Influence of temperature variation on the generation of a photovoltaic system connected to the grid for power generation under field conditions

Influência da variação de temperatura na geração de um sistema fotovoltaico conectado à rede para geração de energia elétrica em condições de campo

Influencia de la variación de temperatura en la generación de uno sistema fotovoltaico conectado a la red para generación de energía eléctrica en condiciones de campo

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Abstract

This experiment aimed to analyze the temperature behavior of photovoltaic modules, with the efficiency of the on-grid photovoltaic system, installed at the State University of West Paraná - UNIOESTE, campus of Cascavel, Paraná. The photovoltaic system consists of two ropes, with a total power of 3.3 kWp. In the first period, it was found that the panel kept clean (Panel 2), during data collection, reached a higher efficiency during the first weeks and practically the same for the last weeks, compared to the dirty panel. Achieve an average efficiency of 13.73% and 14.39%, Panel 1 and Panel 2, respectively. For the second period, the average efficiency of both panels, with inclinations of 21° and 26°, was very close, being 14.25% (Panel 1) and 14.24% (Panel 2). The third period showed a difference in the efficiency of the panels, 13.7% (Panel 1) and 14.54% (Panel 2), with inclinations of 21° and 18°, respectively. The test of means identified that there was a difference between the levels of soiling of the modules, as well as their inclinations of 21° and 18°. As for the 21° and 26° inclinations, there was no significant difference, according to the Tukey Test at 5% significance.
Keywords: Photovoltaic solar system; Photovoltaic modules; Inclination; Dirt; Efficiency.

Resumo

Este experimento teve como objetivo analisar o comportamento da temperatura dos módulos fotovoltaicos, com a eficiência do sistema fotovoltaico on-grid, instalado na Universidade Estadual do Oeste do Paraná - UNIOESTE,

campus de Cascavel, Paraná. O sistema fotovoltaico consiste em duas ropes, com uma potência total de 3,3 kWp. No primeiro período, verificou-se que o painel se manteve limpo (Painel 2), durante a coleta de dados, alcançou maior eficiência durante as primeiras semanas e praticamente a mesma nas últimas semanas, em comparação com o painel sujo. Atingir uma eficiência média de 13,73% e 14,39%, Painel 1 e Painel 2, respectivamente. Para o segundo período, a eficiência média de ambos os painéis, com inclinações de 21° e 26°, foi muito próxima, sendo 14,25% (Painel 1) e 14,24% (Painel 2). O terceiro período apresentou diferença na eficiência dos painéis, 13,7% (Painel 1) e 14,54% (Painel 2), com inclinações de 21° e 18°, respectivamente. O teste de médias identificou que havia uma diferença entre os níveis de sujidade dos módulos, bem como suas inclinações de 21° e 18°. Quanto às inclinações 21° e 26° não houve diferença significativa, de acordo com o Teste de Tukey com significância de 5%.
Palavras-chave: Sistema solar fotovoltaico; Módulos fotovoltaicos; Inclinação; Sujidade; Eficiência.

Resumen

Este experimento tuvo como objetivo analizar el comportamiento de la temperatura de los módulos fotovoltaicos, con la eficiencia del sistema fotovoltaico on-grid, instalado en la Universidad Estadual do Oeste de Paraná - UNIOESTE, campus de Cascavel, Paraná. El sistema fotovoltaico consta de dos ropes, con una potencia total de 3,3 kWp. En el primer período, se verificó que el panel se mantuvo limpio (Panel 2), durante la recolección de datos, alcanzó mayor eficiencia durante las primeras semanas y prácticamente la misma en las últimas semanas, en comparación con el panel sucio. Lograr una eficiencia promedio de 13,73% y 14,39%, Panel 1 y Panel 2, respectivamente. Para el segundo período, la eficiencia media de ambos paneles, con inclinaciones de 21° y 26°, fue muy cercana, siendo 14,25% (Panel 1) y 14,24% (Panel 2). El tercer período presentó diferencia en la eficiencia de los paneles, 13,7% (Panel 1) y 14,54% (Panel 2), con inclinaciones de 21° y 18°, respectivamente. La prueba de promedios identificó que había una diferencia entre los niveles de suciedad de los módulos, así como sus inclinaciones de 21° y 18°. En cuanto a las pendientes 21° y 26° no hubo diferencia significativa, de acuerdo con el Test de Tukey con significación del 5%.
Palabras clave: Sistema solar fotovoltaico; Módulos fotovoltaicos; Inclinación; Suciedad; Eficiencia.

1. Introduction

The growing global energy demand is related to population development and technological and industrial advances, which lead to the acceleration of climate and environmental changes (Kannan & Vakeesan, 2016). One of the solutions found by several countries to reduce environmental impacts, associated with climate change and dependence on fossil fuels, is the use of renewable energy, in which photovoltaic energy stands out (Ferreira et al., 2018).

It is essential for the development of a sustainable energy matrix to improve conversion technologies and use of natural resources. In particular, in Brazil, the use of solar energy is an excellent option to complement the Brazilian electricity matrix, which is predominantly made up of hydroelectric power plants. However, despite the great existing solar potential, the incentive to this technology is still incipient, when compared to other countries that employ and encourage its use (Pereira et al., 2017).

When compared to other conventional energy sources, photovoltaic solar has great long-term potential, being one of the renewable technologies that has developed the most in recent years. With the advancement of technologies and, consequently, gains in specialization, it was possible to obtain a large cost reduction in photovoltaic solar energy, both for production and commercialization (Lacerda & Van Den Bergh, 2016).

In this context, photovoltaic solar energy stands out for its growth worldwide, given its reduced cost compared to other renewable sources, and also for its performance and benefits for society and the environment. In several countries around the world, the incentive to use this renewable source has already been applied in recent years; recently in Brazil, stimuli - such as financing systems - have enabled the expansion and use of this energy source in distributed generation in the country

The interest in solar energy in Brazil became more attractive after Normative Resolution 482/2012 and 687/2015, decreed by the National Electric Energy Agency (ANEEL), which established general conditions for micro and mini generation distributed to power distribution systems, as well as created the energy compensation system (ANEEL, 2012; ANEEL, 2015).

Photovoltaic systems can operate connected to the distribution network, or isolated. The use of each of these options depends on the application or availability of energy resources in the region where the system is installed (Jakoplić et al., 2021). Photovoltaic systems do not produce acoustic or electromagnetic noise, nor do they emit toxic gases or other types of environmental pollution, once installed (Souza, 2016).

Grid connected systems are characterized by being integrated into the public electricity supply system. In this case, where there is no power generation from the photovoltaic system, the consumer uses the utility grid as a source of energy, reducing the credits generated at times when generation was greater than consumption (Tonin, 2017).

The performance of a photovoltaic system is related to parameters external to the photovoltaic module. Photovoltaic cells are influenced by the cover material of the photovoltaic module, the orientation and inclination angle, the type of installation (tracking or stationary), location, temperature of the photovoltaic cell, shading, dust deposition and module dirt (Klugmann-Radziemska, 2015).

The accumulation of dust on the surface of the modules is also a factor that influences the performance of the photovoltaic system. Whenever necessary, deposited dust particles must be removed to improve the incidence of solar irradiance on the photovoltaic cells (Yilbas et al., 2016).

Only a fraction of the solar energy received by the photovoltaic system is converted into electrical energy, and the rest is reflected or converted into thermal energy, raising the temperature of the photovoltaic cells (Medeiros et al., 2021).

The temperature of a photovoltaic module increases as it absorbs solar radiation, causing a decrease in system efficiency, depending on many parameters, such as ambient temperature, wind speed and direction, air pollution, system aging, snow, dirt and shading, installation and weather conditions, module configuration, cell types, thermal properties of the materials used, among others (Jaszczur et al., 2021; Ciulla, et al., 2013).

The voltage of the photovoltaic cell tends to decrease significantly with increasing temperature, while the short-circuit current undergoes a very small, practically negligible increase (Zilles et al., 2012).

The electrical performance of the photovoltaic system has a negative linear correlation with the temperature of the photovoltaic cells. In practical applications, a large part of the solar radiation is absorbed by the photovoltaic modules in the form of heat, which is difficult to be eliminated by natural convection. Increasing the operating temperature of the system results in a decline in electrical efficiency (Singh, 2013; Shan et al., 2014).

External photovoltaic systems, with the increase in solar radiation, the temperature of the panel increases, compromising performance and making the system never work at its maximum power (Shahid et al., 2018). Cell efficiency, open circuit voltage and maximum power point decrease with increasing cell temperature, while short circuit current increases slightly (Shahid et al., 2018; Cotfas et al., 2018).

The research interest was to study the behavior of a photovoltaic system under real operating conditions, evaluating how the slope, temperature and dirt of the photovoltaic modules can influence the solar conversion efficiency of the system. It was observed that the performance of the photovoltaic system has a negative correlation with the increase in temperature, as well as expected. The increase in module temperature resulted in a decrease in electrical efficiency for all studied stations. The inclination of the system is also another factor that influenced the generation of energy, with the ideal inclination varying according to the seasons of the year. In addition, the dirt on the modules represents a negative factor for energy generation, obstructing the passage of solar radiation, consequently reducing energy efficiency. This study provides practical information of a residential photovoltaic system in real operating condition, installed in southern Brazil, providing data for nearby regions with similar climates.

2. Methodology

The experiment was carried out near the facilities of the Alternative Systems Analysis Center (CASA) of the State University of West Paraná (UNIOESTE), campus of Cascavel, Paraná. The geographic location is defined by the coordinates of latitude 24° 59’ South and longitude 53° 27’ West, with an altitude of approximately 781 meters.

The photovoltaic system consists of ten polycrystalline photovoltaic modules from the Risen Solar Technology brand. The module has an efficiency of 17.1% and a maximum power of 330 Wp, totaling 3.3 kWp of installed power (Figure 1).

Figure 1. Photovoltaic system installed at UNIOESTE, campus of Cascavel, Paraná.

Source: Authors.

The modules are organized in two strings with five modules each, being possible to carry out, separately, the evaluation of the generated energy in each string. The photovoltaic modules produce energy in the form of direct current, in this case, as the system is connected to the grid, it is necessary to transform this direct current into alternating current, through an inverter.

The two strings are connected to an inverter to convert the energy generated from direct current to alternating current. The inverter used is Solis's brand, 4 kWp of power.

To measure the global solar irradiance incident on a given plane, a CMP3 pyranometer produced by Kipp & Zonen was used, with a sensitivity of 15.3 μV/W/m². Installed in the horizontal plane, it was necessary to correct the data obtained by the pyranometer to an angle of 21° and, subsequently, to 26° and 16°, values equal to the inclination of the photovoltaic modules. Therefore, a series of equations presented by Duffie and Beckman (2013) was used, considering that the diffuse and ground reflected radiation are isotropic.

Four type J thermocouples, model SMTJ Ø8 mm, Switerm brand, were installed on the back of four photovoltaic modules, to record the temperature of the modules. Another type J thermocouple, used to measure the local ambient temperature, was also installed near the panels.

Since the modules are organized in two strings, it is possible to evaluate, separately, the energy generation of each one. In this sense, the thermocouples were installed in order to record the temperature of two modules of each string, totaling four temperature records, and one record of the ambient temperature.

For data acquisition and storage provided by the pyranometer, CMP3, and thermocouples, a Campbell Scientific CR1000 datalogger was used. The device has been programmed to take a reading every ten seconds and the average is recorded every minute.

Data collection was divided into three periods, considering two factors that affect photovoltaic energy generation: dust deposited on the photovoltaic modules (first period) and the inclination of the photovoltaic modules (second and third period). The first period takes place in the months of February, March, and April, the second period between the months of August and

September, and the third period between October, November, and December of the year 2020.

The first part, the generation of electrical energy and the temperature of each string were evaluated, however, one of them was kept clean during this period. For this, all photovoltaic modules were cleaned, oriented to true North, and inclined to 21° in relation to the horizontal. Then, one of the strings was kept clean (cleaning performed once a week), using only water and a foam squeegee, to avoid damaging the surface of the photovoltaic modules with something more rigid or chemical products, during the collection period data – February 18, 2020, until April 7, 2020.

The second part of data collection is characterized by the inclination of photovoltaic modules. Similar to the first part, only one string changed its inclination, while the other remained in its original position, 21° relation to the horizontal plane.

First, one of the strings had its inclination changed to 26° (maximum value allowed by the inclination device) on August 5, 2020, right after all photovoltaic modules were properly cleaned. The change was maintained until September 22, 2020, totaling seven weeks.

Subsequently, the string that underwent a change in its inclination was modified again, now to 16° in relation to the horizontal (minimum value allowed by the inclination device) on October 13, 2020, and maintained until December 2, 2020, totaling seven weeks.

The energy generation data were obtained through the Solar Man website, as well as the values of power, current and electrical voltage supplied by the system's inverter were stored. In short, the data provided by the website were processed and then the hourly average of energy generation was performed through each string.

The system efficiency was calculated hourly and daily, thus, the horizontal global solar irradiance data (W/m²), obtained by the CMP3 pyranometer and recorded by the CR1000 datalogger, were corrected for the actual slopes of the modules.

To relate the temperature of the photovoltaic modules with the efficiency of each string, the hourly average temperature of the modules was taken, considering only while it was producing energy, that is, night periods were not used.

The hourly average temperature of the photovoltaic modules was organized into intervals, with an amplitude of 10 °C, starting with the lowest recorded value. Then, the hourly average of the system efficiency was performed to then correlate the module temperature data with the respective efficiency, with the same time interval. This process was repeated for the three data collection periods.

The first period of the experiment – the evaluation of the dirtiness of the photovoltaic modules in power generation – aimed to quantify the efficiency of each photovoltaic panel, one of which was kept clean during data collection. The collection interval was between 02/18/2020 and 04/07/2020, totaling 7 weeks. The data from 02/26/2020 was discarded, as the inverter did not record data on that day.

For the second and third period of the experiment, the influence of the slope of the modules with the generation of electrical energy was evaluated. Three different slopes at different periods, starting with a slope of 21° and 26° for the second period, 08/05/2020 to 09/22/2020, and a slope of 21° and 18° for the third period, 13/ 10/2020 to 12/02/2020. The days 10/25/2020 and 10/26/2020 were discarded due to the same problem that occurred in the first period, the inverter did not record the data.

For all periods of the experiment, the variables measured were the global solar irradiance in the horizontal plane (later corrected for the same inclination as the system was in each period), the external temperature of the environment, temperature of the photovoltaic modules, rainfall in the experimental area and the energy generation of each photovoltaic panel. Comparing the electrical energy with the solar radiation incident on the surface of each module.

To verify if there was a statistical difference between the efficiencies of the photovoltaic panels, for three different periods, the Analysis of Variance was used. However, if the null hypothesis is rejected, it will be necessary to apply a mean test to verify if there is a significant difference between the treatment means, the Tukey Test, at 5% significance.

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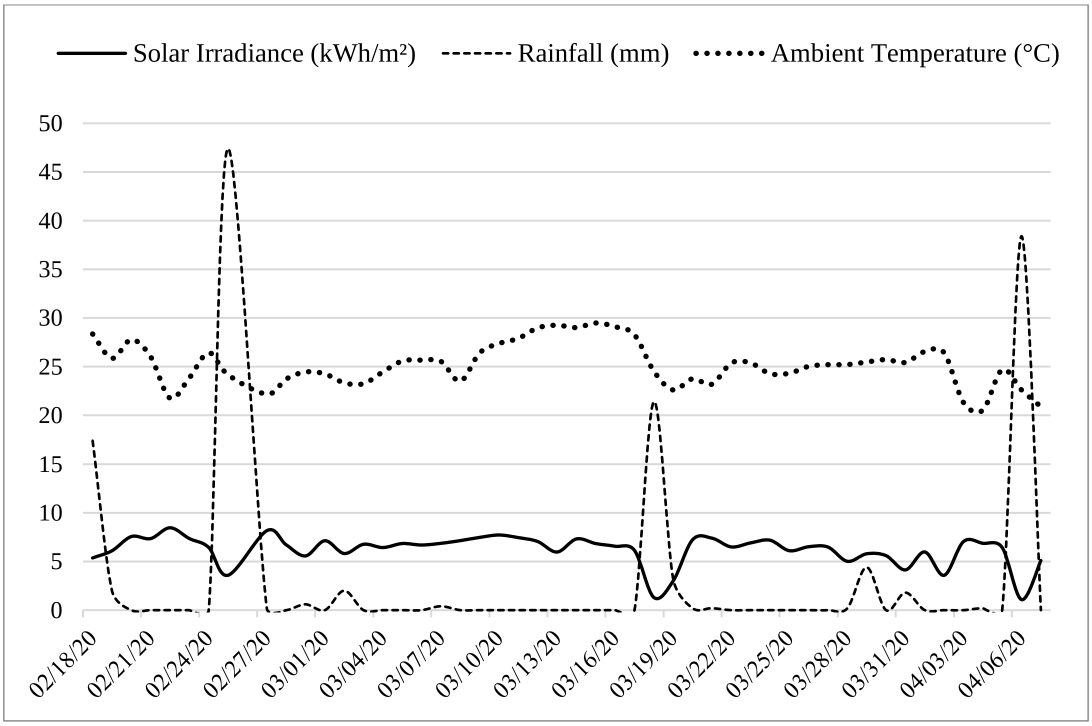
3. Results and Discussion

3.1 Solar irradiance behavior

According to Figures 2, 3 and 4, a behavior that can be perceived in practically the entire period of data collection was highlighted, the relationship between the levels of solar irradiation and the temperature of the environment. As a rule, the decrease in solar irradiance results in a drop in the temperature of the environment, following the same reasoning, the increase in solar radiation results in an increase in temperature.

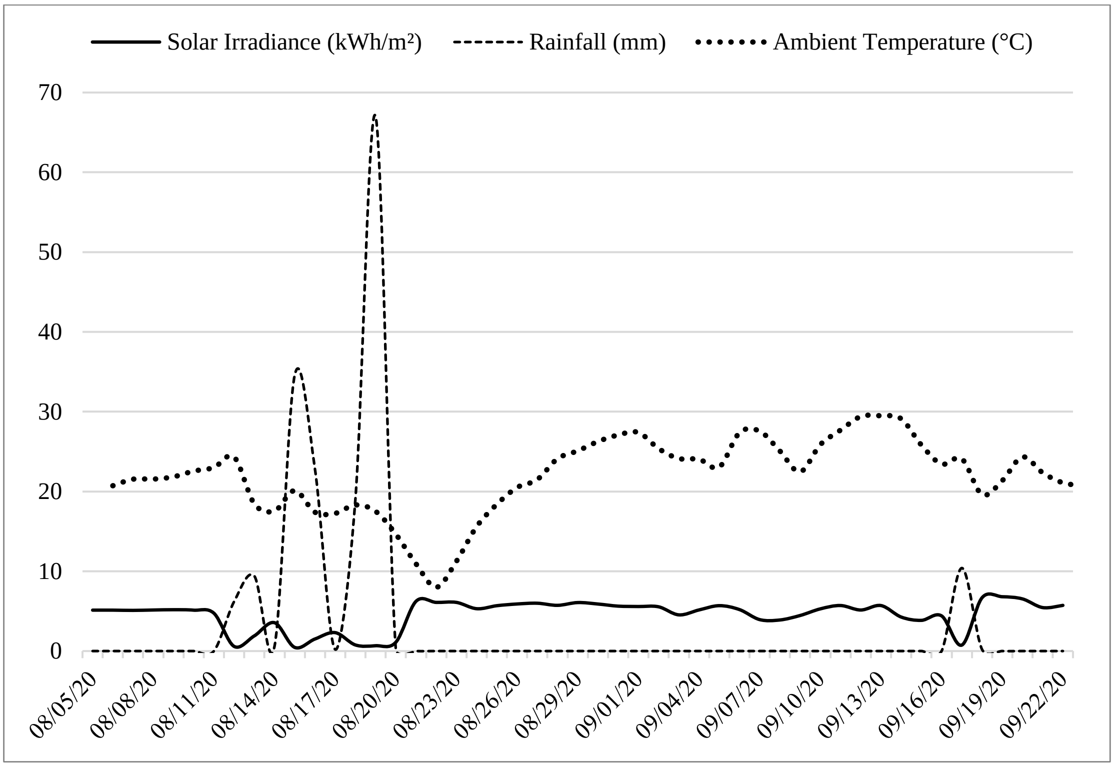
In addition, as can be seen in Figures 2, 3 and 4, there are cases in which the temperature of the environment rises with the fall of solar irradiance, and then it decreases when the irradiance suffers a very large drop, as it happened between days 11/06/2020 and 11/09/2020.

Figure 2. Ambient temperature, solar irradiation, and rainfall between 02/18/2020 and 07/04/2020.



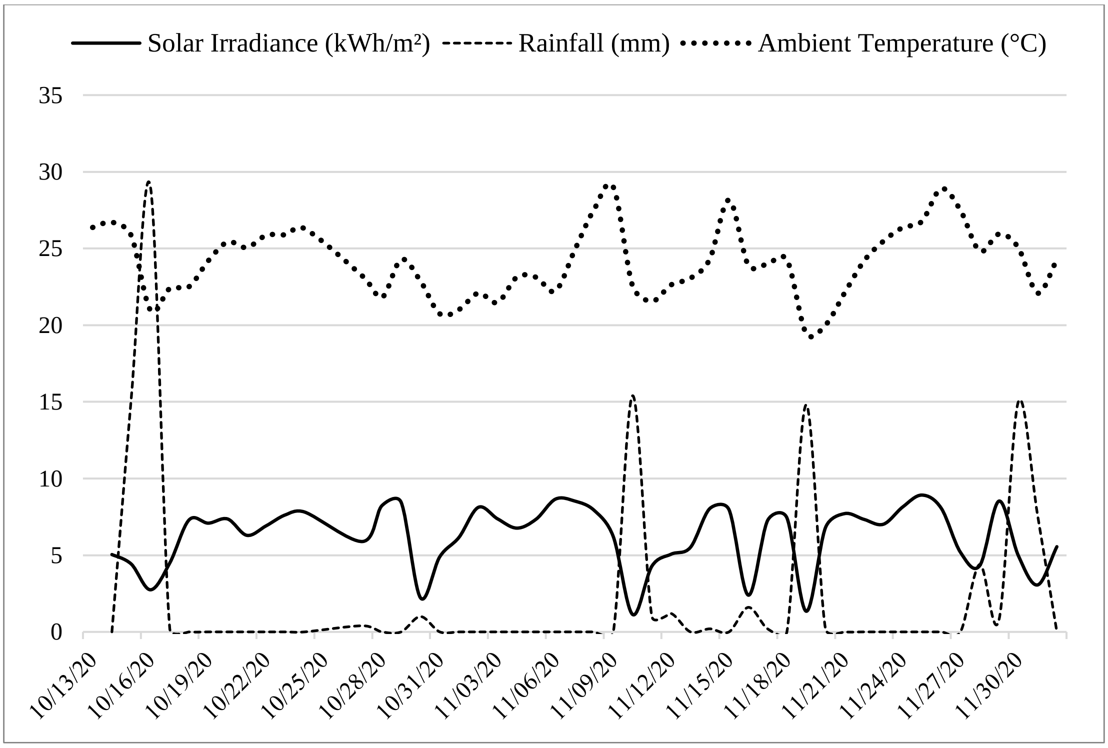
Source: Authors.

Figure 3. Ambient temperature, solar irradiation, and rainfall between 08/05/2020 and 09/22/2020.



Source: Authors.

Figure 4. Ambient temperature, solar irradiation, and rainfall between 10/13/2020 and 12/02/2020.



Source: Authors.

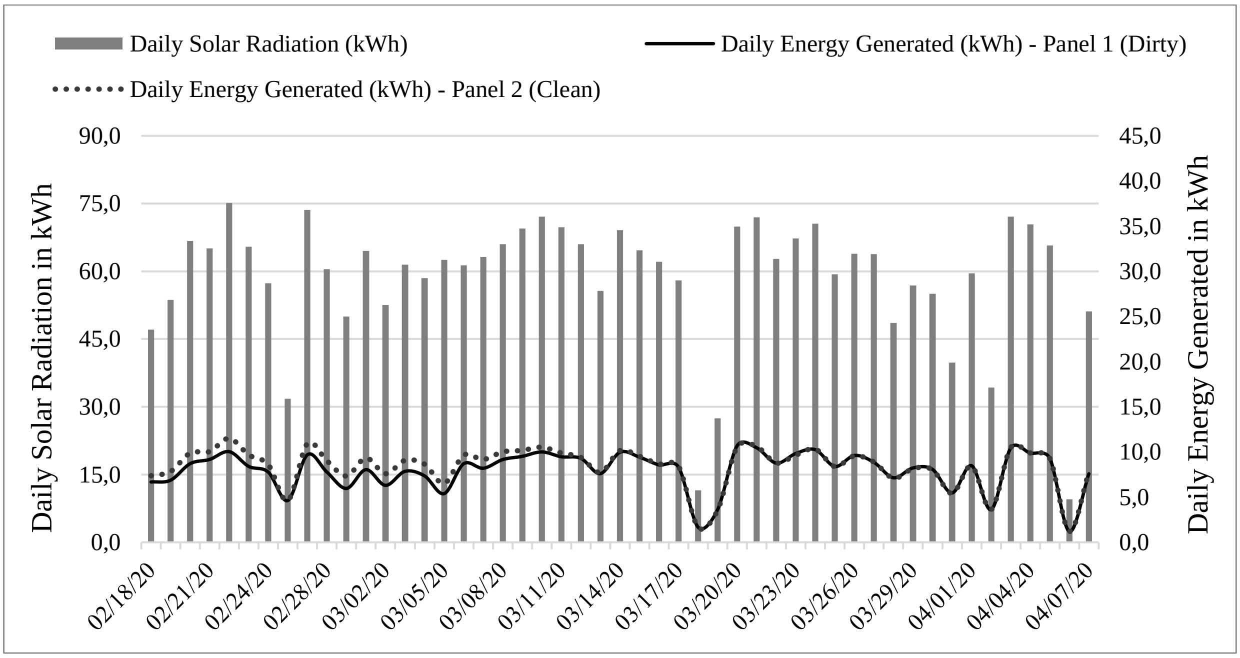
This phenomenon is related to the sun's rays that are trapped between the clouds and the Earth's surface. Thus, when the sky is cloudy, solar radiation decreases, however, the imprisonment of solar rays intensifies the greenhouse effect of the environment, resulting in an increase in the ambient temperature, remaining high until it rains and decreasing again with the rain. After rain, clouds dissipate solar radiation and (consequently) the temperature of the environment increase.

According to Deceglie et al. (2020), light, or the amount of solar radiation, and high temperature are characteristics that influence the efficiency of the system, causing faster degradation than expected, when the system is exposed to high values of these phenomena. This degradation can vary from module to module, even if the modules are from the same manufacturer, same model and made with the same materials.

3.2 Analysis of energy generated by photovoltaic panels with different levels of dirt

From Figure 5, data on daily electricity generation, in kWh, as well as daily solar radiation, in kWh, for the first period can be observed.

Figure 5. Daily solar radiation and energy generated by photovoltaic panels, first period.



Source: Authors.

It can be seen that the energy generated by Panel 2 is superior to Panel 1, for the first days of data collection, and after 03/14/2020 the energy generation of both panels was very close. After 03/14/2020, there was a reduction in the energy generated, and solar radiation, which is related to the occurrence of rain close to 03/18/2020. Afterwards, the power generation of both modules was very close, considering the rain may have caused the superficial cleaning of much of the dust deposited on Panel 1.

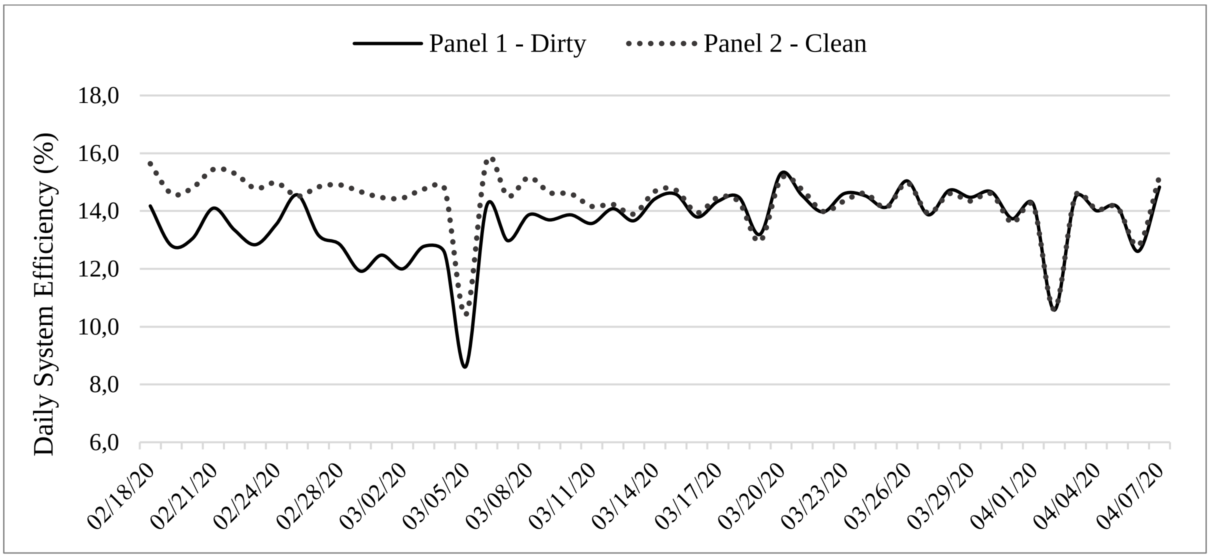
According to Micheli et al. (2020), the accumulation of dust negatively affects the performance of photovoltaic systems and can be corrected through cleaning methods. Optimizing cleaning frequency is essential to minimize dirt losses and, at the same time, costs. Santhakumari and Sagar (2019) add that natural cleaning occurs with the presence of rain, being more appropriate in places where precipitation is abundant and for photovoltaic modules that have a higher slope.

Dust particles accumulated on the surface of the module obstruct the path of solar radiation reaching the photovoltaic cells, reducing the amount of energy produced by the photovoltaic system (Dantas et al., 2020).

Figure 6 shows the daily efficiency of the photovoltaic panels over the first period of data collection, with the averages being 13.73%, Panel 1, and 14.39%, Panel 2.

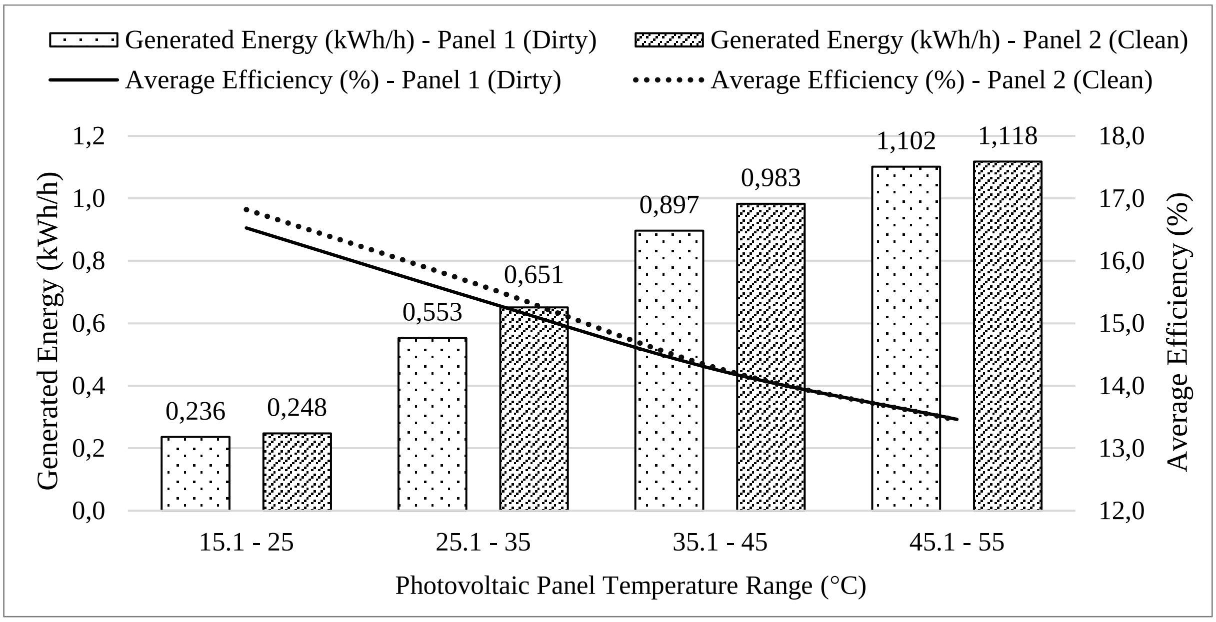
In Figure 7, it is possible to see how the panel temperature influences the efficiency of the photovoltaic system. Higher temperature values are associated with lower efficiency values, as well as higher efficiency values are associated with lower temperature values.

Figure 6. Daily efficiency of photovoltaic panels, first period.



Source: Authors.

Figure 7. Average efficiency and energy generated by photovoltaic panels, first period.



Source: Authors.

Although the higher temperature range produces a greater amount of energy, it is also responsible for the lower efficiency, which could be optimized with a cooling system, or heat exchange, for the photovoltaic modules.

A large amount of solar radiation reaching photovoltaic cells is converted into heat, increasing cell temperature, and decreasing efficiency. Heat can be extracted from the cell through phase change materials, installed behind the photovoltaic panel, which help to dissipate heat. Khanna, Reddy and Mallick (2017) and Sharaf, Huzayyin and Yousef (2021), demonstrate that photovoltaic systems integrated with phase change material are more productive, since they manage to dissipate the

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temperature more easily, increasing the solar conversion efficiency of the cells photovoltaic.

As noted by Rahman, Hasanuzzaman and Rahim (2015), Ali (2020) and Rostami et al. (2020), photovoltaic modules with cooling systems have greater efficiency, compared to modules without any heat exchange system.

An alternative to reduce the temperature of photovoltaic cells is the use of hybrid photovoltaic systems. The performance of hybrid photovoltaic systems, which use a heat exchanger, is superior to conventional systems. This technology consists of using the residual heat from the photovoltaic system to heat some refrigerant fluid, creating thermal energy, and increasing the system's conversion efficiency (Jordan et al., 2021; Medeiros et al., 2021). The change in module temperature and the decrease in incident radiation, resulting from the deposition of dust on the modules, affect the energy efficiency of the photovoltaic modules.

In short, the temperature of Panel 1 (dirty) was higher than that of Panel 2 (clean), in every week of the first period, as shown in Table 1. The dust deposited on the modules affected not only the amount of solar radiation it fails to absorb, but also the energy that is absorbed by the dust, resulting in a small increase in module temperature.

Table 1. Average temperature of photovoltaic panels, between 02/18/2020 and 04/07/2020.

Temperature (°C)	Weeks						
	1	2	3	4	5	6	7
Panel 1 (Dirty)	36.84	34.28	37.25	40.41	35.01	35.69	32.81
Panel 2 (Clean)	35.72	33.29	36.06	38.99	33.57	34.13	31.38

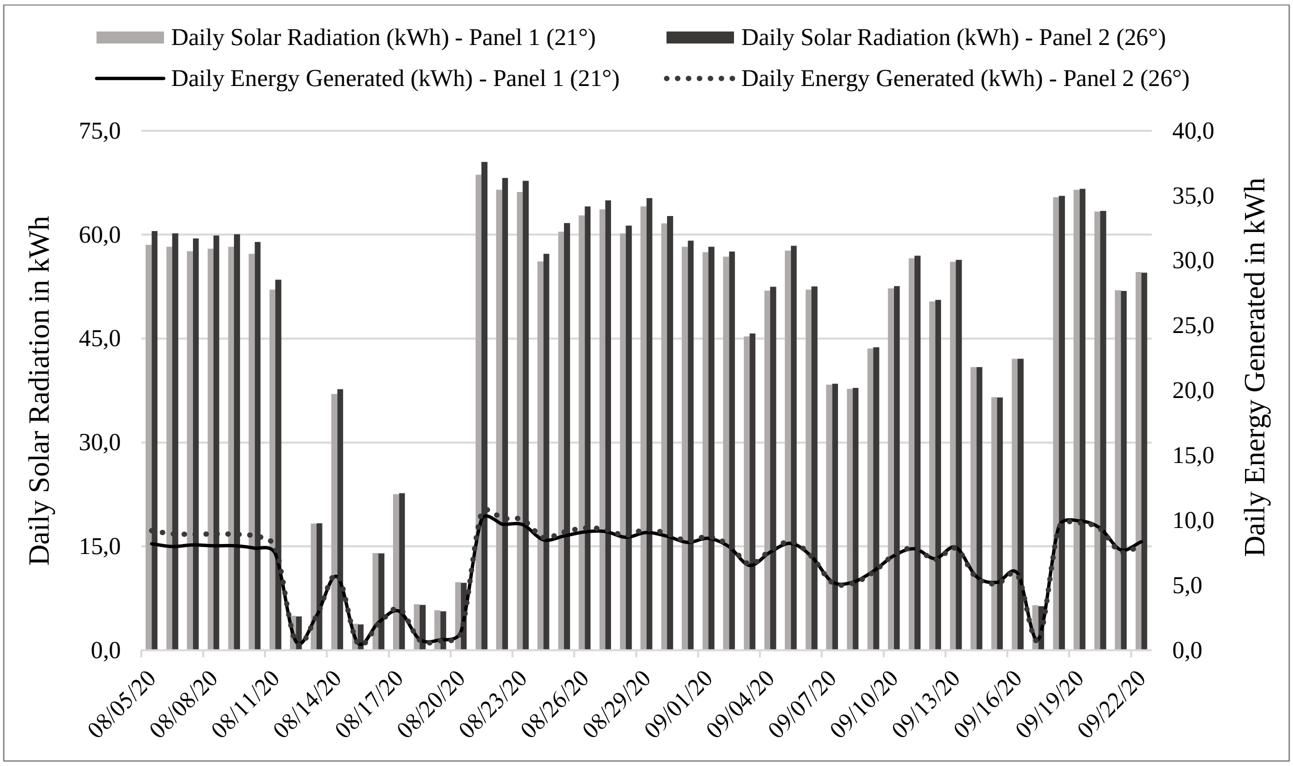
Source: Authors.

3.3 Analysis of the energy generated by photovoltaic panels with 21° and 26° inclinations

Energy generation data will be presented for the second collection period, between 08/05/2020 and 09/26/2020, for the two photovoltaic panels (Figure 8). During this period, the energy generation of the photovoltaic panels was evaluated, with an inclination of 21° in relation to the horizontal (Panel 1). While Panel 2 underwent a change in its inclination to 26°.

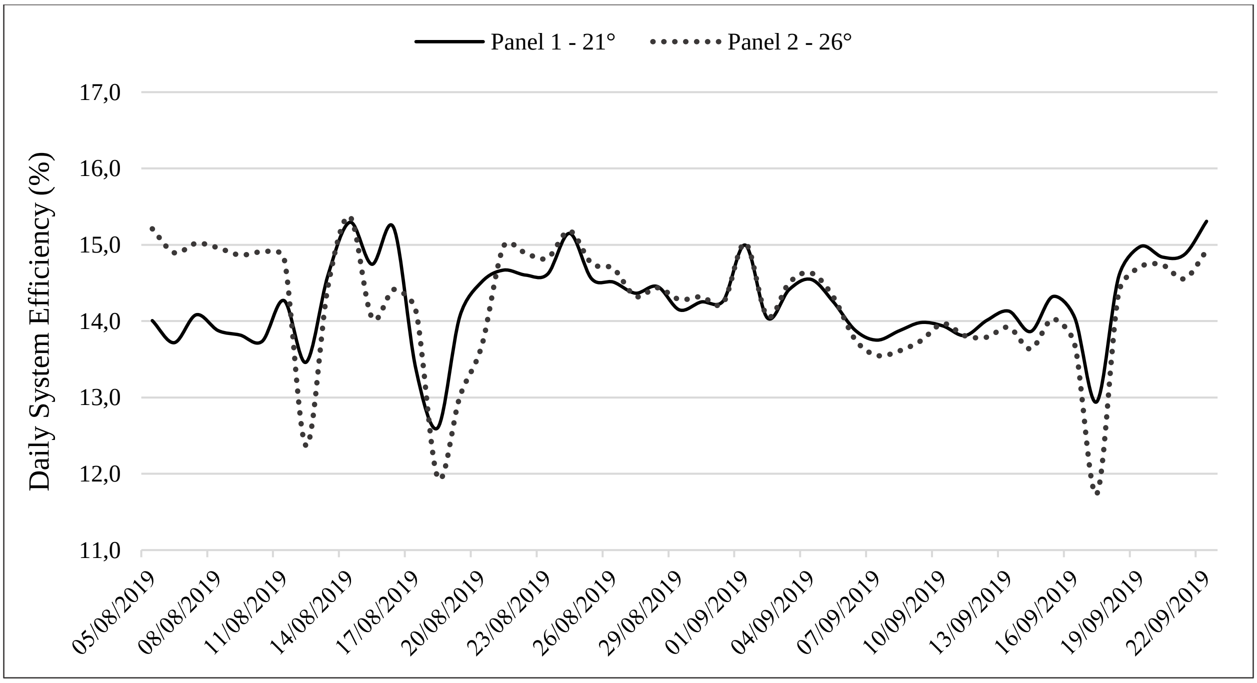
Note that the solar radiation that both panels receive is different, given their different inclinations. According to CRESESB (2018), for the month of August, the greater the slope of the plane, the greater the values of solar irradiation. For the inclination of 21° and 26 °C, it has 5.02 and 5.11 kWh/m².day; In September, for slopes of 21° and 26°, solar irradiation is practically the same in the two values, 4.72 and 4.73 kWh/m².day, respectively. Figure 9 shows the daily efficiency of photovoltaic panels over the first period of data collection.

Figure 8. Daily solar radiation and energy generated by photovoltaic panels, second period.



Source: Authors.

Figure 9. Daily efficiency of photovoltaic panels, second period.

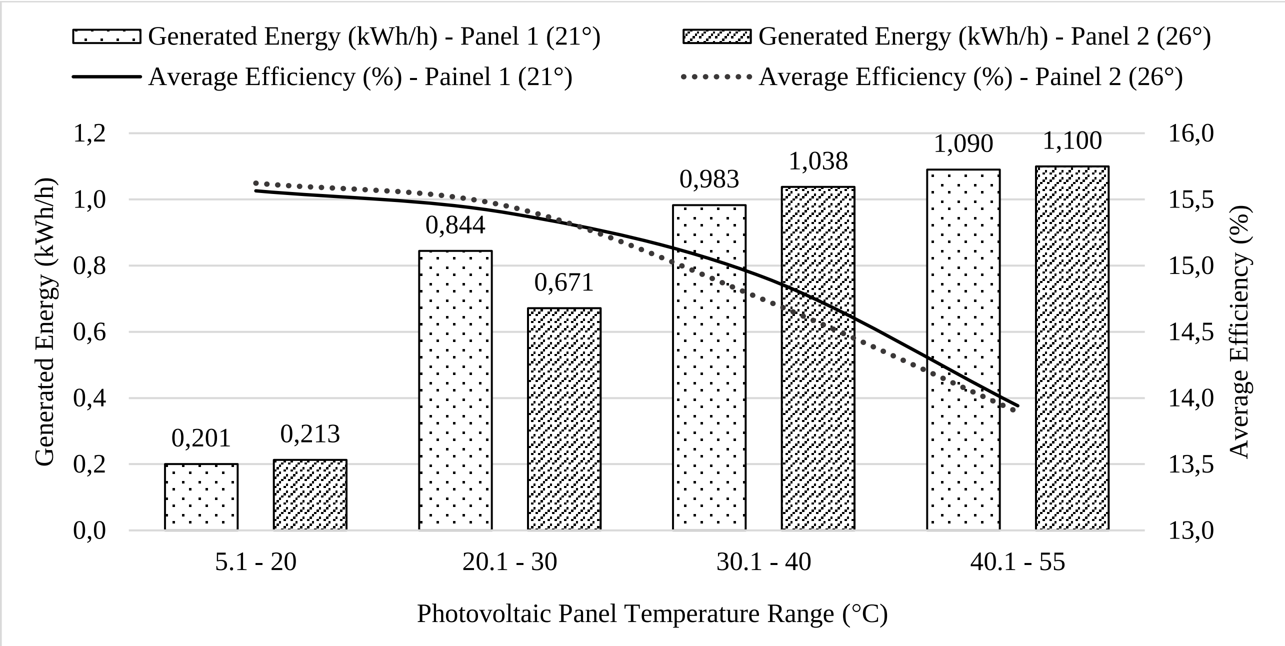


Source: Authors.

Panel 2 showed greater efficiency for the first days of August, following some unstable values during the days of 08/11/2020 to 08/21/2020, due to the rainy periods on these dates. Then, the two panels showed a similar efficiency, with Panel 1, with less inclination, surpassing Panel 2 in the last days of September.

The efficiency of the photovoltaic panels and the energy generated by them, for the second period, is shown in Figure 10. In the second period, as shown in Figure 10, Panel 2 presented a higher energy generation, for the temperature ranges from 5.1 °C to 20 °C, 30.1 °C to 40 °C and 40.1 °C to 55 °C. In the range of 20.1 °C to 30 °C, Panel 1 presented a higher energy generation, 0.8444 kWh/h, than Panel 2, 0.671 kWh/h. It is also noticed, for the second period, that higher energy generation values are associated with higher temperatures of photovoltaic panels. However, these temperatures are related to lower system efficiencies.

Figure 10. Average efficiency and energy generated by photovoltaic panels, second period.



Source: Authors.

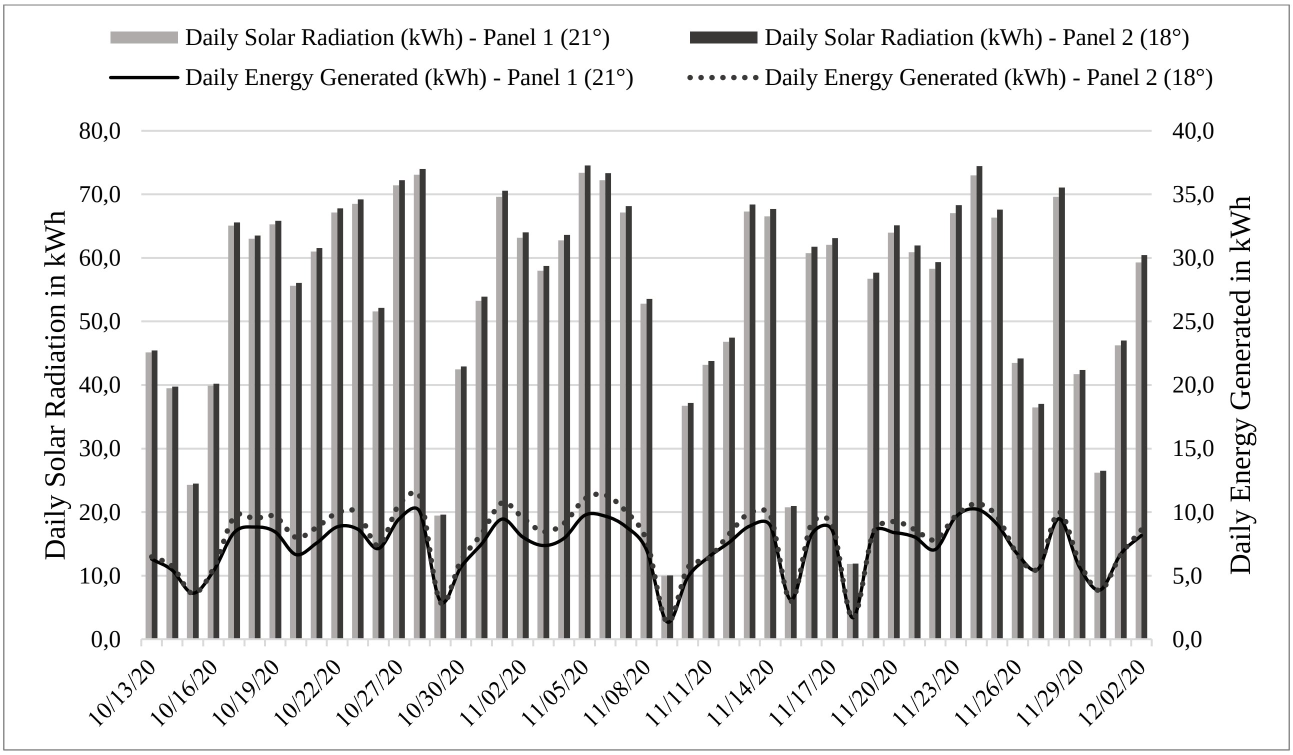
3.4 Analysis of the energy generated by photovoltaic panels with 21° and 18° inclinations

In the third period (similar to the second period) the generation of a photovoltaic panel with an inclination of 21° in relation to the horizontal (Panel 1) was evaluated. While Panel 2 underwent a change in its inclination to 18°. Power generation data dated between 10/13/2020 and 12/02/2020 was presented.

Figure 11 shows energy generation, in kWh, and daily solar radiation, in kWh, for the third and last period.

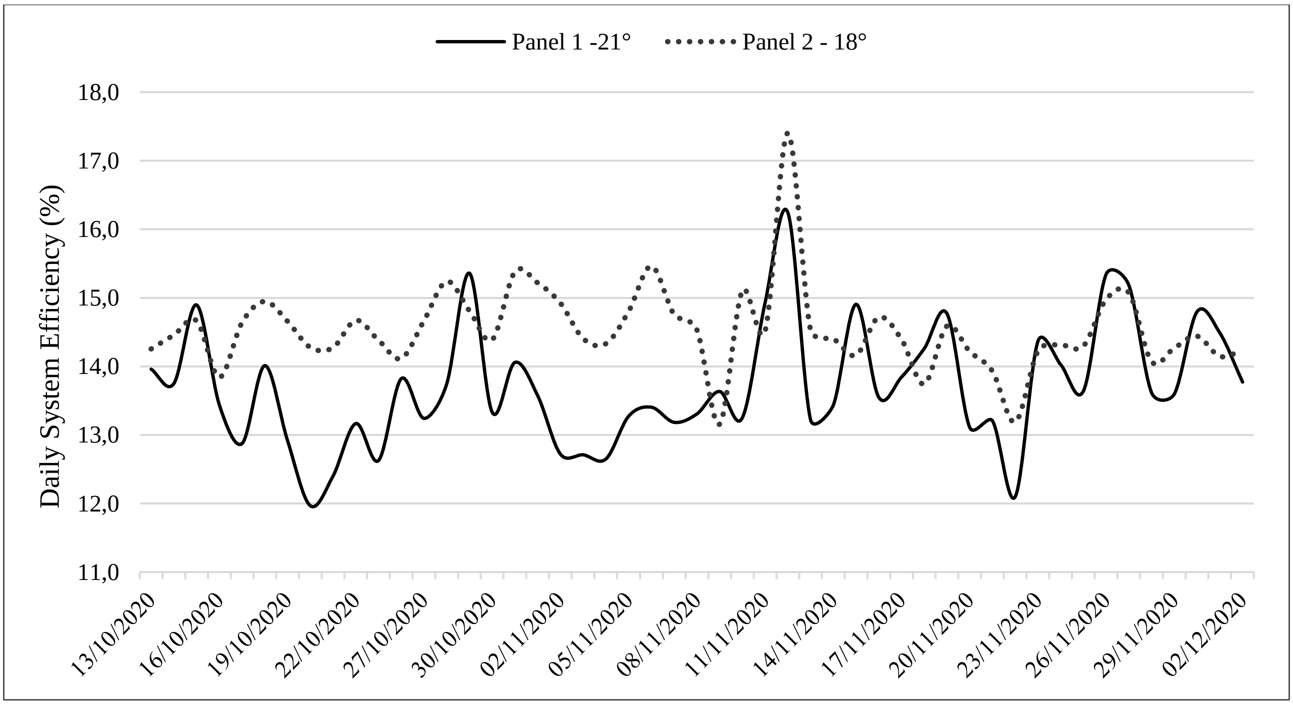
The highest values of solar radiation are associated with the panel with the lowest horizontal inclination (Panel 2). As for the energy generated by the panels, Panel 2 produced a greater amount of energy for most of the period. Figure 12 shows the daily efficiencies of photovoltaic panels for the third period.

Figure 11. Daily solar radiation and energy generated by photovoltaic panels, third period.



Source: Authors

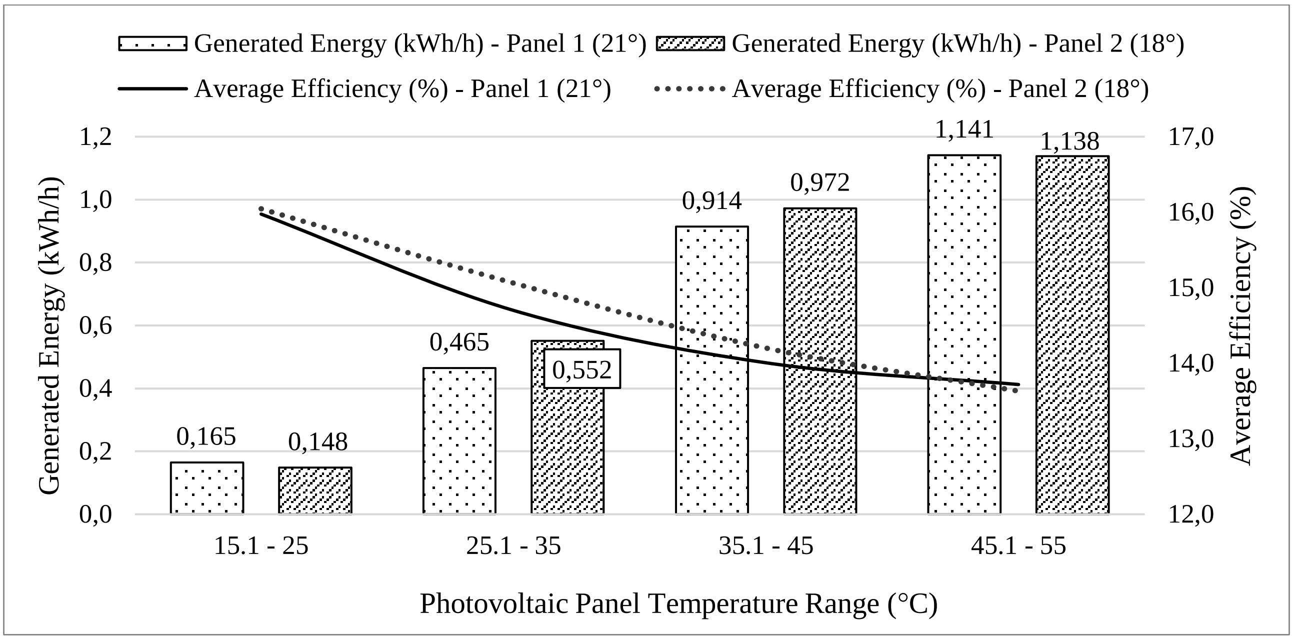
Figure 12. Daily efficiency of photovoltaic panels in the third period.



Source: Authors.

The last days of October showed greater efficiency for Panel 2, with only two days when Panel 1 was superior. In November, there was an alternation between the efficiency presented by the panels. However, Panel 2 was more efficient in this period. Figure 13 presents the energy efficiency and generation data for the third period.

Figure 13. Average efficiency and energy generated by photovoltaic panels, third period.



Source: Authors.

In Figure 13, it is possible to identify that the highest energy generation is related to the highest temperature range, 45.1 °C to 55 °C, with values of 1.141 and 1.138 kWh/h, for Panel 1 and 2, respectively.

As already mentioned for the first and second periods, the module efficiency is low for high temperatures and high for low temperatures.

3.5 Statistical analysis

Through the hypothesis test, the daily efficiency averages of both panels were compared to verify the difference between them. The average test applied was the Tukey Test, with 5% significance. The Tukey test results for the first, second and third periods are shown in Tables 2, 3, and 4, respectively.

Table 2. Average daily average efficiency values between clean and dirty panels for the period between 02/18/2020 and 04/07/2020. * Means followed by the same letter in the column do not differ by Tukey test at 5% significance level.

Treatments	Averages (%)	Results *
1 - Panel 1 (Dirty)	13.732	A
2 - Panel 2 (Clean)	14.395	B

Source: Authors

For the first period, the average for the first treatment, Panel 1, is different from the second treatment, Panel 2. That is, the dirt variable affects the system efficiency, according to the Tukey Test, performed with a significance of 5%.

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Table 2. Average daily average efficiency values between clean and dirty panels for the period between 08/05/2020 and 09/22/2020. * Means followed by the same letter in the column do not differ by Tukey test at 5% significance level.

Treatments	Averages (%)	Results *
1 - Panel 1 (21°)	14.252	A
2 - Panel 2 (26°)	14.247	A

Source: Authors

For the second period, the average of the first and second treatment is not statistically different. Despite showing small differences in efficiencies over this period, Panel 1 and 2 do not differ from each other, that is, statistically both treatments are equal, according to the Tukey Test at 5% significance.

Table 3. Average daily average efficiency values between clean and dirty panels for the period between 10/13/2020 and 12/02/2020. * Means followed by the same letter in the column do not differ by Tukey test at 5% significance level.

Treatments	Averages (%)	Results *
1 - Panel 1 (21°)	13.708	A
2 - Panel 2 (18°)	14.535	B

Source: Authors.

For the last period, the average of the first treatment (Panel 1) is different from the second, Panel 2. Therefore, the slopes of 21 °C and 18 °C are different from each other, that is, the slope variable 21 °C affects the system efficiency differently from the slope variable 18 °C, according to the Tukey test, with a significance of 5%.

4. Conclusion

During the first period, 02/18/2020 to 04/07/2020, the dirt levels of the modules were evaluated, the panel kept clean during the data collection interval, Panel 2, showed greater efficiency for the first four weeks of experiment. Then, in the last three weeks, the efficiency of both panels remained close until the end of the period. The average efficiency for the period was 13.73 and 14.39% for Panel 1 and 2, respectively.

According to the statistical analysis of the first period, it was possible to observe that the variable dirtiness or the deposition of dust on the modules affects the efficiency of the photovoltaic system.

As for the second period of the experiment, 08/05/2020 to 09/22/2020, the panel with an inclination of 21°, Panel 1, had an average efficiency very close to Panel 2, with an inclination of 26°. The average efficiency of Panel 1 and 2 was 14.25% and 14.24%, respectively.

At this stage, it is important to emphasize that there was no statistical difference between the two inclinations, for that period of data collection. In other words, if the data collection was done at another station, the result could be different, since the amount of incident solar radiation varies according to the seasons of the year. For this, it is necessary to analyze a larger amount of data for the same slopes and different periods.

For the third period, 10/13/2020 to 12/02/2020, there is an average efficiency of 13.7% and 14.54%, for Panel 1 (21st) and Panel 2 (18th), respectively. The panel with the lowest slope had a higher average efficiency for the period, considering that for lower slopes, in this period, the average daily solar irradiation is higher. According to the statistical analysis for this period, the variable 21° inclination affects the efficiency of the system differently than the variable 18° inclination.

In the three periods, the increase in temperature results in a decrease in the energy efficiency of the system. The photovoltaic system produces more energy the higher the levels of solar irradiation, although at that time the temperature of the photovoltaic cells is higher, reducing the system's efficiency. In this sense, it is interesting to use cooling or heat exchange systems to optimize energy generation, since the maximum energy production occurs when the system has a higher temperature.

Although module temperature has a great influence on power generation efficiency, it is not the only variable that affects power generation. Other factors, such as slope and dust, also have an influence, although less, on energy generation.

The greater energy generation of the system is associated with a greater amount of solar radiation, however, at this time, the system efficiency is not the highest registered, due to the high temperature of the modules.

In this sense, the intention of the research was to demonstrate how temperature affects the performance of a real system installed in southern Brazil. Controlling the operating temperature of a photovoltaic system is not an easy task, especially for large systems or systems that have already been installed. The differential of this research is to present the consequences that the increase in temperature has on the photovoltaic system, seeking to inspire more research and technological advances in the area, aiming to increase the efficiency of photovoltaic systems

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