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Computer Modeling and Analysis of a Hybrid Renewable Energy System Grid-Connected Using Homer Pro

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Abstract: Renewable energy generation has attracted a lot of attention in recent years. Among the most used sources in this context, Photovoltaic Solar and wind have presented the highest growth in recent years. Considering the new topologies and possibilities that arise with the evolution of technology, the Hybrid Renewable Energy System has been widely explored, being an excellent alternative in the new ways of generating energy in the future. Similarly, the traditional concept of centralized power systems has been replaced by distributed power generation levels. Thus, this work proposed to perform a technical and economic feasibility analysis in order to examine the possibility of an HRES composed by wind and solar sources, connected to the grid. For the development of the study, it was used a methodology based on computational modelling and simulation in HOMER Pro.

Keywords: Distributed generation, Grid-connected system, Hybrid System, Solar energy, Wind energy.

1. INTRODUCTION

The evolution of technology has enabled new concepts regarding power generation, which has imposed major transformations in electrical systems. Among these possibilities, the generation of energy through renewable sources is certainly the one that has attracted the most attention in recent years, being the object of research of the academic community and the industrial sector. Decreased prices for power generation from renewable sources associated with increased energy conversion efficiency, which has driven its growth every year (Adefarati e Bansal, 2016). Among the renewable sources, photovoltaic (PV) and wind are the fastest growing. According to data obtained from the International Renewable Energy Agency (IRENA, 2019), the total power installed worldwide from these sources is already over 1 TW. In fact, renewable generation is more sustainable, less harming nature and contributing to lower carbon emissions and global warming (Al Garni, Awasthi e Ramli, 2018).

Against this backdrop, new approaches to power generation become possible and necessary. One is the combination of more than one generation source through a Hybrid Renewable Energy System (HRES) (Khare, Nema e Baredar, 2016). The literature has widely discussed HRES, its advantages and challenges (Khare, Nema e Baredar, 2016), (Lian *et al.*, 2019), (Imcharoenkul e Chaitusaney, 2019). Considering the typical stochastic feature of renewable sources, combining more than one energy source in a single system enables a complementary power generation profile. Regarding the wind and solar source, for example, during the day the solar radiation is more intense favoring solar generation. On the other hand, at night, the wind current is more intense, which favors wind generation (Venkataraman *et al.*, 2018). This complement enables a better use of natural resources.

Another major change observed concerns about the generation mode. The traditional concept of centralized power systems has been replaced by distributed generation (DG), which has gained an important role in the future of power systems (Mehigan *et al.*, 2018), (Razavi *et al.*, 2019). There are several advantages of this mode of generation and energy. Some of the most important are listed as follow: modularity, greener installation and reduction of energy losses, being closer to the loads. (N. Jenkins; J.B. Ekanayake; G. Strbac, 2010).

It exists a similar thought among researchers about the importance of DG's role in the future. The increasing trend in this type of generation worldwide is being perceived. For example, in Brazil, the growth of DG has been following what occurs worldwide. As can be seen in Fig. 1, there is a high expectation of growth of renewable sources using DG (EPE, 2018).

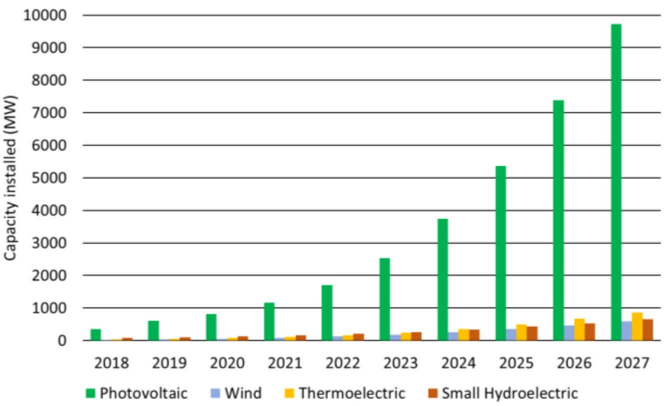

Fig. 1 Scenario for distributed generation.

In several countries around the world, in order to make possible the expansion of the DG, it is important both government incentives and legislation that support the consumer or the entrepreneur of the sector. In this sense, Brazil allows the framing of this type of generation as prescribed by resolution 482/2012 (ANEEL, 2012), subsequently revised by resolution 687/2015 (ANEEL, 2015).

Thus, the present work aims to conduct a study through computer modelling and simulation for analysis of technical and economic feasibility of a HRES composed by PV and wind generation, connected to the power grid. For the study case, the Hybrid Optimization Model for Electric Renewable (HOMER) software developed by the National Renewable Energy Laboratory's (NREL) was used (HOMER Energy, 2019).

2. CASE STUDY AND CONSIDERED SYSTEM

The conception of the present study began from the demand made by a determined consumer in the present research group, demonstrating the need to reduce the expenses related to electricity consumption by checking alternatives within the concepts addressed by this work. This consumer has a set of 50 buildings distributed in different cities of the state of São Paulo, Brazil, and are registered under the same National Register of Legal Entities (CNPJ, in its Portuguese acronym).

Thus, based on the dialogues with the consumer engineering department, the necessary details were detailed and then defined as an initial project, considering a HRES for installation at its main unit in Suzano. This location was chosen because it has an area equivalent to 2,302.30 m2 that can be used to implement an electricity generation system.

In accordance with the current regulations in Brazil, it is possible that a facility containing DG may share surplus energy with its other facilities from different locations, provided by the same concession area of the energy company and registered under the same CNPJ. This use of energy is in credit forms proportional to the excess energy generated, since in Brazil the monetization for energy delivered to the electricity grid is not provided for by law (ANEEL, 2012), (ANEEL, 2015). Considering the above, it would be possible to install, at the institution's headquarters, a generation system sufficiently robust to generate the necessary to meet all the energy demand of the 50 buildings.

For the development of this study, the HOMER Pro software was employed. Among many other software options available in the market, HOMER can be used as a tool to size power generation systems, mainly that intend to consider one more source of generation (Tozzi e Jo, 2017). This software is able to accurately perform optimization procedures from hourly simulations of energy flow occurring on the load and other system components (Zahboune *et al.*, 2016). Another advantage is that the software can estimate the initial installation cost and operating cost, considering a project useful life, presenting all the recommended indicators for a correct economic analysis (Al Garni, Awasthi e Ramli, 2018).

2.1 Demand Calculation

The first step in the project development was the survey of annual electricity demand. The calculation period was from March 2018 to March 2019, considering the total consumption of all 50 buildings. From the study, a total consumption of 297,236 MWh was calculated.

HOMER works with hourly energy demand in kW and energy bills are registered by monthly consumption in kWh. It was necessary to understand the hourly consumption profile of each installation (Singh, Baredar e Gupta, 2017). In addition, it was necessary to perform the conversion between quantities using mathematical methods to be able to perform the correct data entry in the software.

From the used data parameterized in the model, the detailed load profile can be obtained. Thus, the seasonal profile of the total load of all buildings is illustrated in Fig. 2.

2.2 Input Climate Data

For generation system projects it is essential to consider the weather data that interferes with electricity generation. As the present work deals with solar and wind energy, the radiation, temperature and wind velocity profiles were necessary to calculate the potential generation.

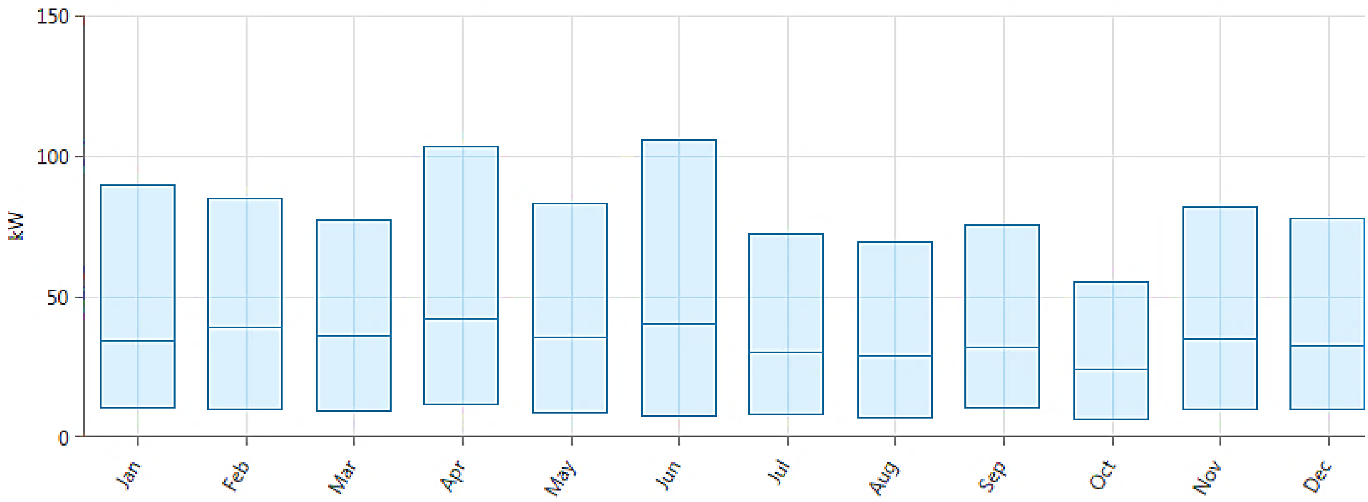

Fig. 2 Monthly Load Profile.

An advantage of the employed software in this study is that the required weather data is automatically loaded by itself as it is integrated into the NASA database. Thus, it was considered the radiation in the horizontal plane (as shown in Fig. 3) in relation to solar generation and temperature (Fig. 4). The data used consider the average monthly value of a measurement period of 22 years.

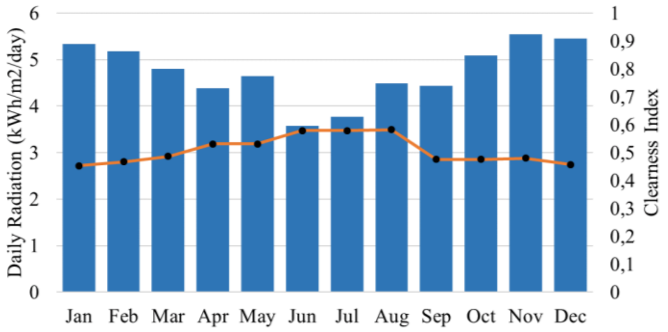

Fig. 3. Radiation and clearness index of the selected local.

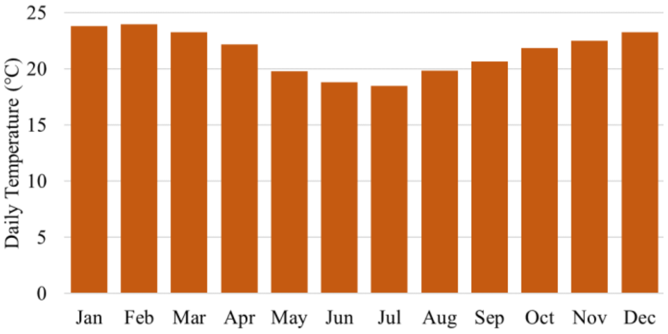

Fig. 4. Temperature of the selected local.

As for wind speed, it was considered the average monthly value over a 10-year measurement period considering a height of 50 meters, as represented in Fig. 5.

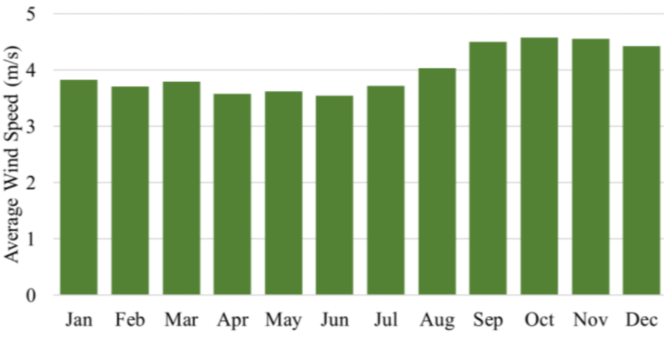

Fig. 5. Wind velocity in the selected local.

2.3 Economic Analysis

Then, it was performed a market analysis in order to relate the price, power ratio of available solar modules, inverters and wind turbines, as well as the other variables that influence the software analysis procedure. It is important to highlight that the consulted component prices used in this report are related to December 2019, and they depend directly on inflation and the value of the dollar at current rate.

From the survey, the information was inserted into the model, configuring each generation unit. The software has a library that assists in this procedure, where from it is possible to get the models of the components to be used in the project (HOMER Energy, 2019).

Some of the economic variables calculated by the software are explained as follows:

1) Net Present Cost (NPC): NPC represents the installation cost and the operating cost of the system throughout its lifetime. It is calculated according to (1).

$$NPC\colon \frac{TAC}{CRF(i, Rpr_j)} \tag{1}$$

Where:

TAC: Represents the total annualized cost ($);

CRF: The capital recovery factor;

i: Represents the interest rate (%);

Rpr_j: Represents the project lifetime (years).

2) Cost of Energy (COE): It is one of the most important parameters to be analysed. COE represents the average cost/kWh of useful electrical energy produced by the system. It is calculated according to (2) (HOMER Energy, 2019).

$$COE\colon \frac{TAC}{L_{prim.AC} + L_{prim.DC}} \tag{2}$$

Where:

$L_{prim.AC}$: The AC primary load;

$L_{prim.DC}$: The DC primary load.

3) Capital Recovery Factor (CRF): It is a ration which is used to calculate the present value of a series of equal annual cash flows. It is calculated according to (3).

$$CRF\colon \frac{i \text{ x } (1+i)^n}{(1+i)^{n-1}} \tag{3}$$

Where:

n: The number of years;

i: Represents the annual real interest rate.

4) Annual Real Interest Rate: It is a function of the nominal interest rate, and it is calculated according to (4).

$$i\colon \frac{i^* - F}{1 + F} \tag{4}$$

Where:

i: Represents the real interest rate;

i^*: The nominal interest rate;

F: The annual inflation rate.

On the other hand, in order to establish project costs, several procedures are required. Regarding the economic variables included in the software, the current interest rate and inflation were used and provided by Brazilian Central Bank (BCB, 2019). From these inputs the software itself calculates the actual interest rate. It is equally important to consider operating and maintenance (O&M) expenses. Following the guidelines of (Sandia National Laboratories, 2016) and (Fraunhofer ISE, 2018), PV system-related expenses cost the system R$ 40.30 kW / yr whereas, in relation to the wind system, this expense was set at 1% of the value of the chosen turbine, therefore 6,000.00 R$ / yr.

Finally, in relation to the electricity grid, the energy purchase tariff considered was R$ 0.88 / kWh. It is appropriate to justify that the chosen tariff value considers all the costs inherent to the energy bill as taxes and public lighting costs, being also considered an increase of 20%, overestimating the tariff.

This was necessary as the cost of availability was disregarded at this stage of the project, as suggested in (Nurunnabi e Roy, 2016). The price of energy sold to the grid was considered the same purchase price, R$ 0.88 / kWh. Legislation in Brazil does not allow the monetization of energy sales, but considering the energy sold equal to that purchased, it is believed to approach the scenario of offsetting credits currently in force in the country.

2.4 Model Description

From the steps described above, it was possible to obtain the model to perform the tests, as shown in Fig. 6. The proposed model considered 5 basic components: PV solar module, Inverter (DC / AC), wind turbine, power grid and primary charge. The PV system needs an inverter as it generates its DC power and AC power is required to deliver power to the grid. Since this is a grid-connected system, a battery-powered energy storage system has not been shown to be necessary as surplus energy will be delivered to the utility.

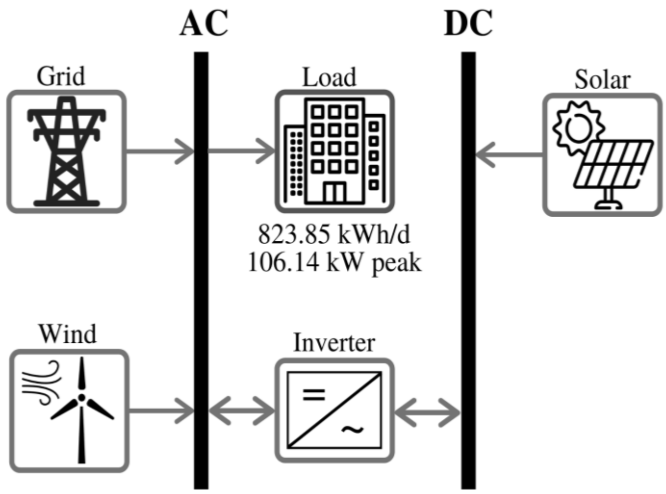

Fig. 6 Diagram of the proposed hybrid system.

3. RESULTS AND DISCUSSION

After the construction of the model, the results were simulated. The software performs optimizations from its algorithms to size the most appropriate proportion of each source's generation, peak power, topologies and all other indicators for system analysis. Thus, the optimal options considered by the software are described in Fig. 7. For better understanding, System 1 will be named the first option presented (Composed by Grid and Solar Generation), marked in green while System 2, the second option presented (Composed by Grid, Solar and Wind Generation), marked in red.

It can be observed that, contrary to the project applicant's desire, the best alternative pointed out by the software does not consider the use of wind generation. The software performs the sorting of optimized alternatives considering Net Present Cost (NPC) and Cost Of Energy (COE). The initial investment of the project corresponding to System 1 is R$ 567,023.00 and System 2 is R$ 1,160,000.00. Through Table 1, it is possible to observe the comparative related to the financial indicators that guide the economic analysis of the two systems.

Table 1. Comparison of Financial Indicators

	System 1	System 2
Metric	Value	Value
Present worth (R$)	R$1,469,449	R$829,019
Annual worth (R$/yr)	R$74,588	R$42,080
Return on investment (%)	14.3	4.7
Internal rate of return (%)	18.3	7.2
Simple payback (yr)	5.29	11.07
Discounted payback (yr)	5.63	12.57

The economic analysis performed was based on consolidated guidelines in the area, considering the reports (Sandia National Laboratories, 2016) and (Fraunhofer ISE, 2018). Therefore, four criteria for project acceptance were employed:

- NPC > 0;
- Internal Rate of Return (IRR) > Real Market Rate;
- Discounted Payback < Desired Payback by the investor;
- COE < Energy tariff paid to the utility,

Looking at Fig. 6 and Table 1, it will be clear that both projects meet all four criteria described above, so they are economically viable and advantageous when analysed over the long term. However, System 1 clearly presents itself as the best option, both for the analysis of the indicators and the order suggested by the software.

Finally, comparisons were made about the energy produced by the two systems during the 1-year period. Thus Fig. 8 presents the results for System 1 and Fig. 9 for System 2. Also, through Table 2, a comparison between the two systems was presented. Both the systems presented approximate results, although System 1 presented more advantages over the lifetime project.

Table 2. Total Energy Production of Systems in 1 year

	System 1	System 2
Metric	Value	Value
Solar Energy (kWh/yr)	288.624	285.607
Wind Energy (kWh/yr)	0	7.632
Grid Purchases (kWh/yr)	180.054	176.194
Grid Sales(kWh/yr)	104.489	105.560

Architecture					Cost				System	
Solar (kW)	Wind	Grid (kW)	Inverter (kW)	Dispatch	NPC (R$)	COE (R$)	Operating cost (R$/yr)	Initial capital (R$)	Ren Frac (%)	Total Fuel (L/yr)
201		999,999	82.4	CC	R$3.74M	R$0.469	R$161,253	R$567,023	55.6	0
199	1	999,999	81.3	CC	R$4.38M	R$0.548	R$163,626	R$1.16M	56.6	0
		999,999		CC	R$5.21M	R$0.880	R$264,622	R$0.00	0	0
	1	999,999		CC	R$5.80M	R$0.979	R$263,906	R$600,000	2.54	0

Fig. 7 HOMER optimization results.

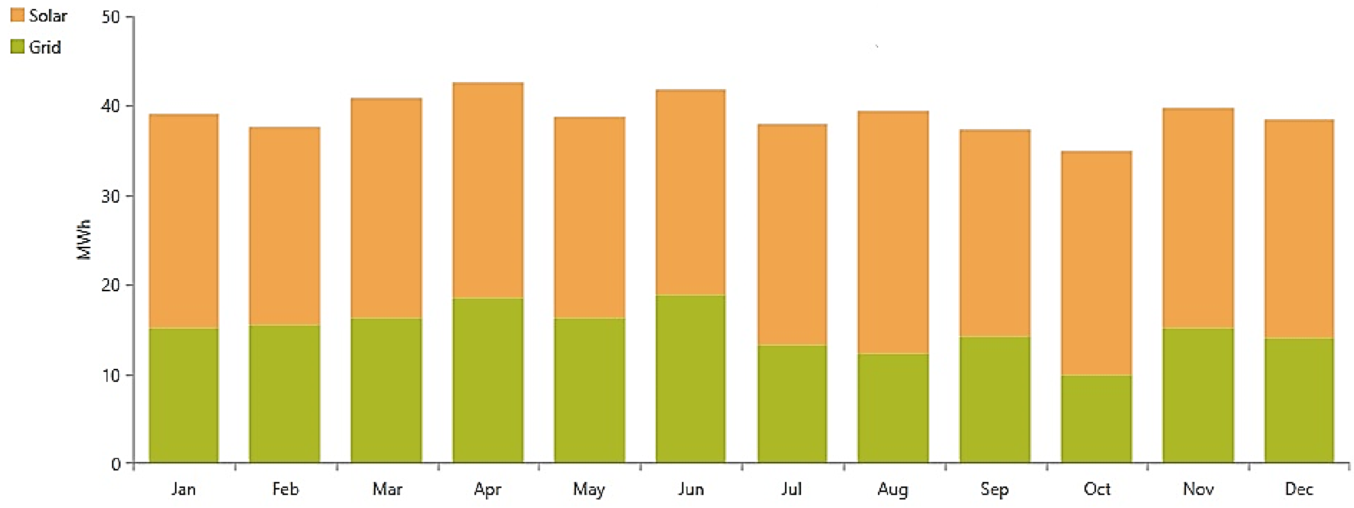

Fig. 8 System 1 Monthly Energy.

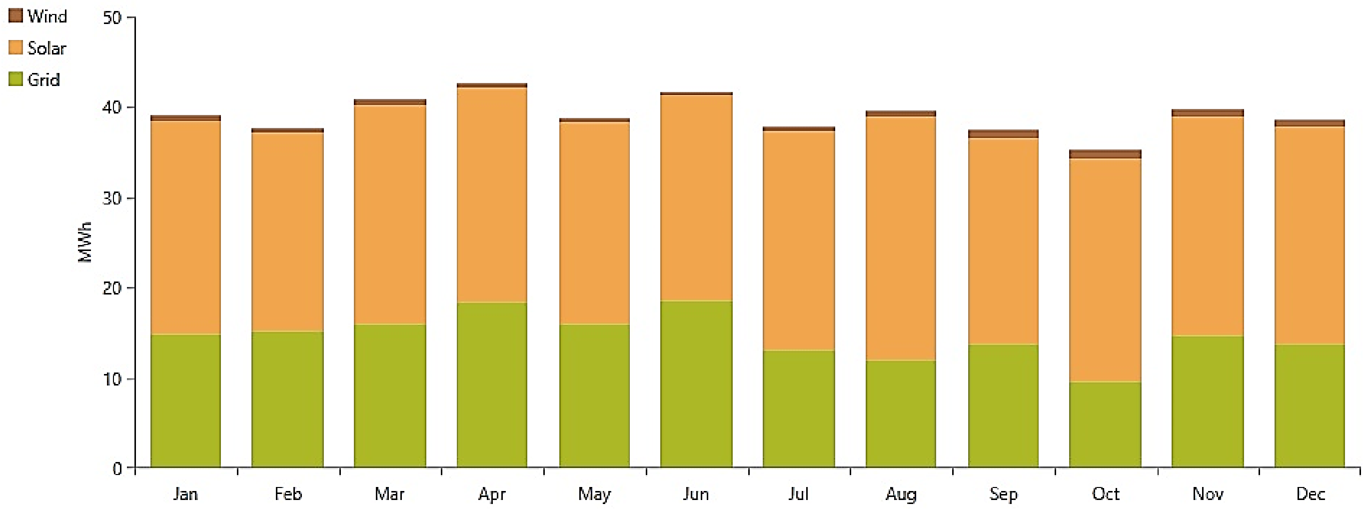

Fig. 9 System 2 Monthly Energy.

4. CONCLUSIONS

This paper presented the study and proposal of a system capable of meeting the electricity demand of 50 buildings in the region of São Paulo, Brazil. Considering the advantages created by the extension of the application of DGs, as well as the current norms, it has been possible to expand the possibilities regarding the ways of using energy. Thus, it was possible to perform the technical and economic analysis of the proposed system, following the guidelines already consolidated in the literature.

The analysis of the results concluded that the most advantageous solution is not a hybrid system, but a system containing only solar photovoltaic generation connected to the grid, although both systems were economically and technically feasible. This can be explained because the covered study region has a good insolation index, but an unsatisfactory wind speed profile. Since the software considers the climatological variables to perform the calculations, the low incidence of wind compromised the power generation rates through wind turbines.

It has been found that the required area for the installation of either system is compatible with the available consumer area. It is worth noting that partial results are shown in this article, where further detailing, modelling and simulations will be performed in the next steps to better bring the results closer to reality.

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