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Optimal Arrangements of Renewable Energy Systems for Promoting the Decarbonization of Desalination Plants

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Abstract: In this research, a renewable energy hybrid system (PV-Wind) is modeled to compare different design options based on their economic and technical features. The energy requirements of a Reversible Osmosis desalination plant located on the island of Tenerife with a water production capacity of up to 20,000 m³/day was considered. The system is connected to the electricity grid. The HOMER software, version 2.75 was used to produce optimum strategies for renewable energy. The assumptions input into the model were: the technical specifications of the devices, electricity demand of the desalination plant, as well as the solar radiation and the wind speed potentials. Numerous arrangements were considered by the software, version 2.75. The optimal results were obtained based on the use of renewable energy. The data used in the study were recorded in Tenerife in the Canary Islands. The experience of this research could be transferred to other Atlantic islands with similar renewable energy sources (specifically the wind) and water scarce conditions.

Keywords: renewable energy; desalination; reverse osmosis; Tenerife; Canary Islands



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1. Introductions

The Canary archipelago is a pioneer in seawater desalination due to its experience in applications with dissimilar technologies. Currently, the Islands have 315 desalination plants, which produce around 242.16 hm³ of fresh water per year [1,2]. In two of the main islands that make up the archipelago (Lanzarote and Fuerteventura), desalinated water accounts for 99% and 86%, respectively, of the water used to supply the population and tourism [1–3].

The main problem with desalination is the energy required, which is harmful to the atmosphere due to the growing pollution caused by the use of fossil fuels. The isolated electrical grid of the Canary Islands poses a problem in its optimization, as does the high dependence on imported fuel [3–7].

The use of renewable energies to procure fresh water from seawater for human consumption is beneficial for the environment, since it reduces pollution and can influence the Levelized Cost of Water (LCoW) of the fresh water produced.

On the island of Tenerife, renewable energy sources such as solar radiation and wind speed are generally high and available throughout the year, allowing optimal use of renewable energy systems (RES) to produce energy. An example of this are the eight solar plants belonging to the “Technological Institute of Renewable Energies” (ITER), with a total of 44.3 MW of installed photovoltaic systems and 65.7 MW of wind energy, installed in different wind farms [8,9]. The groundwater in Tenerife is under threat due to severe overuse. In recent years, desalination from sea water has increased to around 26.64 hm³/year, accounting for 14.0% of freshwater production, and is likely to continue increasing in the medium-term [10]. Therefore, it is essential that the islands find an alternative to the use of fuel to cover the growing energy demand of water desalination plants.

In this paper, different RES based on wind energy and photovoltaic (PV) systems connected to the electrical grid are modeled in order to assess different designs according to their technical and economic properties. The power needs for a reverse osmosis (RO) desalination plant could be guaranteed for a water production volume of up to 20,000 m³/day.

The Hybrid Optimization Model for Electrical Renewable (HOMER) [11] has been used to achieve the best designs of RES to supply reverse osmosis (RO) systems. The starting assumptions were the electrical needs of the RO plant, the technical specifications, and the sources of renewable energy (RE) (solar radiation and wind speed) on the island. HOMER models the RES with a grid connection, and the RES will always try to deliver the highest power required by the reverse osmosis plant.

HOMER has been used in numerous studies carried out in many regions of the world with the objective of finding options to replace part of the conventional energy with RES. Some examples may be found in islands of the Atlantic Ocean [3,6], in Oceania [12], in Eurasia [13], North American [14,15], Asia [16–22], the Arabian Peninsula [23–27], Southeast Asia [28], the north Pacific Ocean [29] and in Australia [30]. These studies were developed in different fields, such as: covering the energy needs of small desalination plants, buildings, hotels, hospitals and small communities; and implementation of RES in the electrical grid of some islands, isolated regions and countries.

Tenerife was selected for this study due to the rising annual water demands on the island, the high tourism industry, the agricultural operations on the island, the decline of groundwater, the high cost of fresh water and the exceptional RE sources on the island.

The main goal of this study was to determine the best RES with a connection to the electricity grid to ensure the energy needs of RO plants for the production of drinking water on the island of Tenerife. This research was carried out taking into consideration the best technical-economic configuration. This study can be extrapolated to other regions with similar circumstances of water scarcity and with good sources of renewable energy, specifically wind.

This paper is arranged in five sections. Following this introduction is a presentation of Tenerife, its population, and the status and production of its drinking water. Section 3 provides the materials and methods that will be used in this study and defines the principal input variables of the HOMER software version 2.75. The results and discussions are reported in Section 4. Lastly, Section 5 shows the most significant conclusions of the study.

2. Contextualization of Tenerife Island

The Canary Islands are situated on the Atlantic Ocean, in Macaronesia region, in the northwest of the African continent, near the coast of Morocco. The archipelago is composed of seven main islands: La Gomera, El Hierro, La Palma, Tenerife, Gran Canaria, Fuerteventura, and Lanzarote (Figure 1). The islands' population is over 2 million. The number of tourists received in the islands in 2023 was in excess of 12.5 million [31]. This type of floating population is challenging for any region, especially when talking about small islands with restricted resources such as food, energy, water, etc. The water consumed per day by a tourist is double that consumed by people who live on the island. The only way to supply this service sector on an island with high water scarcity is by using efficient RO desalination systems [3,4,6,31].

Tenerife is the largest and most inhabited island in the Canary Islands, with around 42.5% of the archipelago's inhabitants. Every single year, more than 5.5 million tourists visit Tenerife, which is why it is considered the most popular island in the Canaries [31].

The largest volume of this tourist population is received in the south of the island, generating a great demand for fresh water, more than 300 L/day-tourist [32,33]. This water demand is covered in large part by desalinated water coming from the different desalination plants in the south of the island.

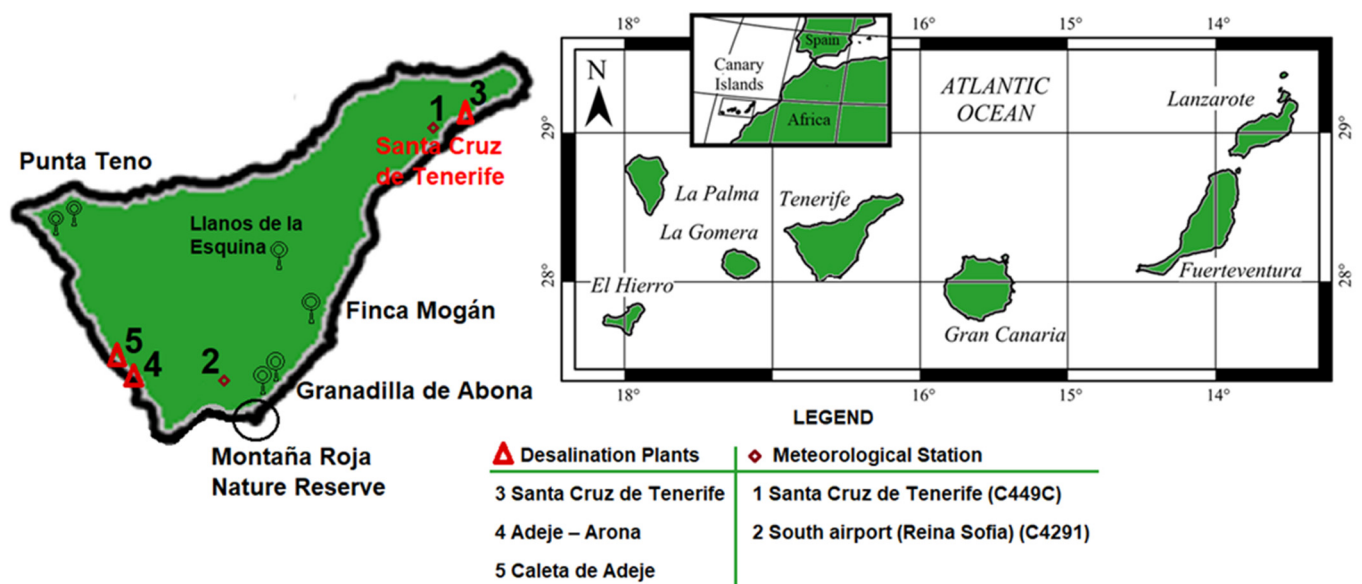


Figure 1. Map of Tenerife showing the locations of desalination plants, wind farms, meteorological stations and selected locations.

Desalination Water in Tenerife

Desalination is nothing more than the process of removing salts from brackish or sea water to make it useful for agricultural, industrial or human consumption. In the Canary Islands, desalination provides a significant percentage of the water supply in many sectors such as agriculture, the tourism industry and especially in the population where 49% of their water comes from desalination [1,3,6,34].

Currently, there are 29 reverse osmosis (RO) seawater desalination plants (EDAM) in Tenerife. The most important plants by water production capacity are shown in Table 1, two of which are located in the south of the island and the other in Santa Cruz de Tenerife, the island's capital. Figure 1 shows the locations of these three desalination plants in Tenerife [10].

Table 1. Fresh water production by three RO seawater desalination plants (EDAM), Tenerife.

RO Desalination Plant (EDAM)	Capacity of Water Production (m ³ /day)	Energy Consumption (kWh/m ³)
Adeje-Arona	30,000	4.51
Caleta de Adeje	10,000	4.29
Santa Cruz de Tenerife	21,000	4.6

The EDAM with the lowest energy consumption is Caleta de Adeje due to the improved energy recovery technology used in the desalination process. The RO desalination plant in Adeje-Arona went into operation in 1998, with a total water production capacity of 10,000 m³/day. Due to the increasing water demand in the region, this water plant's current capacity is 30,000 m³/day [10]. All of these plants supply the demand of the population and tourists, which increases year after year.

Figure 1 also shows, the distribution of the wind farms on Tenerife, which are located in those places on the island with the most wind potential, almost all of which are in the south of the island, especially in the region of Granadilla de Abona, one of the windiest areas of the Canary Islands.

According to the Spanish Wind Observatory [34], on Tenerife wind farms, the preferred wind turbines in both current and new projects are Gamesa, Enercon, Vestas and Made, including the repowering of old wind turbines.

RES such as photovoltaic systems and wind turbines, as well as reverse osmosis desalination, are all mature technologies that can be combined in different arrangements. However, only some desalination plants are currently powered by RES due to the large initial investment required, with no more than 1.0% of the desalination plants on the planet being powered by RES [35,36].

On the island of Tenerife, there is no isolated or connected RES to supply the total energy of a desalination plant, which could reduce the environmental consequences of desalination due to its enormous energy consumption from traditional sources and impact the LcoW of the fresh water produced. The continuous growth of the population means the increase of all types of needs, but one of those that represents a real challenge for humanity is to achieve water for consumption, agriculture, industry, etc. The pollution of the waters of rivers and lakes, major droughts in many regions, and climate change in the world bring with them the need for escalation of the consumption of clean energy such as solar, geothermal, wind, or marine, for the production of drinking water from desalination. All of these arguments are sufficient to affirm that the future of the desalination plant will be to cover the highest percentage of its energy needs with renewable energy.

All of the energy used for the desalination process in Canary comes directly from the electrical grid. It cannot be forgotten that renewable energy sources are not constant throughout the day, and it is necessary to store the energy in batteries, making it impossible to use these storage systems in large desalination plants because they are expensive and require a lot of space. That is the reason behind this research, to propose the optimal renewable energy system with a network connection.

3. Materials and Methods

After evaluating the state of desalination on the island of Tenerife, identifying the main plants, their production capacities and energy consumption, it was decided to consider a maximum production of 20,000 m³/day for this study, with a maximum energy consumption of 4.50 kWh/m³ of desalinated water, although this consumption may be lower depending on energy recovery.

An analysis of Figure 1 and the study conducted by the “*Cabildo Insular del Agua de Tenerife*” (Tenerife Water Council) [37] reveal that many desalination plants are located in regions with a high solar and wind potential.

Taking this analysis into consideration, two possible locations for the study were selected, the first in the extreme south of the island, near the Montaña Roja Nature Reserve, and the second in Santa Cruz, the capital of Tenerife (Figure 1). Both locations have a high solar and wind potential and are close to meteorological stations and existing infrastructure (roads, workshops, electrical substations, equipment and supplies, etc.).

3.1. Input Variables to HOMER Software

On islands like Tenerife, with high renewable energy resources and water stress, a combination of desalination plants and RES can provide a solution to the large energy needs of the desalination industry. Combining the desalination and electrical industries requires an optimal design and consistency, and also that it be sustainable.

Taking these objectives into account, firstly, the sizes of the possible elements of the RES to power the desalination plant need to be selected. The HOMER software was selected to achieve the most satisfactory design. This software can carry out the simulation, optimization, and sensitivity analyses of the RES (PV-Wind) to determine the energy needs of the desalination plants in question [6]. Figure 2 shows the suggested RES for the simulation. These devices can involve PV modules in combinations of various wind turbines, all connected to the electrical grid.

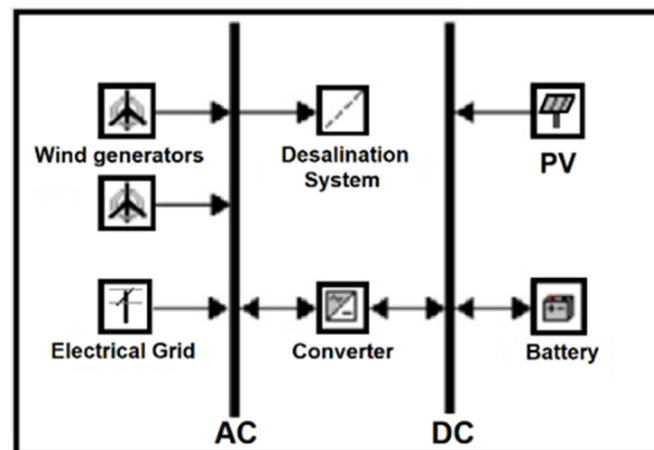


Figure 2. Renewable energy systems HOMER model, with electrical grid connection.

3.2. Electrical Loads

In order to carry out this research, it was assumed there would be a desalination plant with a production of 20,000 m³/day, with a possible energy expenditure of 4.50 kWh/m³ of desalted water; these values were taken based on the technical operation of different plants in the island set out in Table 1 and in specialized literature such as [10]. According to HOMER, the energy consumption of the installation can reach 89,500 kWh/day. The average electricity demand will be 3729 kW, which may increase to 5688 kW at peak hours. Figure 3 displays the annual distribution of electrical energy consumed, the average, and the minimum and the maximum consumption per month.

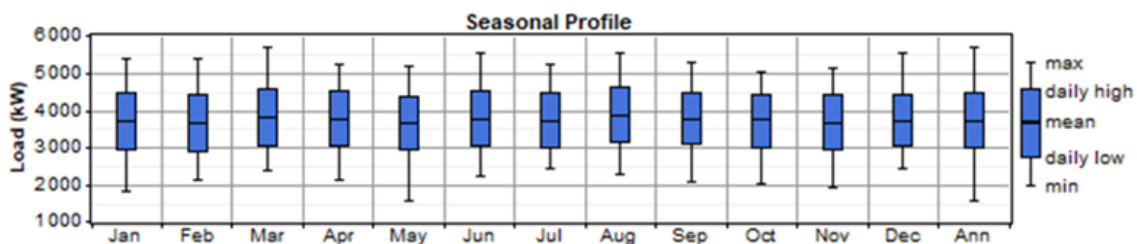


Figure 3. Annual distribution of electrical energy consumed.

3.3. Solar Radiation

HOMER takes the monthly solar radiation directly from NASA data (National Aeronautics and Space Administration of the United States government). Figure 1 shows the meteorological stations used in the study for each location selected, which serve as coordinates for both solar and wind resources. The South Airport (*Reina Sofía*) (C4291) meteorological station was used in the study of the Montaña Roja Nature Reserve, and the Santa Cruz de Tenerife (C449C) station was used to study the case in the island's capital. All of these meteorological stations belong to the Meteorological State Agency (AEMET; Madrid, Spain Government). The coordinates used for the study on the island are shown in Table 2.

Table 2. Coordinates of the Meteorological Stations.

Meteorological Stations	Coordinates (Latitude and Longitude)	Altitude (m) (above Sea Level)
South Airport (<i>Reina Sofía</i>) (C4291)	Latitude: 28°2'51" N Longitude: 16°33'39" W	64
Santa Cruz de Tenerife (C449C)	Latitude: 28°27'48" N Longitude: 16°15'19" W	35

The HOMER computer software processes solar radiation for each hour of the year with the Graham algorithm, both for simulation and optimization. Figures 4 and 5 show the average solar radiation each month over a year at the selected coordinates, at meteorological stations C4291 and C449C. The annual solar average scaled at the selected points is 5.16 kWh/m²/d for the South Airport and 4.99 kWh/m²/d for the Santa Cruz de Tenerife Meteorological Station.

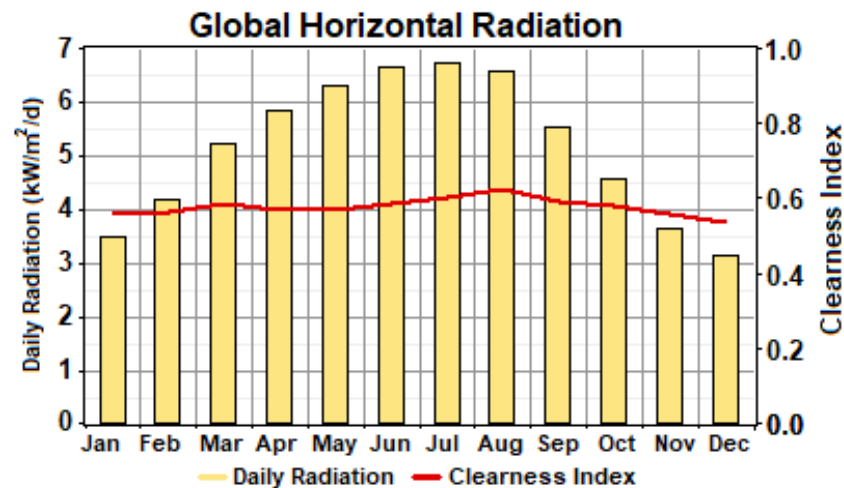


Figure 4. Annual solar radiation of the South Airport Meteorological Station (Reina Sofia) (C4291).

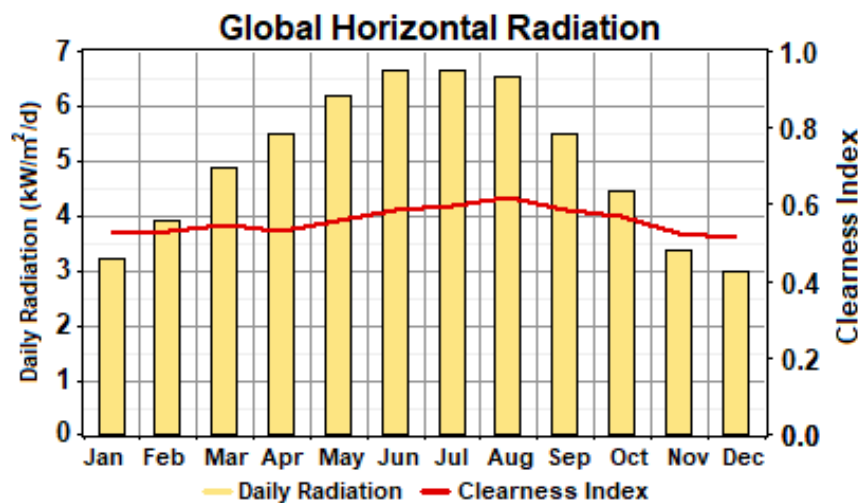


Figure 5. Annual solar radiation of the Santa Cruz de Tenerife Meteorological Station (C449C).

3.4. Wind Speeds

The monthly average wind speeds were taken from the two meteorological stations whose coordinates are shown in Table 2. The first one, located at the Reina Sofia Airport, has a database of more than 35 years and an average annual wind speed of 6.1 m/s. The second is located in Santa Cruz de Tenerife, where the average annual wind speed is 3.0 m/s according to figures dating back over 85 years. The simulation performed by HOMER uses the Weibull probability density function, which is stated as follows [3,6,11]. The Weibull distributions for meteorological stations C4291 and C449C are shown in Figures 6 and 7.

$$f_v = \left(\frac{k}{c}\right) \cdot \left(\frac{v}{c}\right)^{k-1} \cdot \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (1)$$

where k is the shape factor and c the scale factor.

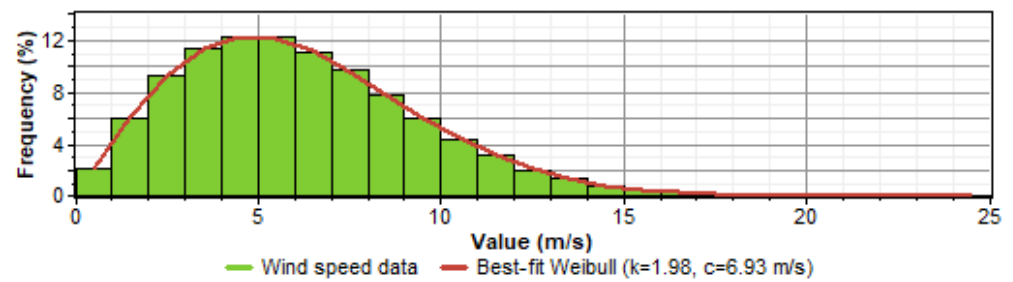


Figure 6. Weibull distribution of wind speeds (m/s) at the South Airport Meteorological Station (Reina Sofia) (C429I).

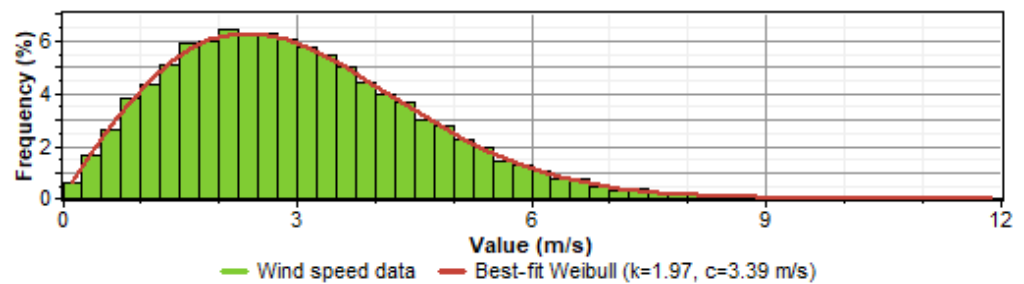


Figure 7. Weibull distribution of wind speeds (m/s) at the Santa Cruz de Tenerife Meteorological Station (C449C).

Equation (2) is the expression used by the HOMER software to calculate the wind speed at different ground levels based on the hypothesis of a neutral atmosphere.

$$\frac{v_1}{v_2} = \left(\frac{h_1}{h_2} \right)^\alpha \quad (2)$$

3.5. PV System

When the model of the photovoltaic system was designed, the software did not take into account the temperature and voltage to which the system is subjected during operation. HOMER assumes that the direct current (DC) output of the PV panel is directly proportional to the incident radiation [38]. Table 3 shows the cost of the photovoltaic panels used in this research. The photovoltaic panel is assumed to have a useful life of 20 years.

Table 3. Economic data.

Components	Initial Capital Cost (ICC _{PV}) \$	Replacement Cost (RC) \$	O&M Cost (\$)	Lifetime
PV panels	2500 (\$/kW)	2500 (\$/kW)	$(0.015) \times (ICC_{PV})$	20 years
Wind turbines	1200 (\$/kW)	$(0.85) \times (ICC_{Wind})$	$(0.025) \times (ICC_{Wind})$	25 years

The software does not take into account the voltage and temperature variables for the period of its exposition during the operation to model the PV system. The direct current (DC) output of the photovoltaic system adopts a linear proportion with the global radiation incident on it [38].

Equation (3) shows the expression to calculate the electrical energy generated by the PV panel array (P_{PV}):

$$P_{PV} = f_{PV} \cdot Y_{PV} \cdot \left(\frac{I_T}{I_s} \right) \quad (3)$$

In this equation, (f_{PV}) is the debating factor, (Y_{PV}) is the total installed capacity of the photovoltaic panel array (kW), (I_T) is the incident global radiation (kW/m^2), and I_s is

the quantity of radiation used to rate the capacity of the photovoltaic panel array, equal to 1.0 kW/m^2 [38].

3.6. Wind Turbine System

Manwell, McGowan and Rogers state in [39] that a standard procedure is used to model wind turbines, assuming that the kinetic energy of the wind turbine is converted to electricity based on a specific power curve. HOMER computes the average wind turbine power (P_{wind}) using the Weibull distribution.

The wind turbine systems used in this study were modeled based on the standard method. The basis of this method is to transform the kinetic energy of the wind into electrical energy, taking into consideration the specific power curve of each wind turbine.

Equation (4) shows how the wind energy density per unit area (P/A) can be calculated:

$$\frac{P}{A} = \frac{1}{2} \cdot \rho \cdot v^3 \quad (4)$$

The expression to calculate the wind energy production for a year (P_{wind}) used by HOMER software is Equation (5):

$$P_{\text{wind}} = \frac{1}{2} \tau \cdot \rho \cdot C_p \cdot A \cdot \sum_{x=1}^j f_{(v)} \cdot v_x^3 \quad (5)$$

where the parameters are time analyzed, in this case, one year (τ); capacity factor of the wind turbine (C_p); wind speed (v); Weibull probability density function $f_{(v)}$; and the class number of the data is nominated as (j) [8,39].

Figure 8 shows the power curves of the wind generators selected for the study, which are manufactured by Enercon, Gamesa and Vestas. All of these machines were tested in different wind farms on Tenerife. The initial economic data for the wind generators and photovoltaic systems are shown in Table 3.

Table 4 illustrates the characteristics of the proposed wind turbines, with nominal powers of 800, 850 and 2000 kW.

Table 4. Commercial characteristics of wind generators (Source: [40–44]).

Characteristics	E48	E82	G52	G90	V52	V80
Nominal power (kW).	800	2000	850	2000	850	2000
Hub height (m)	55	78	55	78	55	78
Rotor diameter (m).	48	82	52	90	52	80
Cut-in wind speed (m/s)	3.0	2.0	4.0	3.0	4.0	4.0
Cut-out wind speed (m/s)	25	25	25	21	25	25

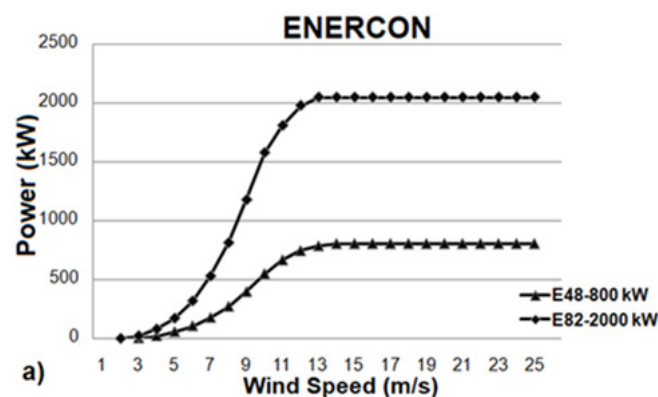


Figure 8. Cont.

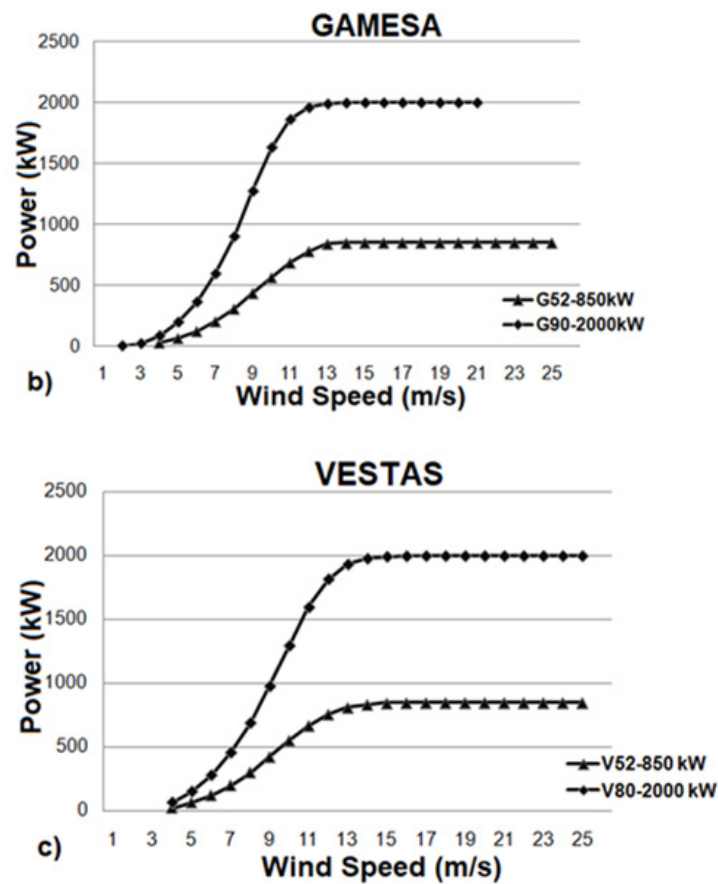


Figure 8. Power curves of the wind generators. (a) Enercon, E48-800 kW and E82-2.0 MW; (b) Gamesa, G52-850 kW y G90-2.0 MW; (c) Vestas, V52-850 kW y V80-2.0 MW (Source: [40–44]).

3.7. Economic Analysis

Typically, conventional electric systems have a lower initial capital cost than RES, while the cost of operation is higher in thermoelectric plants. In the optimization process, the HOMER software compares the economic characteristics between renewable energy systems and the traditional electrical system to recommend the most economical system [38].

The tools used by HOMER to perform the economic analysis are the “Levelized Cost of Energy” (COE), which calculates the average (cost/kWh) of the electricity produced by the system, and the “Total Net Present Cost” (NPC) (\$), which computes the cost to install and operate any system [3,6]. All of the methodology and economic equations can be found in the studies carried out in [3,38,45] and will be presented below.

3.7.1. Total Net Present Cost (NPC)

The Total Net Present Cost (NPC) is used in the software to simulate the installation and operation cost of different combinations of RES, which may or may not be connected to the electrical grid. All of these aspects will be delivered by HOMER in cash (\$). It will be assumed that the useful life of the project will be 25 years for wind generators and 20 for PV systems. The NPC can be calculated in the software HOMER with the following expression:

$$NPC = \frac{C_{a,t}}{CRF(i, N)} \quad (6)$$

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (7)$$

where $C_{a,t}$ is the total annualized cost (\$/year), CRF is the capital recovery factor given by

Equation (7), and in this last expression, i is the annual real interest rate (%) and N is the useful life of the project (20 years for PV systems, 25 for wind systems).

3.7.2. Levelized Cost of Energy (COE)

HOMER software version 2.75 states the Levelized Cost of Energy (COE) as the average (cost/kWh) of electrical energy generated by RES, which may or may not be connected to the electrical grid, but in this case it is connected. The specialized software version 2.75 takes the next equation to calculate the COE [15,45]:

$$\text{COE} = \frac{C_{a,t}}{E_{\text{pr,AC}} + E_{\text{pr,DC}} + E_{\text{gr,sales}}} \quad (8)$$

where $C_{a,t}$ is the total annualized cost (\$/year), $E_{\text{pr,AC}}$ is the AC primary load served (kWh/year), $E_{\text{pr,DC}}$ is the DC primary load served (kWh/year), and $E_{\text{gr,sales}}$ is the total grid sales (kWh/year). This economic analysis contemplates transfer and sale of energy to the electrical grid; the system will be processed as a system connected to the grid in our case.

4. Results and Discussion

The main problem that arises in the design of any RES, whether hybrid or not, is to determine its components and the size of each one, which is conditioned by the RE sources in the region where it is installed.

The HOMER software is an excellent tool to use in this situation since it allows for simulating numerous system arrangements. For example, the NPC makes it possible to sort values that are in the viable range and discard those that are unviable.

The results of the technical-economic simulation carried out by HOMER are shown below. The cost of electricity from renewable energy is assumed to be \$0.15/kWh; the cost of electricity purchased from the grid is \$0.10/kWh; the desalination process is assumed to consume 4.50 kWh/m³ of desalinated water; and the maximum production capacity of the proposed desalination plant is 20,000 m³/day.

4.1. Optimization Results in Santa Cruz de Tenerife

After modeling the technical-economic aspects with RES based on PV and wind systems from different manufacturers, such as Enercon, Gamesa and Vestas, connected to the electrical grid in Santa Cruz de Tenerife to supply energy to a desalination plant, it can be stated that the optimal energy system to supply energy to a desalination plant in the capital is the grid, with an approximate consumption of 32,666,286 kWh/year and an approximate cost of \$3,266,629/year, with a grid electricity cost equal to \$0.10/kWh.

This is mainly due to the low wind speeds in the region analyzed, the high costs of photovoltaic systems and the lack of land in the capital to install a solar farm.

4.2. Optimization Results in Special Nature Reserve “Montaña Roja”

Tables 5 and 6 present the result of the technical-economic and energy simulation and optimization carried out for the Montaña Roja Nature Reserve area by the HOMER software using the data set from the Reina Sofía Airport meteorological station. The RES used in this model is the same as that used to model the system in Santa Cruz de Tenerife (PV wind systems from different manufacturers such as Enercon, Gamesa and Vestas connected to the electrical grid).

Table 5. Technical-economic optimization results for the RES (PV wind electrical grid) in the Montaña Roja Nature Reserve.

Turbine Model	No. of Turbines	Initial Capital Cost (\$)	O&M Cost (\$/year)	Total NPC (\$)	COE (\$/kWh)
G90	2	4,800,000	1,730,579	26,922,606	0.064
E82	2	4,800,000	1,750,828	27,181,456	0.065
V80	2	4,800,000	1,932,697	29,506,358	0.071

Table 6. Energy optimization results for the RES (PV wind electrical grid) in the Montaña Roja Nature Reserve.

Turbines Model	No. of Turbines	Energy Consumption (kWh/year)	Energy Purchased (kWh/year)	Energy Produced (kWh/year)	Renewable Fraction (%)	Energy Sold (kWh/year)	Energy Sold Fraction (%)
G90	2	32,666,340	17,213,290	16,190,625	48.5	737,575	4.5
E82	2	32,666,340	17,555,310	15,941,763	48.0	830,733	5.2
V80	2	32,666,340	18,932,300	14,270,080	43.0	536,040	3.8

Table 5 shows that an initial capital cost of \$4,800,000 is considered, which is the same for all possible wind farms coupled to the electrical grid. The COE for the different wind turbine models varies between \$0.064 and \$0.071/kWh, with the system with two G90 wind turbines being the one with the lowest cost/kWh.

The percentage of renewable energy that can be injected into the electrical grid varies between 43.0 and 48.5%, with the system with two G90 wind turbines being the largest producer of renewable energy, followed by the system with two E82 wind turbines (48%). In the latter, up to 5.2% of the total renewable energy produced in a year can be sold.

After analyzing the systems with G90 wind turbines, the energy required for the desalination system totals 32,666,340 kWh/year, of which 15,453,050 kWh/year (47.3%) come from the 4.0 MW wind farm, and the rest (17,213,290 kWh/year) from the electricity grid.

It is valid to highlight that in all of the cases analyzed in the study these RES are valid as long as the average annual wind speed is greater than 4.6 m/s, without forgetting that it is impossible to carry out a wind evaluation without taking into consideration the Weibull distribution. Otherwise, the best economic option will be to connect the desalination plant to the electrical grid in places with an average annual wind speed lower than the indicated average.

The second proposed RES in all study cases in the south of the island is a system of two wind turbines and 200 kW in photovoltaic panels connected to the electrical grid. This RES system in some cases has a renewable energy penetration capacity of up to 49%, but with a COE greater than an RES composed solely of two wind turbines connected to the electrical grid. Taking into account the territorial restriction that exists in the Canary Islands (national parks, protected spaces, etc.) and on any island isolated from the Atlantic Ocean, the best system will be one composed of wind turbines connected to the electrical grid. Although it allows for the possible use of a small photovoltaic park of up to 200 kW in cases where greater renewable penetration is needed, no matter how small the increase in this penetration may be.

The possible reduction in the cost of the kWh of electricity consumed by the desalination plant, if the proposed RES is implemented, could amount to 36%. This happens because of the cost of electrical energy, since if it is taken from the electrical grid it is \$0.10/kWh, a cost that may increase in the coming years due to different factors such as inflation, increase in fuel prices, etc., but, if the energy is produced through a renewable hybrid system (wind generators through the electric grid), the cost per kWh amounts to only \$0.064/kWh during the lifetime of the system.

The use of RES based on grid-connected wind energy can positively influence the Levelized Cost of Water (LCoW) of the fresh water produced, being able to offer the product at a more competitive market price and with a lower CO₂ footprint.

4.3. Polluting Gas Emissions

Table 7 presents the amounts of polluting gas emissions that can be avoided by wind farms with two G90 wind turbines. This scenario is for the combination with the highest energy production from renewable sources, with a total production of 16,190,625 kWh/year. During the year, only 4.5% of this energy has to be sold to the electricity grid due to excess production, meaning the scenario can be regarded as successful since 95.5% of the energy is used for desalination (Table 6).

Table 7. Pollutants avoided by the wind system.

Wind Farm	Pollutant	Avoided Emissions (kg/year)
2 Turbines (G90)	Carbon dioxide (CO ₂)	8,732,130
	Sulfur dioxide (SO ₂)	81,390
	Nitrogen oxides (NO _x)	39,710

The RES proposed to supply the maximum possible energy from renewable sources to a desalination plant with a maximum production of 20,000 m³/day can avoid releasing into the environment 8,732,130 kg/year of CO₂, 81,390 kg/year of SO₂ and 39,710 kg/year of nitrogen oxides. If the desalination plants installed in the Canary Islands and Macaronesia that can access renewable energy sources take hybrid systems as a viable energy supply, they will be able to avoid dumping millions of tons of pollutants into the atmosphere.

5. Conclusions

The following conclusions can be drawn from the technical-economic analyses conducted for the possible installation of an RES to supply the maximum possible energy from renewable sources to a desalination plant on the island of Tenerife. The places on the island under consideration were the Montaña Roja Nature Reserve and Santa Cruz de Tenerife.

The first technical-economic analysis was carried out for the capital, Santa Cruz de Tenerife, and yielded the finding that an RES cannot be installed in this location to supply energy to a desalination plant due to insufficient wind speed and lack of available land to install a solar farm.

The second technical-economic analysis was carried out for the Montaña Roja Nature Reserve, which has good wind potential. Wind turbines from different manufacturers were analyzed, all of them connected to the electrical grid, which yielded very good results. The G90 wind turbines can inject the greatest amount of energy into the electrical system, with a total of 16,190,625 kWh/year, of which 15,453,050 kWh/year (47.3% the energy required) is used directly in the desalination plant, with the remaining 4.5% being sold to the electricity grid. These RES avoid releasing into the atmosphere 8,732,130 kg/year of CO₂, 81,390 kg/year of SO₂ and 39,710 kg/year of NO_x.

Another possible hybrid renewable system that can be implemented in these regions is a system of two wind turbines and 200 kW of photovoltaic panels connected to the electrical grid, whenever it is necessary to increase the penetration of renewable energies into the system, no matter how small the increase is.

If the RES proposed in this research are implemented, the cost of the kWh of electricity consumed by the desalination plants can be reduced by up to 36%.

This proposed RES can have an effect on the LCoW of the fresh water produced, making it possible to obtain fresh water at a lower price, enabling a greater penetration of the desalinated water industry into the freshwater market. These systems will also allow us to considerably reduce the CO₂ footprint.

The results of this study show that the proposed strategy could be appropriate to be used in the rest of the Canary Islands, in Macaronesia or in other coastal regions of the North Atlantic Ocean, as long as the places meet the condition of presenting an annual average wind speed greater than 4.6 m/s and always take into account the Weibull distribution, with the wind velocity being the determinant variable for the decision.

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