Sizing of a Green Hydrogen Energy System to power a micro-grid for residential use

Abraham Quintana [a], José A. Carta [b], Fabián Déniz [c]

[a] Industrial and Civil Engineering school, University of Las Palmas de Gran Canaria, Las Palmas, Spain, abraham.quintana101@alu.ulpgc.es
[b] Mechanical Engineering Department, University of Las Palmas de Gran Canaria, Las Palmas, Spain, jose.carta@ulpgc.es
[c] University Institute of Intelligent Systems and Numerical Applications in Engineering (SIANI), University of Las Palmas de Gran Canaria, Las Palmas, Spain, fabian.deniz@ulpgc.es

Abstract:

Storage systems are necessary in microgrids based on renewable energy sources to maintain the balance between production and demand. Currently, hydrogen is being promoted by the European Union to be used as new renewable energy vector (green hydrogen) in order to use it for the generation of electrical power, consequently reducing greenhouse gas emissions. Renewable energy sources used to produce hydrogen, such as photovoltaic and wind, are intermittent, therefore an optimal sizing of the hydrogen storage system is required. Another advantage of using hydrogen as an energy vector is the flexibility obtained in the electrical system. This article proposes a technical and optimal solution to create an electric microgrid for a residential area with 100 dwellings using a green hydrogen storage system powered with renewable energy. Results show that a self-sufficient hybrid photovoltaic and wind turbine microgrid with hydrogen storage system can be economically more attractive than a regular photovoltaic collective self-consumption installation. In addition, the self-sufficient gained with hydrogen as energy vector, means a total decarbonisation of the energy sector.

Keywords:

Green hydrogen, microgrid, decarbonisation, renewable energy, resilience.

1. Introduction

Since the Industrial Revolution, the greenhouse gas emissions have been steadily increasing up to the present day. The rising population, linked to the consumerist society in which we live, has led to an increase of the average temperature in the planet. The European Union has set ambitious targets for renewable energies (REs), energy efficiency and greenhouse gas reduction in order to brake climate change. Today, one of those main objectives pursued by the European Union is to decarbonize the energy sector [1] and become the first climate-neutral continent by 2050. In the particular case of the Canary Islands, it is even more ambitious and aims to bring decarbonisation forward by 10 years [2], so that total decarbonisation in the Canary Islands is set for the year 2040.

To achieve those goals, the European Union and their member states are creating and adapting regulations [3,4] to promote RE generation power plants (GPP), so that clean energy can be attractive to the consumers and be competitive in the market. The most common and available energy resources are solar energy and wind energy. Thus, photovoltaic (PV) and wind turbine (WT) technologies are two of the most widespread technologies used worldwide in renewable energy generation power plants (RE GPP). Nevertheless, the implementation of RE GPP have many challenges and limitations [5] due to the integration into the existing grid infrastructure and the need of huge energy storage systems (ESSs). Because of the excellent solar energy resources available in Spain and the relatively low cost of the PV technology, for the last years, the Spanish government [6] has been working on different policies to facilitate the access to the PV self-consumption to the Spaniards.

This paper intends to provide a solution for the decarbonisation of the Canary Islands. The solution studied consists on a self-sufficient microgrid using PV and WT technologies to generate electricity to feed one hundred dwellings. The self-sufficiency of the microgrid is ensured by a green hydrogen-based energy storage system combined with a battery, to improve the resilience [7] of the microgrid. Whereas an isolated microgrid could be a valid solution, a grid connected GPP could give worth to the excess of electricity generated, reducing the levelized cost of energy (COE) of the consumers. In this sense, a discussion of the Spanish PV collective self-consumption regulation is opened, by comparing the benefits of the legislation if it could be applied to hybrid generation power plants.

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To achieve an accurate vision, the rest of the paper is structured in the following way. In section 2, *Background*, the Spanish regulation is exposed identifying weaknesses of PV self-consumption and hydrogen systems legislation. Section 3, *Study area*, identifies a valid location for the microgrid according to the RE resources, the proximity to possible consumptions and the feasible locations according to the current legislation. After this, the section 4, *Methods and modelling of study cases*, shows the methodology followed to build the different study cases using HOMER Energy software [8] and the alternative scenarios proposed. The results from the different scenarios considered are exposed in section 5, *Results*, with a discussion of the findings and its limitations. Finally, section 6, *Conclusion,* summarizes the main ideas concluded from this paper.

2. Background

2.1. Current Spanish self-consumption regulations

In 2019, the Spanish government published the Royal Decree 244/2019 [7], which regulates the administrative, technical and economic conditions for the self-consumption of electrical energy. One of the biggest steps of this regulation is the recognition of different self-consumption modalities [9], distinguishing:

- Self-consumption without surplus
- Self-consumption with surplus
  - Net billing: limited to a maximum GPP of 100 kW, this modality allows to inject the surplus to the general electricity grid (GEG) receiving the prosumer a fixed economic compensation per kWh. The electricity bill cannot have a negative value, this means, the retailer will never pay you for the surplus, but make a discount on your bill. This modality has practically no administrative formalities neither taxes applied to the surplus.
  - Direct Sell (DS): the surplus are sold at market prices, with no constrain. Taxes regarding to the generation and the incomes must be paid. The GPP needs to register as an electricity generator.
- Individual self-consumption
- Collective self-consumption: group of several consumers who are supplied, on an agreed basis, with electrical energy from production facilities close to and associated with those of consumption.

Also, the Royal Decree 244/2019 enables the self-consumption not only to installations connected to the consumers internal grid, but also through the general electricity grid. More in depth, collective self-consumption is allowed in the modality of self-consumption with surplus through the general electricity grid when the generation and the consumers are connected to the low voltage GEG within 500 meters distance of each other.

After the Royal Decree 244/2019, the Spanish government has approved new constraints regarding the self-consumption in the Royal Decree-Law 18/2022 [10] and the Royal Decree-Law 20/2022 [11]. On the one hand, the Royal Decree-Law 18/2022 claims that generation linked to self-consumption is mainly photovoltaic and therefore generated at low voltage, it is the reason why the maximum distance cannot be larger, in order to transport the energy without causing high voltage drops and high losses. At the same time, the regulation promotes self-consumption through the GEG by increasing the distance to the consumption up to 1000 meters in the case of power plants located on the rooftop. On the other hand, the Royal Decree-Law 20/2022 encourages self-consumption through the GEG by increasing the distance of self-consumption up to 2000 meters in the case of photovoltaic power plants located on rooftops, industrial land and artificial structures for other purposes, such as those used to cover parking spaces or other uses.

In a nutshell, the actual Spanish law allows self-consumption with surplus through the general electricity grid when distances between the distance between generation and consumption are under 2000 meters radio and they use PV GPP.

2.2. Current Spanish hydrogen regulations

Although the "Report on current regulations and legislative development needs, November 2019" [12] highlights the need for a new regulation on hydrogen production by hydrolysis, hydrogen production in Spain is currently classified as a chemical industry and is therefore considered an industrial activity, regardless of the production method, storage capacity or purpose of the same. For this reason, until updated regulations are approved, hydrogen production facilities must be located in industrial areas [13].

3. Study area

Self-consumption using RE generation power plants requires critical characteristics of the location, which are:

- High renewable energy resources
- Proximity to residential areas

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In addition, the solution proposed in the paper pretends not only to implement self-consumption, but also to ensure the self-sufficiency of the microgrid using a hydrogen-based energy storage system. Therefore, according to the current legislation an extra condition is required:

- Compliance with regulatory requirements, particularly for the hydrogen storage system

Considering those key aspects, the placement chosen for the project is the Arinaga Industrial Estate (Polígono Industrial de Arinaga).

3.1. Location

Arinaga Industrial Estate has good renewable energy resources and different neighbourhoods within 2000 meters radio, as shown in Figure. 1. It is an industrial area which allows chemical industries [14, 15] and energy infrastructure use.

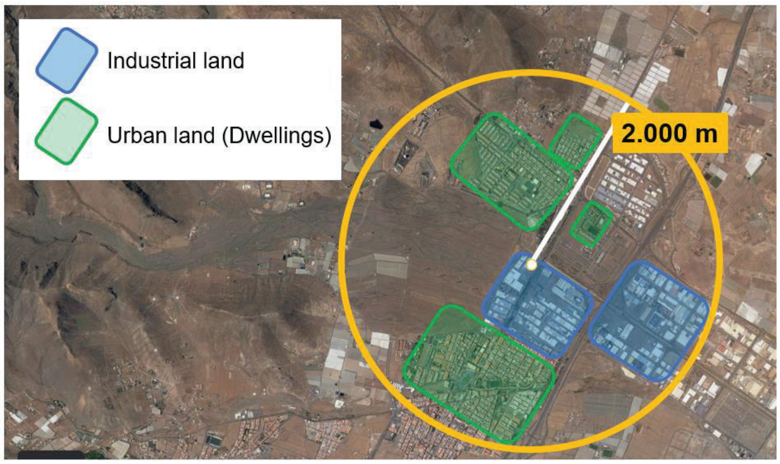
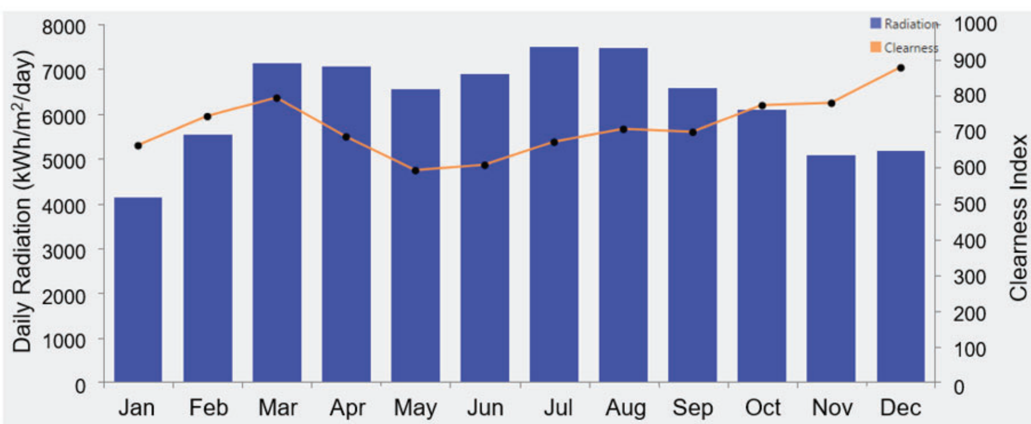


Figure. 1. Location for the proposed microgrid [16]

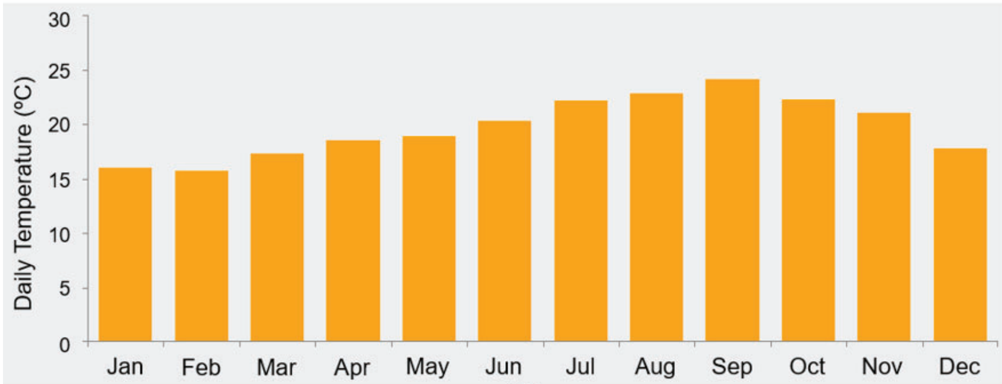
3.2. Energetic resources

3.2.1. Solar energy

The solar radiation and temperature data were taken from the "PVGIS-SARAH2" database [17] published by the European Commission and correspond to the hourly data for 2006. Figure. 2 shows a monthly average of hourly data on solar radiation and temperature in the location of Arinaga Industrial Park.



(a)



(b)

Figure. 2. Solar radiation and temperature in the Industrial area of Arinaga, year 2006. (a) Average daily solar radiation (kWh/m^2/day). (b) Average daily temperature (ºC)

3.2.2. Wind energy

The wind data taken as a reference correspond to hourly measurements at 10 meters height on the Arinaga dock in 2006. The wind speed data have been corrected due to the variation in height from the anemometer height (10 m) to the wind turbine hub height (65 m) applying the logarithmic variation of the wind speed profile with a roughness factor of 0.1. Figure. 3 shows a monthly average of hourly data on wind speed.

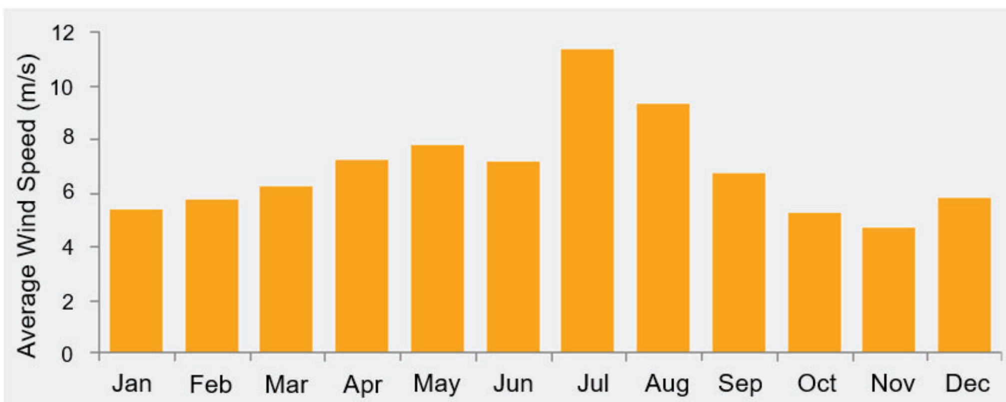


Figure. 3. Wind speed in the Industrial area of Arinaga at 65 m height, year 2006 (m/s)

The chosen year, 2006, had in Gran Canaria an average speed wind under the mean speed during the period 2001-2014, according to Ref. [18]. Taking as reference a year with unfavourable wind resources, the reliability and the resilience of self-sufficiency of the system is increasing.

3.3. Electric demand

To elaborate a base demand power curve profile, real hourly data over the year 2021 for a set of 40 residential meters in the municipality of Alojeró, on the island of La Gomera, were taken as reference. After this, the power curve profile was scaled for a group of 100 dwellings by knowing the minimum power prevision according to the Spanish regulation [19], 5750 W per residence with a simultaneity coefficient of 54.8 %, which results in a total peak power prevision of 315.1 kW. Figure. 4 shows the power curve profile obtained from the reference data. The main electric demand characteristics for 100 dwellings, after scaling the base data according to the minimum installed peak power required, are shown in Table. 1.

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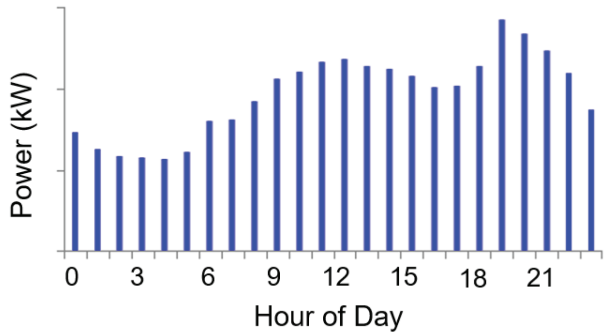


Figure. 4. Daily base demand power curve profile

Table. 1. Electric demand

	Average Energy (kWh/day)	Average Power (kW)	Peak Power (kW)
Base data 40 dwellings	226.5	9.4	21.5
100 dwellings (study case)	3321.1	138.4	315.1

The data presented in Table. 1 show that the base data taken as reference had a very poor electric consumption, the reason behind this fact, is that Alojeró is a municipality where most of the dwellings are second residences and therefore, the mean electrical consumption is very low. Nevertheless, the power curve profile obtained from the data is correct for residential use. The study case has been obtained by scaling the base data until reach the minimum installed power (or Peak Power) for new residences according to the Spanish current regulations, therefore, the scale factor between the real base data and the theoretical study case is nonlinear. Regardless, the study case for 100 dwellings is coherent, with an average power of 1.38 kW per dwelling. This possible oversizing of the demand, just results in a higher resilience of the system and can be justified by the possibility of increasing the number of dwellings attached to the collective self-consumption microgrid in a real case application.

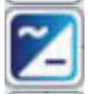
4. Methods and modelling of study cases

The paper's goal is to evaluate the feasibility of a renewable energy self-sufficient green hydrogen microgrid in Gran Canaria to achieve the decarbonisation, attending to the actual legislation, in particular the collective self-consumption and also attending to the actual cost of RE GPP and ESSs technologies.

In order to guarantee the self-sufficiency of the system, an energy storage system is needed to meet the energy demand in the most unfavourable energy resource situations. The solution adopted for this problem is to use green hydrogen as an energy vector. Green hydrogen's greatest virtue is its 100% renewable origin and its small carbon footprint, compared to other storage systems such as conventional batteries. On the other hand, the lack of development of hydrogen technology makes its installation more expensive. At the same time, hydrogen has a great energy density (Wh/kg) but a relatively low power density (W/kg). Whereas a higher energy density indicates a longer autonomy, a low power density means a slower transient response [20]. To solve this problem, another ESS is implemented, a Li-ion battery, which has a lower energy density but a higher power density compared to hydrogen. With the combination of those two ESS, the resilience of the microgrid increases. Furthermore, the minimum power output of proton exchange membrane fuel cells is around 20-30% of its nominal power, for this reason, the use of two ESS is not only justified but also indispensable.

HOMER ENERGY [9] is the software used to design and model different scenarios to determine the best technical solution optimizing the cost of the proposed scenarios. All scenarios are located in the same area, so that all cases have the same RE resources. At the same time, the same electric demand (3.3 Electric demand) is considered for the different scenarios. Same costs of equipment and same lifetime have been considered, which are shown in Table. 2. Equipment costs are set according to the reference bibliography [21,22,23,24,25,26] taken into account.

Table. 2. Equipment, economics and characteristics

Equipment	Symbol	Capital cost	Replacement cost	Lifetime	O&M cost	Other characteristics
Photovoltaic (PV) GPP		1100 €/kW	760 €/kW	25 years	0.1 €/kW year	STC efficiency: 20.9%
Wind turbine (WT)		1180 €/kW	1000 €/kW	25 years	5 €/kW year	Hub height: 65 m
Converter		100 €/kW	100 €/kW	15 years	-	Efficiency: 95%
Electrolyzer		1400 €/kW	1400 €/kW	15 years	28 €/kW year	Efficiency: 75%
Hydrogen tank		669 €/kg	669 €/kg	30 years	6.69 €/kg year	Tank type: IV Pressure: 380 bar
Fuel cell		1800 €/kW	1800 €/kW	25000 hours	0.01 €/op. hr	Slope: 65 g H_2/h/kW Minimum load: 20%
Li-ion battery		650 €/kWh	650 €/kWh	15 years	10 €/kWh year	Minimum SoC: 20%

According to section 2.1 Current Spanish self-consumption regulations & [10], the self-consumption regulation allows the direct sell of the surpluses. Regarding to this, the grid was modelled introducing two different prices of energy:

- Power price: is the price of the energy purchased from the grid (€/kWh). Those data correspond to the monthly mean prices of the voluntary pricing for small consumers tariff 2.0 (PVPC 2.0 TD) [27] during the year 2022. The data used in the study is available on Spanish Consumers and Users Organisation website [28].
- Sellback rate: is the price of the energy dumped on the GEG. Those data correspond to the hourly prices of the day ahead market during 2022. These prices are set by the Spanish market operator (OMIE) [29].

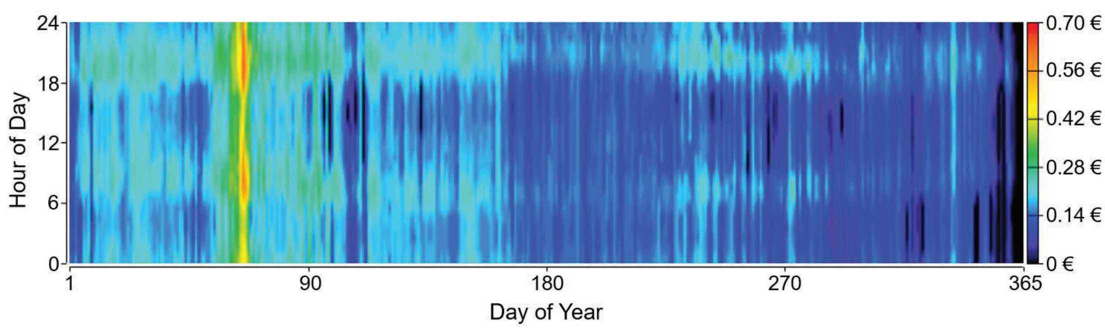


Figure. 5. 2022 Day ahead market prices (OMIE)

The different scenarios Figure. 6, where modelled according to the methodology set out as follows. The first scenario considered, *4.1 Grid connected PV generation plant. Scenario (*A), corresponds to a usual collective self-consumption modality, according to the regulation, which will be the starting point to compare the cost of energy from different alternatives. After this, *Isolated PV self-sufficient microgrid. Scenario (*B), and an *Isolated PV + WT self-sufficient microgrid. Scenario (*C), are modelled to estimate the capacity of the RE GPP and the hydrogen storage capacity in order to satisfy the electrical demand in an isolated self-sufficient microgrid. Whereas scenario (B) makes use of PV technology, scenario (C) utilize a hybrid PV and WT GPP. Lastly, scenario (D) and scenario (E) sections *4.4* and *4.5* respectively, maintain the same self-sufficiency restriction (same ESS capacity and same RE GPP capacity compared to scenarios (B) and (C) respectively)

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but are connected to the GEG, with the aim of reducing the cost of energy using the collective self-consumption with surplus through GEG and direct sell modality.

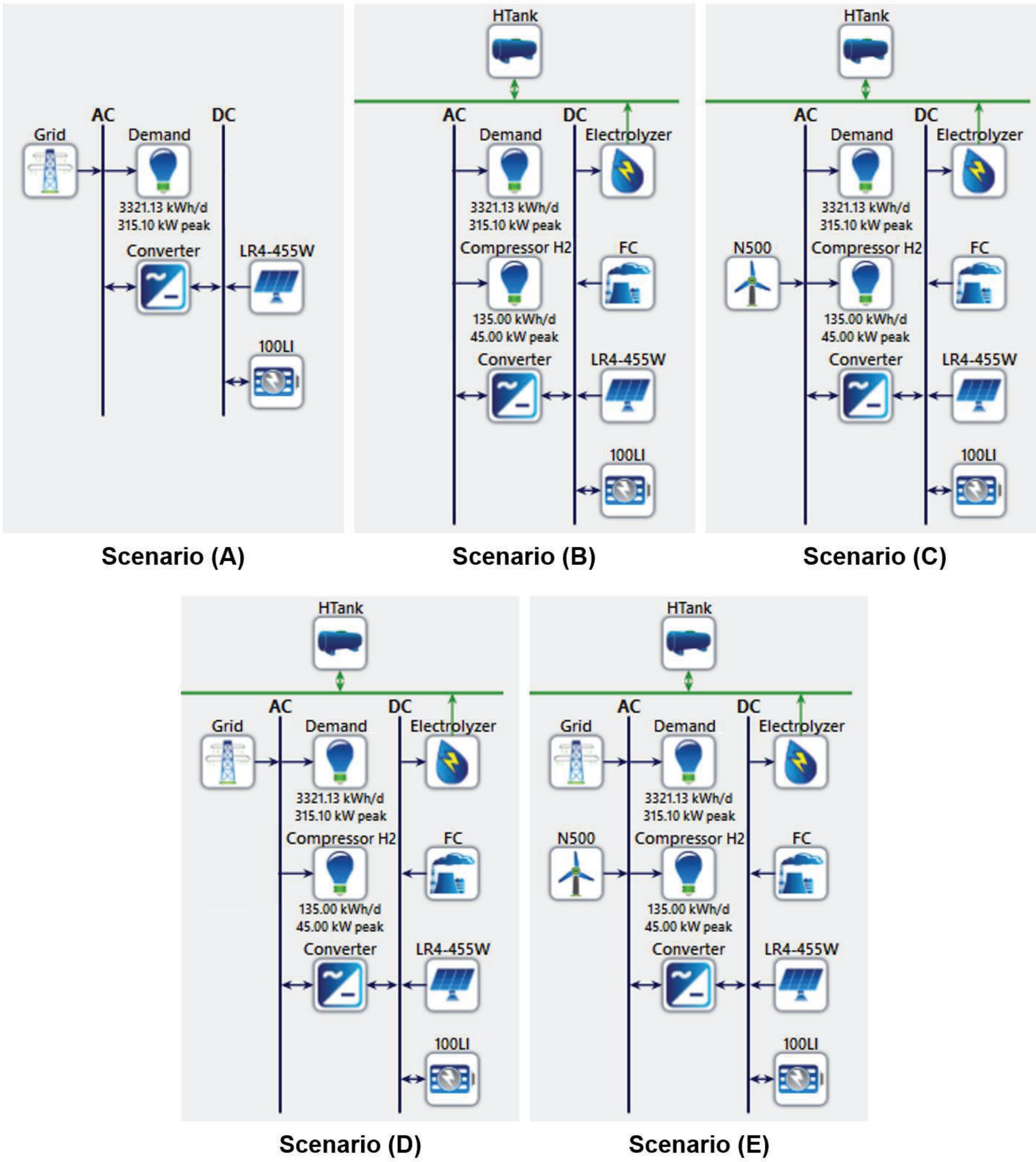

Figure. 6. Study cases scenarios

Table. 3. Study cases scenarios characteristics and equipment capacities

	SS	GEG DS 350 kW	PV (kW)	WT (kW)	Converter (kW)	Li-ion battery (kWh)	Electrolyzer (kW)	H_2 Tank (kg)	FC (kW)
Scenario A	-	✓	1098	-	700	100	-	-	-
Scenario B	✓	-	1665	-	700*	100	1000	1000	250
Scenario C	✓	-	450	500	700*	100	300	1000	250
Scenario D	✓	✓	1665	-	700*	100	1000	1000	250
Scenario E	✓	✓	450	500	700*	100	300	1000	250

*: 700 kW converters are used in every scenario to match the same costs of the equipment required in the most critical scenario.

The GEG is modelled limiting the maximum power output to the grid to 350 kW, so that all systems are equivalent in relation to the access power required and therefore all scenarios can sell the same maximum amount of power. One of the limitations of this methodology is the differentiation made by HOMER between the GEG and the loads, not considering the loads through the GEG, but in a direct line to the consumers. For this reason, a 700 kW converter is chosen in Scenario A, so that the system is able to supply the peak power of the electrical demand considered, and dump up to 350 kW to the GEG at the same time.

All scenarios are compared attending to the levelized cost of energy, which is the average cost per kWh of useful electrical energy produced by the system [9]. With units in €/kWh, HOMER calculates the COE dividing the annualized cost of producing energy by the total electric load served as given in Eq. (1).

$$COE = \frac{C_{ann,tot} - c_{boiler} H_{served}}{E_{served}} \tag{1}$$

Where:

- $C_{ann,tot}$ is the total annualized cost of the system (€/year), which is the annualized value of the total net present cost.
- c_{boiler} is the boiler marginal cost (€/kWh) of thermal energy from the boiler.
- H_{served} is the total thermal load served (kWh/year), which is the total amount of energy that served the thermal load during the year.
- $E_{served}$is the total electrical load served (kWh/year), which is the total amount of energy that went towards serving the primary and deferrable loads during the year, plus the amount of energy sold to the grid.

As the second term in the numerator results from the thermal load served, this term is zero for RE technologies, as for example PV or WT.

4.1. Grid connected PV generation plant. Scenario (A)

Scenario A is the reference study case. It is an ordinary PV GPP in the modality of collective self-consumption through the general electricity grid with direct sell of the surplus, not being self-sufficient. Scenario A is modelled using HOMER optimiser to size the PV capacity to reach the lowest COE. The sizing of the system is presented in Table. 3.

4.2. Isolated PV self-sufficient microgrid. Scenario (B)

Scenario B intends to model an isolated self-sufficient microgrid by using PV as GPP. The aim of this scenario is to size the PV capacity and ESS needed in order to achieve self-sufficiency, only using PV technology. Two ESS are implemented, hydrogen and Li-ion battery, combined to improve the dynamic response of the system. As shown in Table. 2, the hydrogen tank works at 380 bar pressure, therefore two electrical loads are considered, one hundred dwellings electrical demand and a hydrogen compressor. Hydrogen compressor load refers to the electrical consumption of a 45 kW compressor. This load has been scheduled to work only 3 hours a day. Those 3 hours are the ones with the highest RE penetration.

4.3. Isolated PV + WT self-sufficient microgrid. Scenario (C)

After modelling scenario B, scenario C pretends to size the RE GPP capacity and ESS needed in order to achieve self-sufficiency when two technologies are combined, PV and WT. So, Scenario C, an isolated hybrid microgrid (PV + WT), is dimensioned by HOMER optimizer maintaining the same constrains as scenario B, which are self-sufficiency, combination of green hydrogen and Li-ion battery as ESSs and two electrical loads (100 dwellings electrical demand and hydrogen compressor).

4.4. Grid connected PV self-sufficient microgrid. Scenario (D)

Scenario D matches the same equipment capacities as scenario B differentiating each other in the connection to the GEG. By matching the same generation an ESSs capacities, scenario D ensures self-sufficiency, only using PV technology. In addition, scenario D is in line with the constraints of the regulations, which only allows self-consumption through the general electricity grid when distances between the distance between generation and consumptions are under 2000 meters radio and they use PV GPP. In this scenario, by connecting to the GEG, there is no need to build a private distribution line to the consumers and, at the same time, there is the possibility to sell the surplus.

4.5. Grid connected PV + WT self-sufficient microgrid. Scenario (E)

Scenario E is a hybrid PV and WT microgrid connected to the GEG. With same sizing of the RE GPP and ESSs as Scenario C, this new scenario E, is self-sufficient and at the same time is capable of dumping and selling the surplus to the GEG.

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5. Results

A summary of the different scenarios is presented on Table. 4, where the generation of the different technologies are shown not only in MWh/year, but also its percentage out of the total energy production (GEG purchased energy is also considered production). In addition, Table. 4 exhibit two economic parameters, which are the COE and the initial capital cost. These economic parameters are closely related to the total amount of energy discharged to the GEG (GEG sales) of each scenario. All scenarios cover the energy demand of 1261.5 MWh/year required by the 100 dwellings as a whole.

Table. 4. Scenarios analysis: generation, GEG exchange and economics

	SS	PV (MWh/year)	WT (MWh/year)	H_2 FC (MWh/year)	GEG Purchases (MWh/year)	GEG Sales (MWh/year)	Initial capital (€)	COE (€/kWh)
Scenario A	-	2238.2 (78.9 %)	-	-	598.1 (21.1%)	1095.4	1.37 M	0.0503
Scenario B	✓	3393.9 (83.4%)	-	674.3 (16.6%)	-	-	4.50 M	0.409
Scenario C	✓	917.1 (22.9%)	2903.6 (72.4%)	190.8 (4.76%)	-	-	2.76 M	0.217
Scenario D	✓	3392.9 (76.5%)	-	873.4 (19.7%)	171.3 (3.8%)	131.3	4.52 M	0.363
Scenario E	✓	917.1 (20.3%)	2903.6 (64.4%)	570.9 (12.7%)	115.5 (2.6%)	1253.6	2.78 M	0.0450

Scenario A is the only non-self-sufficient study case. As a result, scenario A purchase a total of 598.1 MWh/year energy to cover the total electrical demand. This GEG purchased energy is a 21.1% over the total energy production (as GEG purchased energy is also considered production to the microgrid), but a 47.41 % out of the total load of 1261.5 MWh/year required by the 100 dwellings. Canary Islands power system generates electricity mainly out of diesel groups and combined cycle groups, therefore the GEG purchased energy has an associated CO2 emissions factor of 0.776 kg CO_2/kWh, as [30] states. At the end of the year, scenario A adds to the atmosphere 464062 kg carbon dioxide per year. Although scenario A has the second lower COE because of the difference between the energy sold and the energy purchased, this scenario does not contribute to the target of total decarbonisation set in the Canary Islands for the year 2040.

Scenarios B and C are isolated self-sufficient microgrids. The fact of not being connected to the GEG and being a self-sufficient system out of RE implies that it has no associated emissions from energy purchased from the GEG. Otherwise, compared to scenario A, the initial capital costs of scenarios B and C are higher because of the need for a higher GPP capacity and because of the ESSs implemented to ensure the self-sufficiency of the system. Thus, and because of not having the possibility to sale the surplus to the GEG, the COE are higher for both scenarios, in the particular case of scenario B, it has the highest COE from all cases considered.

Scenarios D and E, pretend to reduce the COE of the systems B and C maintaining the condition of self-sufficiency. Both scenarios, D and E are connected to the GEG, so that the surplus can be sold and therefore, the COE decreases. Scenarios D and E could not have any carbon dioxide emission associated as they are dimensioned with the same generation capacities as both isolated systems, B and C respectively.

When a location matches a good mixture of solar and wind renewable energy sources, a hybrid WT and PV generation power plant is the optimal system [31] increasing the average production among the year. Therefore, a hybrid generation system has the advantage of being able to generate enough electricity those days when one of the energy sources is not available, increasing the reliability and the self-sufficiency of the microgrid. As a result, hybrid GPP in scenarios C and E, generate more energy at the end of the year with a lower power capacity compared to scenarios B and D, which only use PV technology.

When focusing on the economics, there is also a clear tendence in the costs reduction of a self-sufficient system if two generation power plants are used, PV and WT. As a PV and WT hybrid system require a lower generation capacity and less energy storage capacity compared to PV microgrid, the initial capital cost is reduced comparing scenario C and B and comparing scenario E and D. On the other hand, the COE is reduced dramatically when the system is connected to the GEG and can sell the surplus. This can be clearly identified by comparing scenarios D and B and comparing scenarios E and C respectively.

Additionally, a GEG connected microgrid (scenarios D and E) improve the resilience of the power system, so that the electrical demand can be covered at every single moment even the years with lower RE penetration. A grid connected system, also allows the microgrid to stop working for programmed maintenance. The resilience of scenarios B, C, D and E is also increased by the use of two ESS, a Li-ion battery and a green hydrogen based ESSs [32]. The combination of both energy storage system improves the energy storage capacity and the dynamic response of the microgrid when the hydrogen fuel cell starts up [33], and when the minimal load of the FC is not covered.

5.1. Discussions

The results presented show that a hybrid PV and WT GPP self-sufficient microgrid (scenario E) is a cleaner solution compared to scenario A and it can also can be an economically better solution in comparison with a regular PV self-consumption GPP (scenario A). Because more energy is generated with a lower power capacity in the proposed hybrids microgrids, when the microgrid works in the modality of self-consumption with surplus through the general electricity grid and direct sell, the hybrid microgrid results in a lower COE. Nevertheless, the present Spanish laws Royal Decree 244/2019, Royal Decree-Law 18/2022 and 20/2022 only allow collective self-consumption with surplus through the general electricity grid for PV GPP because it is the most extended technology used in self-consumption. The restriction of a maximum distance of 2000 meters pretends to avoid high voltage drops and high losses. This condition does not make any sense as there is not a restriction on the maximum power of the GPP in the self-consumption DS modality, as the voltage drops depends not only on the distance but also depends on the power. According to the current regulation, only scenarios A and D could work in the modality of self-consumption with surplus through the GEG and DS.

A key aspect of the collective self-consumption consumption with surplus through the general electricity grid and direct sell is the possibility of using the GEG in a radio of 2000 m. This allow a GPP to provide electricity to different locations within an area, which makes the collective self-consumption more accessible to the consumers and at the same time, more attractive to the companies, reducing the costs from building a new distribution line. The current regulation does not provide this opportunity to generation technologies other than photovoltaics, as for example mini wind turbine, biomass or other RE technologies.

If decarbonation is a real objective for the Spanish government, as part of the European Union, it is opened the discussion, whether the collective self-consumption regulation could be applied also for hybrid PV generation power plants. As shown on the results, hybrid microgrids can be economically competitive and with an appropriate energy storage system they can provide 100 % green energy to the society.

5.2. Limitations

The methodology followed to develop this work have some important limitations which conditionate the results presented. The limitations are detailed below:

- No generation taxes are considered: Spanish legislation provides for a tax on generated electricity supplied to GEG of 7 % and a grid access fee of 0.5 €/MWh. HOMER optimizations were not executed considering these generation taxes.
- No construction costs and no land acquisition costs have been considered.
- Simulations have only been carried out over one year. HOMER does not run multi-year simulations with hydrogen systems. Therefore, the COE showed on the results have only been calculated considering direct sales of surpluses over one year and not over the 25-year life of the project.
- Simulations were executed under 2022 electricity prices. 2022 has been the year with the highest energy prices in Europe history, so the direct sell of the surplus turns out in the highest incomes compared to other years. On contrary, the purchased energy in 2022 was the most expensive too.

Although these important limitations denote that the COE obtained is not accurate, they apply equally to all scenarios. Consequently, the simulations are valid to identify which system is the most economically profitable.

6. Conclusion

This work studies different microgrids scenarios to reach the decarbonisation of the energy sector in the Canary Islands attending to the current self-consumption regulations in Spain. To reach the decarbonisation, self-sufficient renewable energy generation power plants microgrids with green hydrogen energy storage systems are proposed. Different combinations of photovoltaic and wind turbines generation technologies are proposed in search of an economic competitive system.

After studying the current Spanish self-consumption and hydrogen regulation, a study area and a location in proposed. The location chosen in the industrial area of Arinaga is in compliance with the regulation and counts with suitable renewable energy resources, which are presented in detail. All microgrids proposed are dimensioned with an electrical demand modelled for 100 dwellings.

The methodology and different scenarios are presented. For the self-sufficient scenarios, two energy storage systems are considered, hydrogen due to the its energetic density and Li-ion battery to improve the dynamic response of the system. The results show that hybrid photovoltaic and wind turbine microgrids are more economic for the particular study case compared to a photovoltaic microgrid. In addition, a self-sufficient hybrid microgrid can be economically more attractive than a self-consumption non-self-sufficient regular photovoltaic power plant. Consequently, a discussion is opened whether the collective self-consumption regulation could be applied also for hybrid photovoltaic generation power plants.

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Abbreviations

AC	Altern current
COE	Cost of energy
DC	Direct current
DS	Direct sell
ESS	Energy storage system
FC	Fuel cell
GEG	General electricity grid
GPP	Generation power plants
H_2	Hydrogen
O&M	Operation and maintenance
PV	Photovoltaic
RE	Renewable energy
SoC	State of charge
SS	Self-sufficient
STC	Standard test conditions
WT	Wind turbine

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