

Comparative analysis of energy efficiency between solar panels and wind turbines using RETscreen Software: a case Study in a residence in Xique-Xique in Bahia

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Abstract: This paper presents a comparison between solar and wind energy, innovative alternatives for generating clean and efficient energy. Solar energy is the direct conversion of sunlight into electricity by means of photovoltaic cells. Brazil has a high potential for the production of photovoltaic energy due to its high incidence of solar radiation, and contributes to the reduction of greenhouse gas emissions and the mitigation of impacts associated with non-renewable energy sources. Wind energy is based on the use of airflow in the atmosphere, capturing the kinetic energy of the wind through the blades of the wind turbine and converting it into electrical energy. With technological advances, Vortex Bladeless wind turbines have emerged, which feature an innovative design, using the magnetic confinement system to adjust the rigidity of the turbine according to the intensity of the wind. The main characteristic of wind and solar energy is that these energy sources are clean, renewable and cause little environmental impact. In this context, a comparative analysis was conducted to evaluate the energy efficiency of a residence in the city of Xique-Xique, Bahia. Solar panels using Kyocera KD 135SX polycrystalline silicon modules showed 68.89 % higher energy efficiency at a higher cost, while the Vortex Bladeless turbine proved to be an economically attractive option, with a 90 % improvement in costs, but showed lower energy efficiency. This comparison serves as a guide for sustainable and economically viable decisions when choosing renewable energy sources.

Keywords: wind turbine, solar panels, sustainability, energy efficiency.

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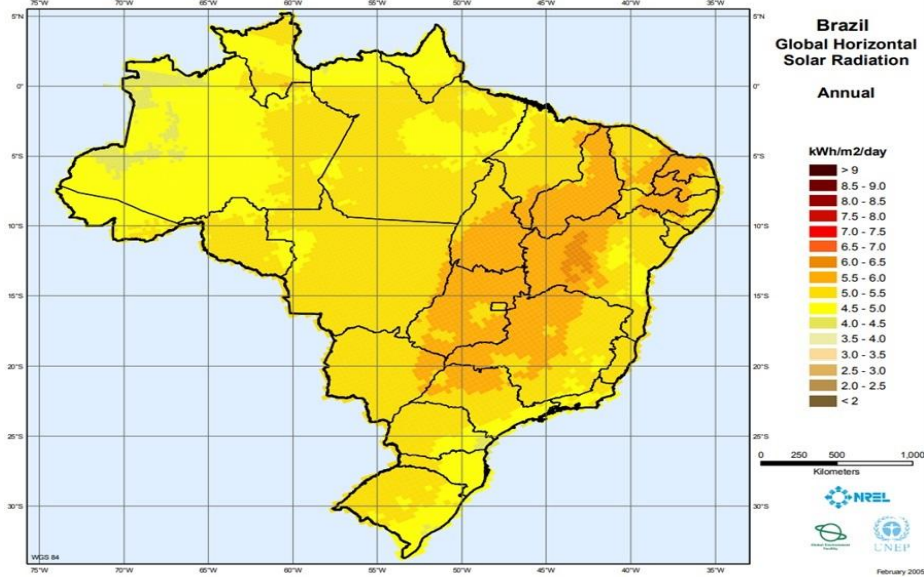
I. INTRODUCTION

Brazil, with most of its territory located between the Equator and the Tropic of Capricorn, enjoys favorable solar incidence due to the absence of large variations in radiation during the day as illustrated in Figure 1. This places it in an important worldwide spot in the use of renewable energy in its energy and electrical matrices (Santos and Torres, 2016).

The vastness of the Brazilian territory is responsible for a remarkable climatic diversity, with an annual average wind speed of 1.8 m/s, according to data from INMET (National Institute of Meteorology). This climatic diversity is reflected in the country's diverse environments and landscapes, which were meticulously analyzed by geographer Aziz Ab'Saber. He introduced the concept of "morphoclimatic domains", which comprise a combination of factors, including relief, soil types, vegetation, hydrography and distinct climatic conditions (Pigatto and Lopes, 2019).

The Northeast region has the highest levels of solar radiation. According to the Energy Research Company (EPE), in some states, such as Piauí, Alagoas, Paraíba, Maranhão, Bahia, Ceará, Tocantins, Minas Gerais and Sergipe, the photovoltaic generation on residential roofs can exceed residential consumption by up to twice, with a ratio of over 300% (Silva, 2018). In 2022, in addition to solar radiation levels, the country had a total of 1,197 wind farms, with a capacity of 35.6 GW, and a total of 9,671 photovoltaic panels, with a capacity of 44.4 GW. Wind farms are predominantly located in the Northeast and South regions, while photovoltaic solar plants are more widely distributed, with a notable concentration in the Northeast (Santos and Torres, 2022).

Figure 1. Annual global horizontal solar radiation (kWh/m²/day).

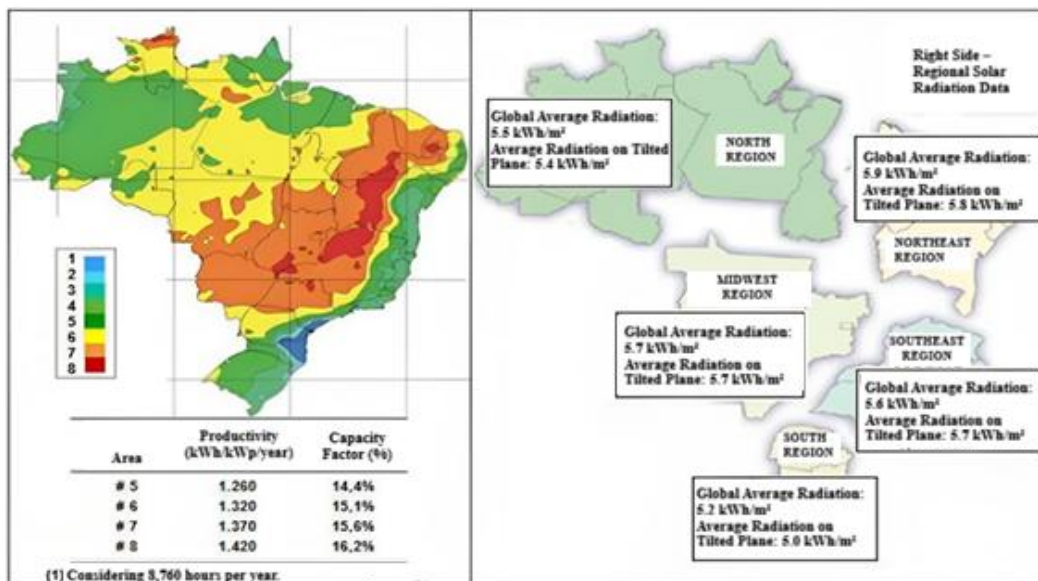


Bahia is the largest state in the Brazil northeast territory, with 600,000 km² (36.41 % of the region's area), has a varied relief, including plains, valleys, hills and mountains from 800 to 1,200 meters above sea level. This topographic diversity, combined with different atmospheric circulation systems, results in a complex and varied climatology, especially in terms of precipitation. Annual average temperatures vary, with values above 25 °C in hot areas, between 20 and 25 °C in most of the state and below 20 °C in certain areas. The state records an average wind intensity of 2 m/s, according to INMET, and in the Northeast region, the highest state index of solar radiation (maximum annual average of 6.1 kWh/m²) is found in western Bahia (Santos, 2016).

1.1 Solar Energy in Bahia

In 2001, the SWERA (Solar and Wind Energy Resource Assessment) Project began in Brazil to map the potential of solar and wind energy, promote public policies and attract private investment in renewable energy. Studies carried out by SWERA in 2006 and by the Energy Research Company (EPE) in 2012 highlighted the high solar potential in Brazil, enabling considerable photovoltaic productivity. EPE identifies areas of high solar irradiation, mainly in regions 5 to 8 in Figure 2, with average productivity between 1260 and 1420 Wh/Wp/year and an average capacity factor of 14.4 to 16.2%. (Santos and Torres, 2016).

Figure 2. Irradiation of Brazil and Average Annual Solar Energy Potential in Brazil.



The Northeast leads Brazil in solar energy, with 70.7 % of centralized projects and 18.9 % of distributed generation. Within this scenario, Bahia stands out with 23.7 % of centralized projects and the highest rate of solar irradiation on the inclined plane, reaching 6.1 kWh/m² in the caatinga region. On the coastal region of the state, the average irradiation on the inclined plane varies from 5.5 kWh/m² in Recôncavo, where Salvador city and its metropolitan region are located, to lower values in the central strip (Imperial and Pereira, 2014).

1.2 Installation of solar panels

The sizing of photovoltaic modules requires the sizing of the number of batteries required, therefore, the following two equations are used and the highest value between them is selected.

$$C = \frac{CT \times A}{TBB \times P} \quad (1)$$

$$C = \frac{CT \times A}{TBB \times PN} \quad (2)$$

Where:

C - Capacity (Ah): Battery bank capacity in Ah;

CT - Total consumption (Wh/day): Wh/day consumption corresponding to each scenario;

A - Autonomy (days): Establishes a period without sunlight availability, varying from 3 to 5 days according to local weather conditions and the desired reliability. Normally, in homes, 3 days are chosen, while in telecommunications systems, 5 days are considered standard;

TBB - Battery Bank Voltage (V): 12V is commonly used, although in larger systems, it is advisable to consider using 24V or 48V;

P - Depth of discharge at the end of autonomy (pu) or PN which is Depth of discharge at the end of each Night (pu/day); Table 1 shows the influence of the depth of discharge on the battery's useful life, highlighting that lower values increase the battery's durability (Teixeira; Carvalho and Leite, 2011).

Table 1. Battery life as a function of depth of discharge.

Depth of Discharge	Number of Cycles	Useful Life in Years
10 %	2,500	6.84
20 %	1,500	4.10
30 %	900	2.46
40 %	600	1.64
50 %	440	1.20
60 %	360	0.98
70 %	220	0.60
80 %	140	0.38

The proper sizing of equipment will depend on the application of a method that establishes the minimum power required for the generator. To this end:

$$PMG = \frac{CT}{HE \times FPP \times FPS} \quad (3)$$

Where:

PMG - Minimum generator power (Wp): The minimum total power required by the set of modules to meet the load's energy demand;

CT - Total consumption (Wh/day): Wh/day consumption corresponding to each scenario;

HE - Equivalent Hours of Full Sunshine (Hours/day): Depends on the latitude and cloud cover level of the location;

FPP - Power Loss Factor;

FPS - Loss and Safety Factor: Considered to account for the reduction in module generation due to manufacturing tolerances, temperature variations, presence of dust, degradation, shading, misalignments, electrical losses in the battery, controller, installation, in addition to the uncertainties associated with the data used and the expected consumption. Typical value: 0.8 (Feroli et al., 2022).

To size the inverter, it is necessary to calculate the power of the AC (Alternating Current) loads and choose an inverter with 10% more capacity. The input and output voltages must match the batteries and AC loads, respectively. The size of the heater depends on the sunlight, number of users and temperature preferences,

and water consumption. The Brazilian Technical Standard (NBR - 128/ABNT, 1963), which governs the installation of hot water in Brazil, stipulates temperatures of: 35° to 50 °C for personal use and 60° to 70 °C for kitchens. Daily water consumption at 60 °C varies from 36 liters (low-income housing) to 60 liters (apartment) per person. The authors adopt averages of 30 to 50 liters per person between 50° and 60 °C (Teixeira; Carvalho; Leite, 2011).

To determine the number of solar panels needed to meet the home's demand, it is essential to assess the potential for solar radiation in the installation region. By dividing the home's daily consumption by the average solar radiation, we obtain the value in kW/peak that the system needs to achieve (Silva, 2023).

$$NM = \frac{PMG}{PM} \quad (4)$$

Where:

NM - Number of Modules: Quantity of solar panels used to meet the energy needs;

PMG - Minimum generator power (Wp): The minimum total power required by the set of modules to meet the energy demand of the load;

PM - Power of the module to be used: Quantity of energy in Watts that the module can generate.

Photovoltaic systems, despite not generating pollutants during their operation, represent a promising sustainable energy alternative that, however, brings with it environmental impacts to be evaluated, such as:

- Emissions and other effects resulting from the generation of energy required for the stages of manufacturing, transportation, installation, operation, maintenance and decommissioning of the systems;
- Release of harmful substances throughout the process of obtaining raw materials for the manufacturing of modules and peripheral components, including acids, carcinogenic compounds, as well as emissions of $CO_2SO_2NO_x$ and particles; Use of space for the installation of the project, with the potential consequence of impacts on natural habitats (especially in sensitive regions). However, photovoltaic systems can take advantage of existing areas and structures, such as roofs and facades;
- Possible visual impacts that can be reduced by selecting less sensitive locations;
- Potential risks linked to toxic materials present in photovoltaic modules, such as arsenic, gallium and cadmium, and in other components, such as sulfuric acid in batteries, including threats of fire, acid leakage and exposure to sensitive parts of the body;
- Proper disposal and recycling of batteries, often lead-acid, and other toxic materials in electrical and electronic modules and components is crucial. The average useful life of components is 20 to 30 years (FERIOLI et al., 2022).

1.3 Wind Energy in Bahia

The total wind power generation capacity in Brazil reached 14,873 MW in 2019, with a predominance of 86 % (12769 MW) in the Northeast region. Of the nine northeastern states, eight have wind power projects, with Rio Grande do Norte (4020 MW) and Bahia (3770 MW) standing out. Currently, wind power leads in the Northeast region, representing 35.6 % of the regional electricity matrix (Bezerra, 2019). The Brazilian Wind Power Atlas, developed by CEPEL (Center for Electric Energy Research) in 2001, estimates a gross potential of 143.5 GW for 50 meters high towers, highlighting the advantageous characteristics of winds in Brazil for electricity generation, including good speed, low turbulence and uniformity, which allows generation capacity factors of up to 50 % in some locations. More recent estimates by ELETROBRAS indicate a potential of 345.0 GW when measuring wind at 100 meters high. These figures highlight wind energy as a relevant option for diversifying the country's electricity generation matrix (Santos, 2016). In Brazil, the strongest winds occur from June to December, coinciding with low rainfall, which highlights a complementary potential for energy production. The Northeast, South and Southeast regions have the greatest potential for wind generation, while the Amazon Region has limited potential (EPE, 2009).

According to the Wind Atlas of Bahia, the state covers a transition zone between different wind regimes. In the North, trade winds predominate, while further south, the interaction between the South Atlantic Subtropical Anticyclone and polar masses is significant. The coastal area of Bahia, which extends to the east, has relatively flat terrain due to vegetation. The central region, in turn, contains the plateau, an area of notable elevations with less roughness. On the coast, the relief is not an obstacle to winds coming from the sea, but the presence of tropical forest and dense vegetation reduces the intensity of surface winds (Nascimento, 2014).

The expansion planned to serve Bahia's growing wind generation center also benefits the development of solar plants, which can take advantage of the new electrical infrastructure. At the National Wind Forum, the new Bahia Wind Atlas was presented, with an estimated potential of 195 GW at 150 meters high, highlighting promising areas for wind projects. (Imperial and Pereira, 2014).

The rainfall distribution is consistent throughout the year in the coastal strip of the southern coast, maintaining stable vegetative indices. This region records the highest rainfall in the state, exceeding 1200 mm per year. In the far west, on the plateaus, rainfall is seasonal, occurring in spring and summer, with dry periods during the rest of the year. Annual rainfall in this area exceeds 1000 mm (Nascimento, 2014).

About the Wind, two main patterns prevail: the South Atlantic Subtropical Anticyclone, periodically affected by polar masses, and the constant trade winds from the North. These systems result in predominant winds from the northeast, east and southeast. Due to its vast size, the state experiences different mesoscale regimes, including sea/land breezes and mountain/valley breezes, with mainly diurnal cycles that affect wind speed and direction. Regarding seasonality, Bahia records maximum winds during the second half of the year, covering winter and spring (SFORCIN, 2022). Considering wind turbines with a capacity greater than 1 MW and towers with heights starting at 70 meters, the estimated wind potential for Bahia is approximately 14.5 GW and an annual generation of around 31.9 TWh, as indicated by the Wind Potential Atlas of the State of Bahia. In comparison, the installed capacity of hydroelectric plants in the Northeast region is 10 GW, with an annual production of around 53 TWh.

Bahia stands out for its remarkable wind energy potential, estimated at 14.5 GW for 70 meter high towers. This value represents 10.1% of Brazil's wind potential and 19.3% of the potential of the Northeast region. (Magalhães, 2018).

1.4 Implementation of the Vortex Bladeless

According to Villareal, 2018, when considering the Vortex Bladeless turbine, the length used must take into account only the diameter of the cylindrical structure. This is due to the fact that the turbine is not only a static object, but its oscillation must also be taken into account:

$$\Phi = D + a * X \quad (5)$$

Where:

Φ - Characteristic length of the turbine;

D - Tower diameter;

a - Adjustment factor that varies according to the Reynolds number;

X - Oscillation amplitude 'X'.

Regarding the design of the device, it involves a flexible bar of length L that extends from the highest part of the device to the ground. Therefore, the tower is a rigid body capable of oscillating only at small angles; the oscillation amplitude can be considered as zero when it is at a height of L/2. At this point, the characteristic length coincides with the tower diameter, resulting in:

$$\Phi = D * (L/2) \quad (6)$$

Where:

Φ - Characteristic length of the turbine;

D - Diameter of the tower;

L - Length of the flexible bar;

And the frequency would be:

$$f = \frac{S_t * v_{\infty}(L/2)}{D} \quad (7)$$

Where:

f - Turbine vortex shedding frequency;

S_t - Strouhal number;

v_{∞} - Infinite wind speed (m/s);

D - Tower diameter;

L - Flexible bar length;

In order to determine the vortex shedding frequency along the entire length of the tower, it is necessary to estimate the velocity gradient. To achieve the desired resonance, this frequency must be in tune with the natural oscillation of the structure. Given that the vortex shedding frequency is uniform throughout the tower:

$$D(y) = D * \frac{v_{\infty}(y)}{v_{\infty}(L/2)} - a * X(y) \quad (8)$$

Where:

D(y) - Difference between the fluid speed at the top and the base of the tower;

a - Acceleration;

v_{∞} - Infinite wind speed (m/s);

D - Tower diameter;

L - Length of the flexible bar;

X(y) - Vortex shedding frequency is directly proportional to the fluid speed at the base of the tower.

To increase the working hours per year, it is crucial to expand the operating speed range of the device. Resonance is limited due to a single natural oscillation frequency of the structure. In addition, the vortex shedding frequency varies with wind speed. In a VIV wind turbine without a regulation system, the tower mass is supported by a rod and the power losses are braked by the alternator. Resonance occurs when the oscillatory force of the wind is appropriate (Sudarshan, et al., 2022).

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m} - \left(\frac{c}{2m}\right)^2} \quad (9)$$

Where:

f - Natural frequency of a damped mass-spring system;

k - Spring constant of the system;

m - Mass of the system;

c - Damping coefficient of the system.

To determine the output power, we can perform the calculation as follows:

$$E = 0,5 * \rho * A * v^3 * Cp \quad (10)$$

Where:

P - Output power (Wh);

ρ - Air density (kg/m³);

A - Turbine cross-sectional area (m²);

v - Wind speed (m/s);

Cp - Power coefficient (Betz coefficient).

The maximum efficiency limit that an ideal turbine can achieve is called the Betz limit. According to Betz's law, the maximum theoretical power coefficient for a rotating turbine in a fluid flow is 0.593 (Cruz, 2018).

To conclude, Vortex Bladeless wind turbines include the technical specifications and power curve presented in their technical specifications, as shown in Table 2 (González, 2019).

Table 2 - Technical Specifications

Parameter	Value	Parameter	Value
Energy production (kWh/month) (avg. wind speed 5.4 m/s)	24	Cut-in wind speed	3.5 m/s
Rated power	100 W	Rated wind speed	9 m/s
Maximum power	109 W	Nominal oscillation Frequency	6.9 Hz
Rated voltage	24 V DC	Maximum tolerated wind speed	35 m/s
Total height	2.75 m	Swept área	0.97 m ²
Maximum diameter	0.261 m	Temperature range	-25 °C to 60 °C
Maximum amplitude angle	2.7°	Number of bolts	5
Maximum oscillation frequency (approx.)	7.5 Hz	Bolt diameter	M5
Net weight	14 kg	Recommended fuse	10 A
Start-up wind speed	3 m/s	Regulator adjustment range (approx.)	27.1 Vdc to 33 Vdc

1.5 Xique-Xique

Bahia stands out for its wind potential inland, unlike many northeastern states that concentrate it on the coast. Regions such as Sobradinho, Sento Sé, Xique-Xique, Brotas de Macaúbas, Caetité and others have great wind potential. Figure 3 shows a comparison between these regions in a monthly average diurnal regime of the incidence of solar radiation with the incidence of winds (Magalhães, 2018).

Figure 3 - Comparison of the incidence of solar radiation with the incidence of winds between regions of the northeast.

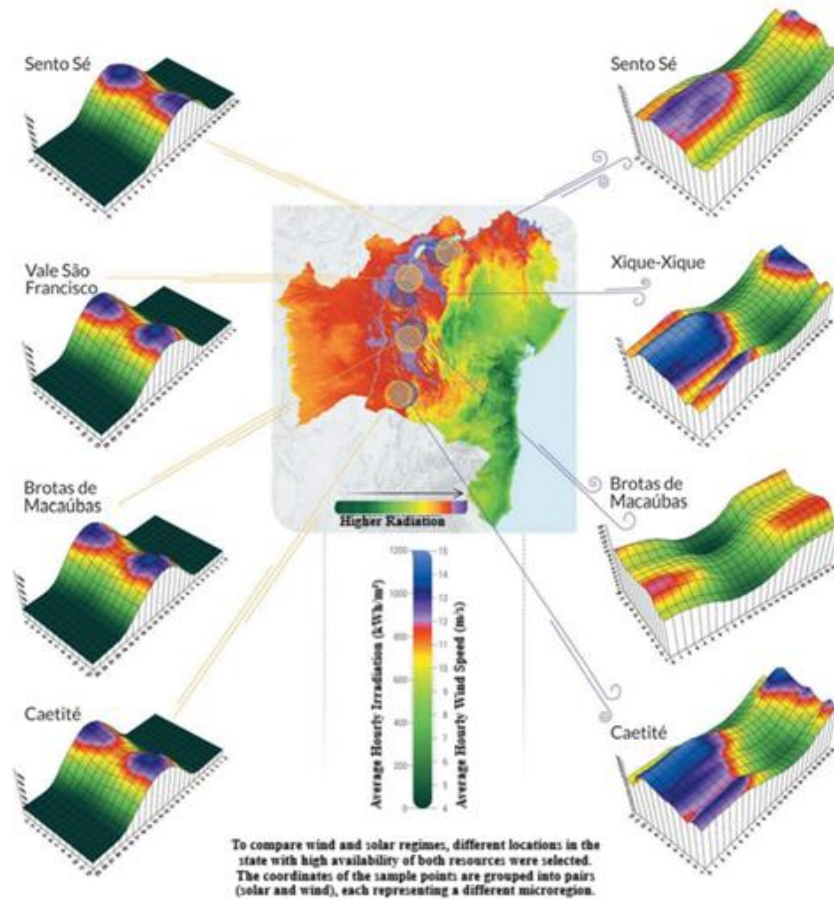
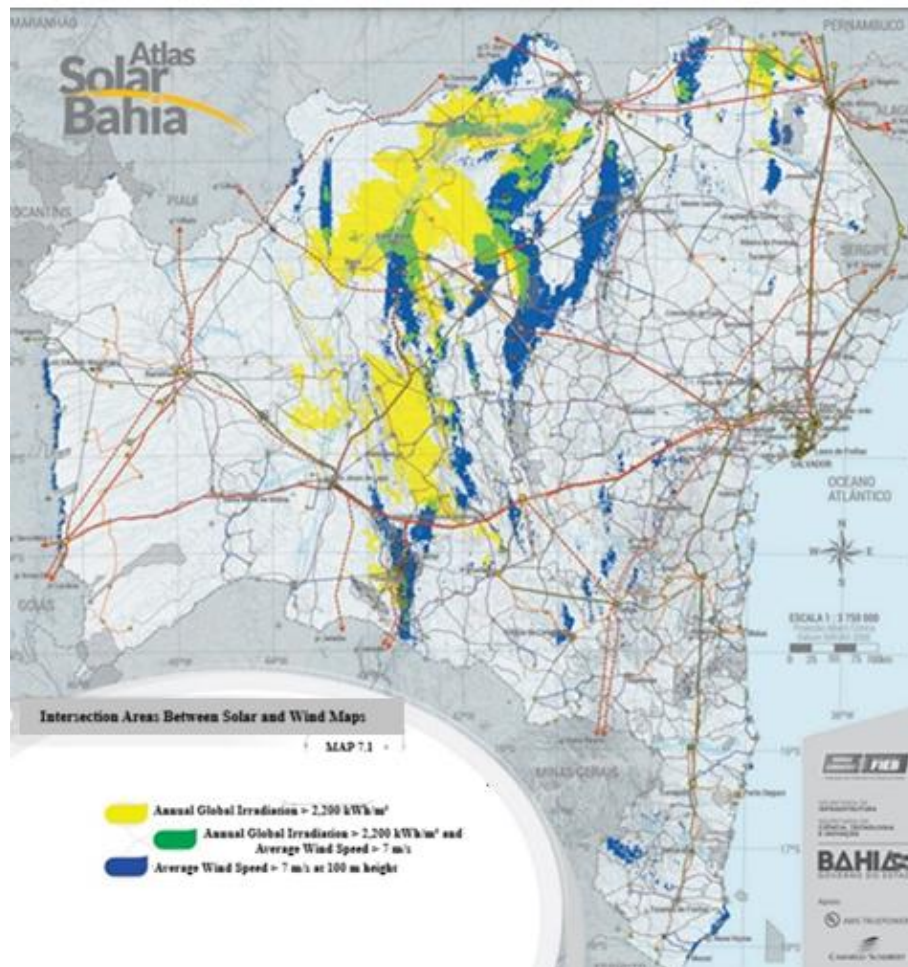


Figure 4 shows a map illustrating the overlap of the most suitable areas for wind energy (in blue), with the areas of greatest solar radiation (in yellow), as a result of a recent survey. This convergence of areas (in green) is concentrated in the central part of the state, extending from north to south, in cities such as Xique - Xique (BAHIA, 2018).

Figure 4 - Superposition of the best wind and solar radiation areas.

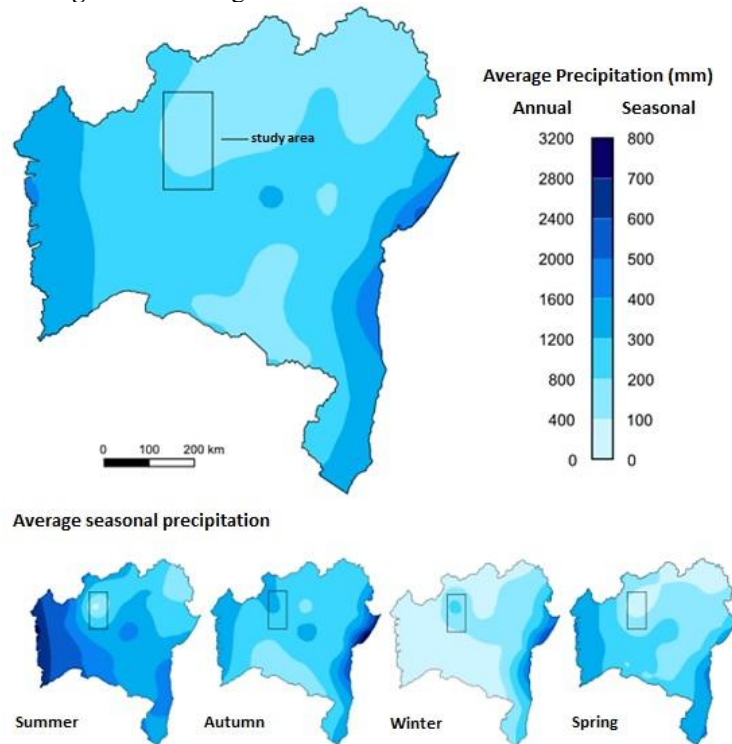


Xique-Xique is a city located in the middle of São Francisco region, with approximately 45 thousand inhabitants. Directly associated with the São Francisco River, the Xique-Xique wind system is the largest dune field in the interior of the Quaternary in Brazil (about 8000 km²) and stands out for its large dimensions and the association of stabilized and active parabolic dunes with the alluvial plain of the São Francisco River (MESCOLOTTI, 2021).

Xique-Xique has a short, scorching and partly cloudy summer, followed by a short, mild and almost cloudless winter. The climate in the region is dry with strong winds throughout the year. Temperatures range from 19 °C to 36 °C, rarely falling below 18 °C or exceeding 37 °C. The annual average solar radiation is 6.5 kWh/m², with moderate seasonal variations. The sunniest period spans 2 months, from August 31 to November 1, with a daily average of 6.9 kWh/m². September is the brightest month, with an average of 7.1 kWh. Conversely, the darkest period extends from late April to mid-July, with a daily average of 5.9 kWh/m², with June being the darkest month, with an average of 5.6 kWh (Weather Spark, 2023).

Xique-Xique records an average annual rainfall of less than 600 mm, with winter and spring standing out as its driest seasons. Relative humidity varies throughout the year, with summer and autumn being the wettest seasons, as shown in Figure 5 (SFORCIN, 2022).

Figure 5 - Average annual and seasonal rainfall in the State of Bahia.



The region has higher wind speeds during the dry seasons (winter and spring), with an average annual wind speed of 13 km/h. The wind is strongest during the drier months, from May to October, with an average speed above 14 km/h. The wind is weaker during the wetter months, from November to April, with an average speed below 12 km/h. The predominant hourly average wind direction in Xique-Xique is from the east throughout the year (Weather Spark, 2023).

II. EXPERIMENTAL PROCEDURE

2.1 Regional Data Collection

To conduct the study, data were collected through sources such as the Brazilian Institute of Geography and Statistics (IBGE), state agencies and market research. Demographic information was collected on the average number of people per residence in the city of Bahia and subsequently, an additional phase of the research involved the estimation of basic expenses that provides a broad and contextualized view of the residential scenario. This analysis provided a more holistic understanding of the costs associated with maintaining a residence in Xique-Xique.

2.2 Defining the number of solar panels

In designing an efficient photovoltaic system, determining the number of solar modules is an important step, and this process is linked to several factors. First, the capacity of the batteries that will store the energy generated was defined, ensuring the stability and availability of the system during periods without sunlight. The choice of the number of batteries, chosen next, must be carefully considered, taking into account not only the expected energy demand, but also the storage capacity needed to meet eventualities.

In addition, the minimum power required was established and then the appropriate inverter was chosen to convert the energy captured by the solar panels into usable alternating current. Choosing the inverter is crucial to improving the efficiency of the system as a whole. With these settings defined, the ideal number of photovoltaic modules was determined, adjusting it according to the user's specific energy needs and local environmental conditions. Thus, by integrating all these elements, it is possible to obtain a complete and efficient solar system, capable of meeting energy demands.

2.3 Selection of Software for the Study

In the context of the installation, the RETScreen 4 software was chosen because it can evaluate and optimize the technical and financial viability of energy projects. With this, the energy efficiency of the solar and wind systems was determined, taking into account specific parameters. Aspects such as the ideal orientation and inclination of the solar panels, as well as the strategic location of the wind turbines, were considered. The

simulation produced monthly and annual energy efficiency results, and allowed the observation of temperature and wind variations throughout the year.

2.4 Comparison between solar panels and the Vortex Bladeless turbine

The comparative study between the energy efficiency and cost of solar and wind energy systems in a residence in the city of Xique-Xique, in Bahia, was carried out through a graphical analysis made by the authors based on the results of the software used. To this end, the installation processes of both systems were evaluated, taking into account the energy efficiency of each of them and aspects such as the number of inverters and batteries, as well as the costs associated with each type of system.

Energy efficiency was a highlight in the comparison between the systems. The energy conversion rates of each technology were evaluated, taking into account factors such as the electrical energy generation capacity of the residence. It is important to note that the comparison with the Vortex Bladeless turbine was made indirectly, since the turbine is innovative and not included in the system to date. It was compared based on a traditional horizontal turbine and, subsequently, analyzed based on the data from the comparison with the Vortex Bladeless turbine. This analysis therefore allowed us to identify which system presented better energy performance and greater use of available renewable resources.

III. RESULTS AND DISCUSSIONS

According to data from the latest demographic survey conducted by IBGE in 2010, the predominant number of inhabitants per household in Xique-Xique is two individuals. Given this, based on the total daily consumption of a residence, a study of an autonomous system is carried out, in which the dimensioning of the equipment is described in Table 3.

Table 3. Electric load survey of a residence

Devices	Quantity	Voltage (V)	Power (W)	Time in use (h)	Wh/day	Days in use per week	KWh/month
Shower	1	220	6000	0,50	3000	7	90,00
Lamp	10	220	19	5,00	95	7	2,84
TV	1	220	200	5,00	1000	7	30,00
Fridge	1	220	500	24,00	12000	7	360,00
Microwave oven	1	220	1200	0,33	400	7	12,00
Waching machine	1	220	1500	1,00	1500	2	12,00
Air conditioner	1	220	755	8,00	6040	7	181,20
Total			10174	43,83	24035		688,04

The residence under study, with all the items that make it up, has a significantly higher consumption compared to state and national indices. According to data from the Energy Research Company (2012), while the average consumption in Bahia reaches 143.13 KWh/month and in Brazil it is 152.2 KWh/month, the average residence in Xique-Xique has a notable consumption of 688.04 KWh/month. Several factors can influence this difference, such as local climate characteristics, consumption patterns, and the availability of efficient technologies. This discrepancy highlights the need to explore more efficient and sustainable energy solutions, aiming not only to reduce costs for local consumers, but also to contribute to the preservation of the environment.

The analyses performed for solar and wind energy were based on the RETscreen 4 software, which has a climate database referenced by NASA. This study was based on the city of Xique-Xique.

To meet the energy demand of 24,035 Wh/day, 10% was added above this total value, to obtain an oversizing of the inverter. This made it possible to better use the maximum power of the inverter in periods of lower solar radiation, finding a value of 11,191.4 W, choosing the 12KW 3x220 V GoodWe Photovoltaic Inverter, according to the datasheet of the electronic component.

With an estimated autonomy of 2 days, a 12 V battery was chosen, formed by connecting several cells in series, whose voltages add up to 12 V. According to the manufacturer, the battery can be discharged to 60 % of its total capacity, containing 40 % residual charge, which guarantees greater durability. The daily depth of discharge (pu/day) was set at a maximum of 0.20, as lower values extend the battery's useful life: 0.20 (useful life of 4 years). Based on equations (1) and (2) respectively, the following was obtained: C - Capacity (Ah) = 6676.39 and C - Capacity (Ah) = 10014.58.

The largest number was used and the FREEDOM DF4001 battery was chosen, with a capacity of 240 (Ah) in 100 hours. Therefore: Number of batteries = $10014.58/240 = 41.73 \cong 42$ batteries

Using equation (3), knowing that:

- Equivalent hours of full sunlight (Hours/day): According to Weather Spark, July is the month with the highest temperature and 6 hours of full sunlight.
- Power Loss Factor (PPF) = 0.68 according to the chosen 12 V battery.
- FPS - Loss and safety factor: This factor includes the module's generation losses due to manufacturing tolerance, operating temperature, dust, degradation, shadows, misalignments and electrical losses in the battery, controller, installation and uncertainties about the data used and expected consumption. Typical value: 0.8. We have: Minimum Power = 7,363.664 Wp

Analyzing the material of the modules and their characteristics, a model of electrically interconnected crystalline silicon module was chosen, Kyocera KD 135SX – UFSB, with a power of 135 W, according to equation (4) we then have: Number of modules = 55 modules

With this, the location to insert the panels was analyzed. Taking into account the sun throughout the day, the following was chosen: Chosen inclination of 25° and 0° to the south and 180° to the north.

All the analysis done when included in the RETScreen 4 software, obtained an energy efficiency supplied to the load of 8.55 MWh per year, distributed by months in Table 4.

Table 4 - Energy efficiency provided by solar panel load

Months	Daily solar radiation – horizontal kWh/m ² /d	Daily solar radiation – inclined kWh/m ² /d	Electricity supplied to the load
January	5.81	4.97	0.73
February	5.98	5.39	0.66
March	5.66	5.48	0.73
April	5.63	5.94	0.70
May	5.33	6.10	0.73
June	5.29	6.35	0.70
July	5.64	6.70	0.73
August	6.29	6.96	0.73
September	6.68	6.71	0.70
October	6.41	5.89	0.73
November	5.85	5.06	0.70
December	5.74	4.84	0.73
Annual	5.86	5.87	8.55

With this, it is possible to observe through graphical analysis the performance of photovoltaic modules throughout the year, as shown in Figure 5.

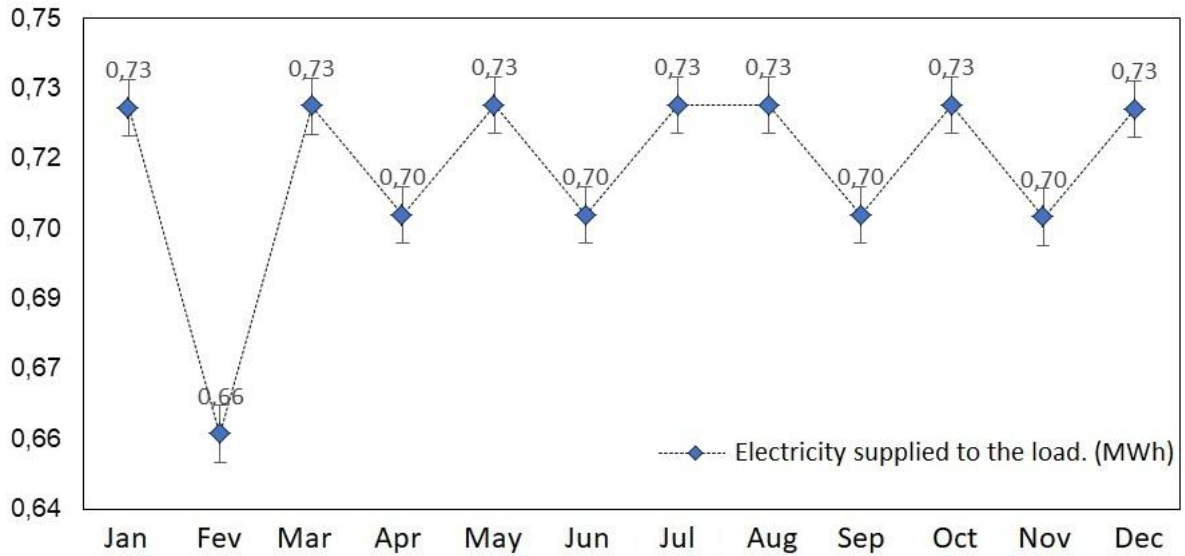
Subsequently, an analysis was carried out for wind turbines. Initially the study was done for a traditional, horizontal turbine, based on Table 5.

Table 5 – Parameters of the traditional turbine used.

Parameters	Small turbine
Height	12 m
Power	100 W
Rotor diameter	8m
Wind shear coefficiente	0,1

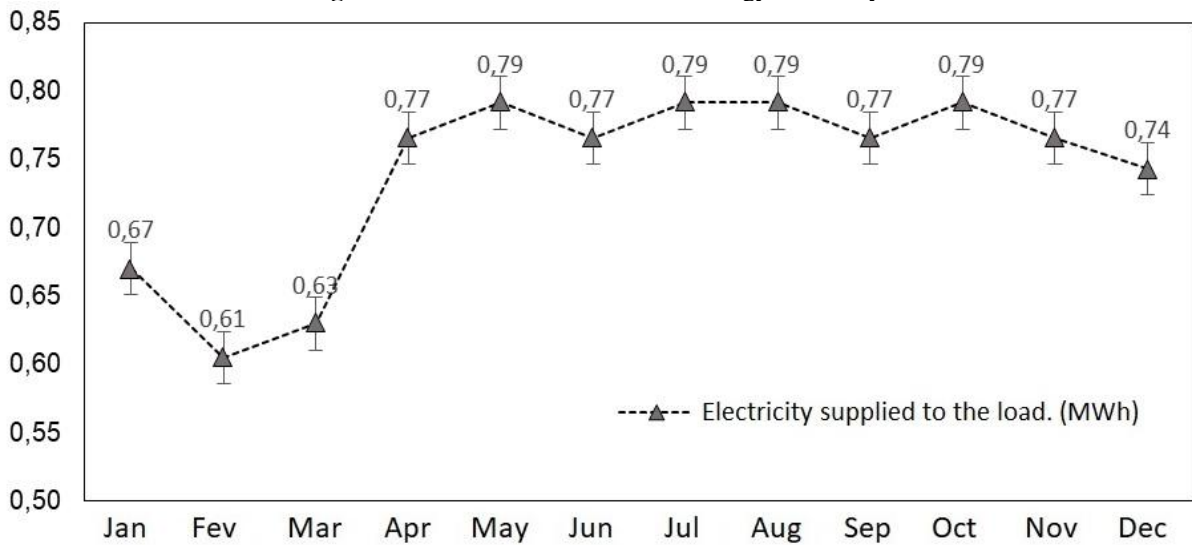
Source: Adapted from Martinello (2015)

Figure 5 – Energy efficiency of photovoltaic panels.



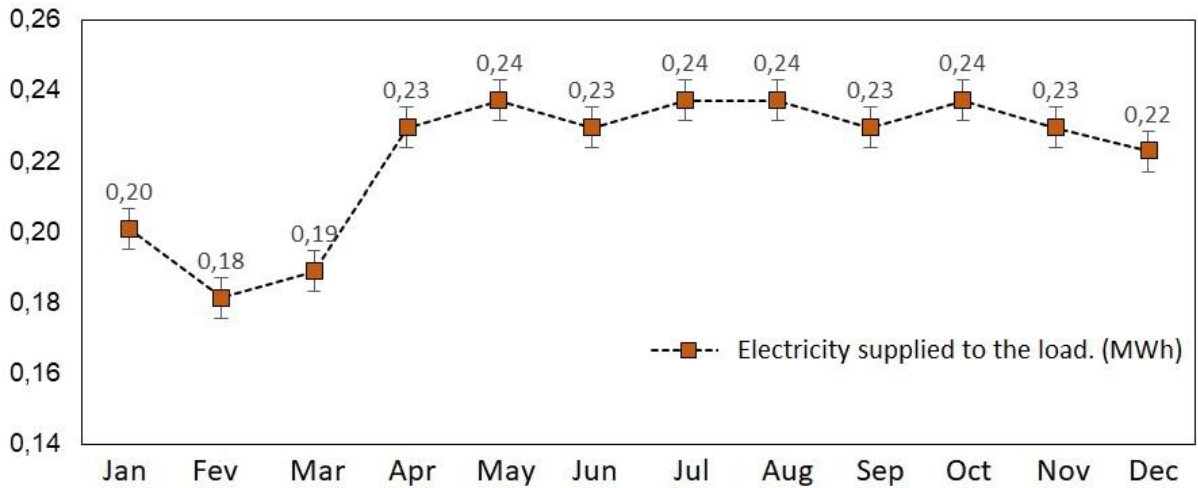
The same daily consumption, batteries and inverter are taken into account in order to obtain the same analysis. For this, the most current wind speeds found on the Weather Spark (2023) website were entered. All this information, when added to the RETScreen 4 program, generated an energy efficiency supplied to the load of 8.88 MWh per year, distributed by months. With this, it is possible to observe through the graphical analysis, the performance of the traditional turbine throughout the year, as shown in Figure 6.

Figure 6 – Traditional wind turbine energy efficiency.



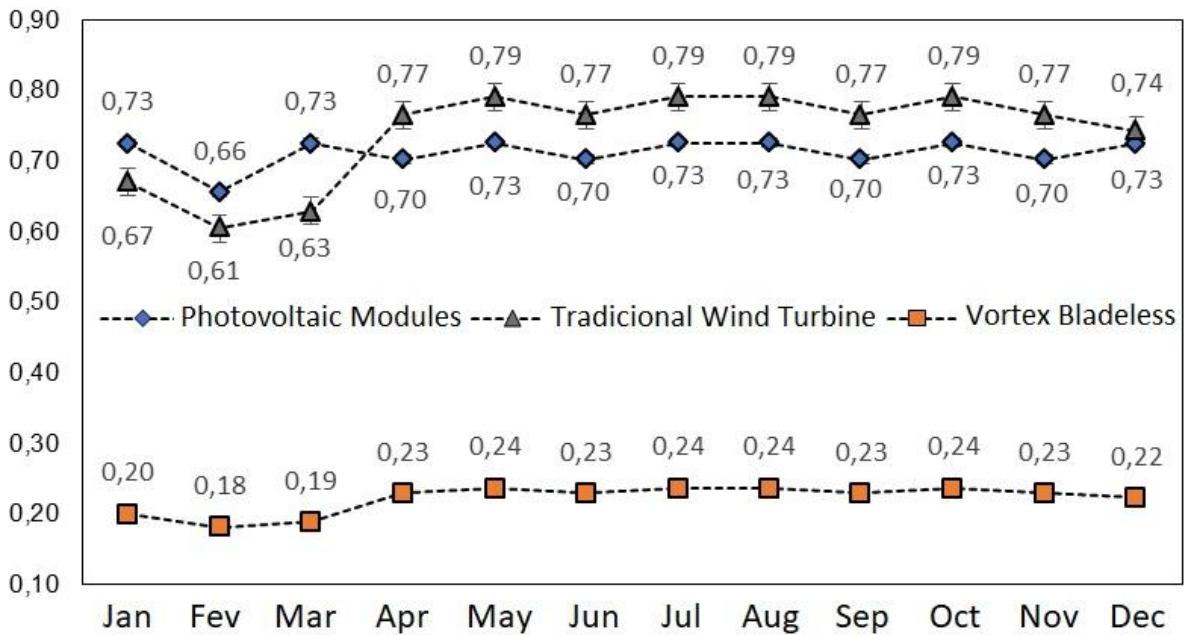
According to Ordoñez and Duke (2019), the Vortex Bladeless Tacoma is equivalent to 30% of the energy efficiency of a small turbine, compared to a traditional model with the measurements of the turbine analyzed. Thus, it is possible to observe through the graphical analysis, the performance of the Vortex Bladeless throughout the year, as shown in Figure 7.

Figure 7 – Vortex Bladeless Wind turbine energy efficiency.



The comparative assessment of the energy efficiency of the sources under study is carried out considering all periods of the year, based on the graph in Figure 8.

Figure 8 – Energy efficiency comparison.



IV. CONCLUSION

After a comparative analysis of energy efficiency in a residence in the city of Xique-Xique, Bahia, between solar panels and the Vortex Bladeless turbine, it was concluded that both technologies have advantages, although with different characteristics. The solar panels, using Kyocera KD 135SX polycrystalline silicon modules due to their low cost, demonstrated superior energy efficiency, with 68.89% more than the Vortex Bladeless. These panels not only offered a reliable and sustainable source of electricity, but also have a relatively simple and effective installation. On the other hand, the Vortex Bladeless turbine, although it stood out as a viable and economically attractive alternative, presenting a 90% improvement in costs compared to solar panels, revealed inferior energy efficiency.

Considering the specific context of Xique-Xique city, we note that the region benefits from both solar incidence and constant wind speeds, making it suitable for an efficient combination of solar and wind energy. In this sense, an integrated approach that combines solar panels and the Vortex Bladeless turbine can be a balanced solution.

It is important to highlight that the choice between solar panels and the Vortex Bladeless turbine, as well as the selection of suppliers for both technologies, is a complex process that takes into account essential factors such as cost, efficiency and installation solutions in each residence. So, the analysis of suppliers plays a crucial role in determining energy efficiency, as each manufacturer presents variations in terms of power and innovation. This differentiation may influence the associated costs, which may be higher than the values initially used in this study. Therefore, careful consideration of suppliers is essential to ensure the optimization of both efficiency and the investment associated with the selected energy solutions.

Conflict of interest

There is no conflict to disclose.

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