenario selected for this study. It is located in the north-east of the island of Gran Canaria, in Piedra Santa industrial area, where it coexists with another important industry, namely Jinámar Thermal Power Station. Figure 1 shows that both industries are close to the sea, which allows us to take advantage of the aforementioned marine renewable energies. The desalination plant produces a volume of 80,000 m^3/day of fresh water and consumes 90,669.52 MWh/year of energy to perform the entire treatment process. The plant operates with Reverse Osmosis technology and consists of three membrane racks with the following nominal production capacities [11]:

- Lines A-H: 57,000 m^3/day
- Line I: 8.000 m^3/day
- Lines K-L: 15.000 m^3/day

The high-pressure booster pumps that drive these racks are characterised for being the equipment with the highest energy consumption, as they need to reach 50-60 bar pressure in order to obtain product water with suitable quality for human consumption.

Fig. 1. Location Las Palmas III desalination plant.

In order to satisfy the energy needs of the desalination plant, the methodology used consists of three different phases, which are described below:

- Analysis of the feasibility of implementing marine renewable technologies in technical and environmental terms.
- Selection and configuration of the marine renewable technologies used in the study.
- Evaluation of the energy production by marine renewable energies and analysis of their coupling with the energy needs of the desalination plant in terms of coverage percentage.

Appropriate location of marine renewable technologies are the first step in this study to ensure the preservation of the environment and biodiversity [12]. To do this, an assessment of protected natural areas and restricted areas is done. For this purpose, the main effects described in article 10 of Royal Decree 1028/2007, which aims to regulate the procedures and determine the conditions and criteria that must govern the obtaining of the administrative authorisations and concessions required for the construction and expansion of electricity generation facilities that are physically located in the territorial sea, are considered as restrictions [13]. In addition, bathymetric ranges and minimum coastal buffer distance are also parameters to be considered when selecting the site for the installation of the technologies. The evaluation of the renewable resource is carried out through the SIMAR points provided by "*Puertos del Estado*" [14]. This modelling provides historical data on wind speed at 10 metres and wave direction, significant wave height and wave period. Its network has a meshing with a spatial resolution of 25 km. This makes it possible to easily evaluate various locations within an economically and technically (taking into account the evacuation of energy by submarine cable) feasible radius to the desalination plant.

The selection of technologies is made with the need to guarantee equipment that has a high technological readiness level (TRL). With regard to wave technology, the selection of the wave converter is based on the results of previous studies conducted by the authors. In these studies, the WEC-location pairing of the different technologies on the coastlines surrounding the island of Gran Canaria was analysed [8]. In this sense, the Danish Wavepiston technology leads the selection ranking as its attenuator classification takes advantage of wave spectra characterised by relatively short periods and heights to harness wave energy effectively. The wave converter will consist of 32 energy collectors per string with a nominal power of 0.25 MW [15]. This device allows for a farm configuration with a linear layout requiring an inter-wec distance of 60 metres.

Figure 2 shows a picture of the selected wave technology. This device is currently being tested on a pre-commercial scale and in a real marine environment at the PLOCAN test platform, located a short distance from the desalination plant under study in this research.

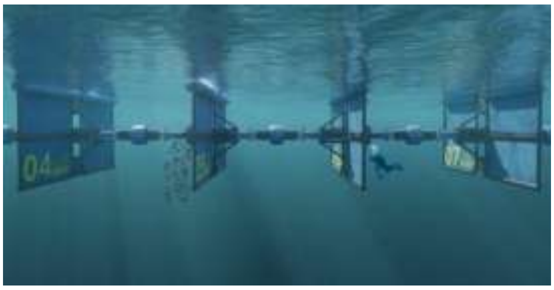

Fig. 2. Wavepiston Technology. Wave energy converter [15].

Determining the maximum number of converters that can be installed as a farm (which is restricted by the availability of space) is essential. This availability is clearly limited by the proximity to the coast and the possible uses and/or amenities in the vicinity of the pilot area.

Furthermore, the minimum number of converters is estimated according to the maximum energy production that can be extracted from this technology with the minimum operating costs (as this value fluctuates according to the number of WECs).

The selection of the wind turbine to be used is a difficult issue given the strong competition and confidentiality between companies. It is challenging to obtain the technical data sheets of the marine wind turbines. Nevertheless, considering the bathymetries and average speeds of SIMAR points, the wind turbine used in El Gofio Project (a possible offshore wind farm located to the southeast of the island of Gran Canaria), has been selected. The wind turbine used is the HALIADE-X 12.5 MW wind turbine from GE Renewable Energy [16]. A floating offshore wind turbine whose nominal speed (10 m/s) is compatible with the average speeds of the SIMAR points (approximately 8.3 m/s).

After selecting the technologies to be installed, the next methodological step is to analyse the energy coverage that can be supplied by marine renewable energies. In order to maximise this coverage, it is necessary to perform an exhaustive analysis of the potential combinations between the wave converter and the offshore wind turbine at the SIMAR points near the Las Palmas III desalination plant.

The analysis of the different combinations will include the total energy production, the level of energy demand satisfaction (as a percentage) and the possible surplus energy produced. This last point is also important, as the fluctuations that characterise renewable energies mean that not only do we have moments of deficit, but we also have too much energy available at specific moments. It could be feasible to sell this surplus to the grid, thereby reducing the purchase costs at renewable shortfalls in energy supply.

The sale of this surplus energy will also becoming part of the budget items included in the economic and financial study below. This last analysis will assess the viability of the project in economic terms. Development expenses (DEVEX), capital expenses (CAPEX) and operating expenses (OPEX) of the two renewable installations were evaluated. Precise estimates were made of the amount of savings produced by the energy surplus and the financial profitability of the project was calculated using net present value (NPV) and the internal rate of return (IRR). This took into account a useful life of 20 years, an annual consumer price index (CPI) variation rate of 2.5% and a required discount rate for the investment of 4%.

Savings are calculated by analysing the cash flow over the project useful life, taking into account CAPEX, DEVEX and OPEX as expenditures and the savings derived from the need to purchase less energy from the grid as a result of the electricity generation produced by the designed renewable installation as income.

III. Results

This section will present the results obtained from the three steps detailed in the methodology section, starting with the technical-environmental feasibility of the coastal zone, followed by the configuration and combination of the selected technologies and ending with the evaluation of the energy coverage produced by the installation, as well as its economic reliability.

Figure 3 shows the technical and environmental restrictions that have been taken into consideration. It includes the Natura 2000 network, protected natural areas, areas of importance for the conservation of birds, restricted areas (comprising areas of priority use for national defence and areas of priority use for research, development and innovation), as well as submarine cables. As the Las Palmas III desalination plant is marked with a black icon, it is finally observed that only the following restrictions could affect the location of renewable technologies:

- Priority use areas for research, specifically the PLOCAN research area.
- Submarine cables, but only in the case of the installation of offshore wind turbines using fixed foundation technology.

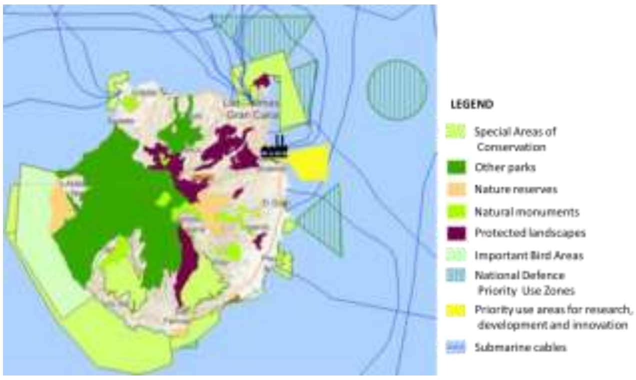

Fig. 3. Restriction areas in Gran Canaria island.

Taking into account the above restrictions, the location of the renewable technologies is determined by using the nearest SIMAR points. Table 1 shows the coordinates and identification of each SIMAR point selected.

Table. 1. SIMAR identification.

SIMAR	Coordinate N	Coordinate O
421038045	28.05°	15.39°
4038009	28.08°	15.33°
4038010	28.00°	15.33°
1019012	28.00°	15.25°
4040010	28.08°	15.17°

Further to the restrictions mentioned above, there are some additional technical requirements that must be met. The minimum distance to the coast for offshore wind turbines has been established in the Maritime Space Management Plans, recently approved by Royal Decree 150/2023 of 28 February 2023. This stipulates a minimum distance of 5.8 km for the island of Gran Canaria [17]. In bathymetric terms, it is determined that the maximum depth for fixed bottom is 70 m and for floating technology is 1000 m [17].

Figure 4 shows the bathymetry, distance to the coast and average wind speed for each SIMAR point.

Fig. 4. SIMAR points characterisation

Of the points identified in Figure 4, it should be noted that wave converter operating range is between bathymetries of 20-100 metres. In addition, it is important to note that the length of the mooring cable used to anchor the device varies depending on the size of the pilot area, ranging from 100 metres to 200 metres [9]. In this sense, SIMARs 4038009, 4038010, 101901 and 4040010 exceed 100 metres depth. Consequently, the SIMAR point 421038045 is the proposed location to install the Wavepiston wave converter. Once SIMAR has been selected, the farm configuration is delimited by the proximity to the coast and the PLOCAN research area. Maintaining a distance of 500 m from both constraints results in a potential area of 1 km long and 3.5 km wide (see Figure 5). In compliance with the interWEC distance, 50 wave converters can be installed in the selected area.

Fig. 5. Identification of the area intended for the deployment of the wave farm

For wind technology SIMAR 421038045 has been discarded as a possible option, as it does not comply with the minimum distance to the coast (5.8 km), being 2.15 km. SIMAR points 101912 and 4040010 have also been discarded, as the floating technology allows a maximum bathymetry of 1000 m and both exceed it. Therefore, the data to be processed are those from SIMAR points 4038009 and 4038010.

Table 2 shows all the simulated scenario configurations for supplying the desalination plant with marine renewable energy. The two SIMAR points identified for wind energy and the possible wave farm, which could consist of 30, 40 or 50 wave converters, are included.

Table. 2. Simulated scenarios for energy production.

Nº	Combinations	Energy production (MWh)	Satisfied demand (%)	Energy surplus (MWh)
1	SIMAR 4038009 + 30 WECs	81,091.2	71.13%	16,597.2
2	SIMAR 4038009 + 40 WECs	88,607.3	73.52%	21,943.5
3	SIMAR 4038009 + 50 WECs	96,123.5	75.52%	27,645.5
4	SIMAR 4038010 + 30 WECs	74,414.6	67.87%	12,876.6
5	SIMAR 4038010 + 40 WECs	81,930.7	70.94%	17,608.5
6	SIMAR 4038010 + 50 WECs	89,446.9	73.34%	22,945.4

As can be seen in Table 2, locating the wind turbine at SIMAR points 4038009 or 4038010 and using 50 wave converters (combinations 2 and 3), are the combinations that generate the lowest amounts of unsatisfied demand, with a total of 24,005.73 MWh and 22,191.62 MWh respectively. However, these same combinations also produce much higher energy in excess, with a total of 21,943.56 MWh and 27,645.59 MWh respectively.

To overcome this situation and make the offshore hybrid system more viable, it is necessary to sell this surplus to other interested parties in order to obtain remuneration for it. Therefore, the choice of the combination between the offshore wind turbine and the wave converter will be determined by an economic and financial analysis.

The combination with the highest profitability and viability results from the integration of a floating wind turbine located at SIMAR point 4038009 and the installation of 50 wave converters. Since this configuration presents the highest NPV (73,385,890.58), and has an IRR higher than the discount rate, 5.4%.

Likewise, this combination is the one that generates the greatest amount of savings (156,840,280.87 €), and the highest demand satisfaction of the desalination plant.

IV. Conclusions

Desalination plants, which are predominantly located in regions with scarce water resources, tend to be located in areas close to the sea. This work raises the possibility of making the sea as the main source of energy and water for a desalination plant. Harnessing the intrinsic energy of the sea would make the intensive energy consumption of a desalination plant clean and safe.

The results obtained in this work show the feasibility of self-supplying a large-scale desalination plant with a hybrid marine renewable system. In this case the hybrid renewable system covers the vast majority energy needs of the plant on an annual scale, and the energy surplus can be sold to make the system more economically profitable.

Future studies could perform hourly scale simulations to verify wind and wave energy production patterns in order to improve the efficiency of the hybrid system.

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