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Improving the efficiency of photovoltaic generation by adapting to meteorological elements

Mejora de la eficiencia de la generación fotovoltaica adaptándose a los elementos meteorológicos

Melhoria da eficiência da geração fotovoltaica por meio da adaptação aos elementos meteorológicos

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Abstract

The production of clean electricity, which does not harm environmental systems, has been one of the main global priorities in recent times. The range of ultraviolet radiation, sent through sunlight, which can be captured by photovoltaic cells and transformed into electrical energy, makes the sun the most promising source to supply the electrical needs of human beings. The climate is of considerable importance in capturing solar energy, as the efficiency of a cell system is directly related to local climate conditions. This paper aims to analyse the influence of meteorological elements on the efficiency of photovoltaic energy generation and its climatic effect. The methodology is based on measuring the generation of electricity through photovoltaic cells, compiling meteorological elements and panel temperature, studying the relationship between electricity generation using photovoltaic cells and other parameters, and surveying parameters to improve the efficiency of clean energy generation. The results show a relationship between the generation of electricity through photovoltaic cells and the other parameters, providing an average generation 11% higher in wind directions between 330 and 360° at the study site, as well as enabling an alternative to reduce of up to 5.3% of the emission of greenhouse gases through the expansion of photovoltaic energy generation and reduction of energy generation by hydroelectric and thermoelectric plants, which are currently positioned as the largest sources in Brazil.

Keywords: Photovoltaic, Solar energy, Climate and environment, Meteorological elements, Greenhouse gases.

Resumen

La producción de electricidad limpia que no dañe los sistemas medioambientales ha sido una de las principales carreras mundiales de los últimos tiempos. Los niveles de radiación ultravioleta, enviada a través de la luz solar, que pueden ser captadas por células fotovoltaicas y transformar la luz en energía eléctrica, hacen del sol la fuente más prometedora para satisfacer las necesidades eléctricas de los seres humanos. El clima tiene una importancia considerable a la hora de captar energía solar, ya que la eficiencia de un sistema celular está directamente relacionada con las condiciones climáticas locales. Este trabajo tiene como objetivo analizar la influencia de los elementos meteorológicos en la eficiencia de la generación de energía fotovoltaica y su efecto climático. La metodología se basa en la medición de la generación de electricidad mediante celdas fotovoltaicas, en la recopilación de elementos meteorológicos y temperatura del panel; en el estudio de la relación entre la generación de electricidad mediante células fotovoltaicas y el resto de parámetros y en el estudio de los parámetros para la mejora de la eficiencia de la generación de energía limpia. Los resultados muestran una relación entre la generación de electricidad a través de células fotovoltaicas y el resto de parámetros, proporcionando una generación promedio un 11% mayor en direcciones del viento entre 330 y 360° en el sitio de estudio, además de permitir una alternativa de reducción de hasta 5,3 % de la emisión de gases de efecto invernadero a través de la expansión de la generación de energía fotovoltaica y la reducción de la generación de energía por centrales hidroeléctricas y termoeléctricas, que actualmente se posicionan como las mayores fuentes de Brasil.

Palabras clave: Fotovoltaica, Energía solar, Clima y medio ambiente, Elementos meteorológicos, Gases de efecto invernadero.

Resumo

A produção de eletricidade limpa, que não agride os sistemas ambientais, tem sido uma das principais corridas globais dos últimos tempos. As faixas de radiação ultravioleta, enviadas através da luz solar, que podem ser captadas pelas células fotovoltaicas e transformar a luz em energia elétrica, fazem do sol a fonte mais promissora para suprir as necessidades elétricas do ser humano. O clima tem considerável importância na captação de energia

solar, pois a eficiência de um sistema celular está diretamente relacionada às condições climáticas locais. Este artigo tem como objetivo analisar a influência dos elementos meteorológicos na eficiência da geração de energia fotovoltaica e seu efeito climático. A metodologia baseia-se na medição da geração de energia elétrica por meio de células fotovoltaicas, na compilação de elementos meteorológicos e temperatura do painel; no estudo da relação entre a geração de energia elétrica por meio de células fotovoltaicas e os demais parâmetros e no levantamento dos parâmetros para melhoria da eficiência da geração de energia limpa. Os resultados mostram uma relação entre a geração de energia elétrica através de células fotovoltaicas e os demais parâmetros, proporcionando uma geração média 11% maior nas direções do vento entre 330 e 360° no local de estudo, além de possibilitar uma alternativa de redução de até 5,3 % da emissão de gases de efeito estufa através da expansão da geração de energia fotovoltaica e redução da geração de energia pelas usinas hidrelétricas e termelétricas, que atualmente se posicionam como as maiores fontes do Brasil.

Palavras-chave: Fotovoltaica, Energia solar, Clima e meio ambiente, Elementos meteorológicos, Gases de efeito estufa.

Introduction

Global warming and clean energy production are important concerns related to climate and the environment. The lack of investment, combined with the lack of information and practical projects on the part of public authorities, justifies the slow progress in the conquest of clean energies.

The increase in global temperature is exacerbated by anthropogenic actions that disrupt the planet's natural greenhouse effect, primarily due to rising greenhouse gas emissions. This is caused by the burning of fossil fuels in thermoelectric plants, the decomposition of organic matter left over from the cutting of trees and the carbon present in the soil flooded by hydroelectric plants, among other emission sources.

The energy generated by the sun, an inexhaustible source on the timescale of planet Earth's existence, in its two main functions of heat and light, is undoubtedly one of the most promising energy alternatives for providing the energy necessary for human development. When talking about energy, it should be remembered that the sun is responsible for the origin of virtually all other energy sources on Earth (Hayat *et al.*, 2018). Atmospheric factors generally observed in the production of solar energy are cloudiness, air humidity and ambient temperature, but the availability of solar radiation, which is the incident energy on the earth's surface, is also influenced by the inclination of the planet in relation to the sun that varies during the day, month and year (ANEEL, 2008).

The duration of sunlight varies according to the region of the planet and time of year, specifically mentioning the issue of the solstices that occur at the North Pole, when on December 21st there may even be no sun exposure, or on June 21st, when it can reach

up to 24 hours of sun exposure (Raza *et al.*, 2019).

The first studies on the photovoltaic effect were observed in 1839 and improved with the use of other materials. The first significant advances in these studies occurred between the 1930s and 1950s of the last century, with the development of photovoltaic cells composed of silicon crystals, which form the basis of current cells (Wolfe, 2018).

The photoelectric effect is a physical process of the element that converts sunlight into electrical energy, and the light energy absorbed by the photovoltaic cell is transferred to its atoms and electrons. These electrons are released from the component atoms of the semiconductor material, allowing for the electric current to flow through in an ordered manner (Hanifi *et al.*, 2018).

Photovoltaic modules are a set of encapsulated photovoltaic cells, whose purpose is to protect the cells from the weather, mainly from air humidity (Kholod *et al.*, 2018).

Pure photovoltaic generation is one that does not involve any other form of electricity generation. Since the system generates electricity only during sunny hours, autonomous or off-grid systems are equipped with accumulators that store energy for periods without sunlight, which take place every night, and during rainy or cloudy periods. Accumulators are batteries sized according to the autonomy of the system. Conventional off-grid power systems for charging battery banks require a charge controller with Maximum Power Point Tracking (MPPT) technology (Jain *et al.*, 2021).

According to the National Electric Energy Agency (ANEEL, 2018), Brazil has an installed solar generating plant capacity of

1,797,580 kW, which represents 1% of the total power of projects in Brazil. However, the number of solar photovoltaic generating centres is 2,273 units, representing approximately 32% of the total number of installed projects, second only to thermoelectric plants.

Regarding the effective participation in the generation of electricity in the Brazilian electrical system, solar energy has evolved in recent years, with 5.7% in 2016, 7.2% in 2017, and 8.3% in 2018. That is, investments in new generating units have been increasing (ANEEL, 2018).

However, according to Matin *et al.* (2020), only 33.33% of the light energy incident on photovoltaic cells is absorbed for the generation of electricity; that is, the generation efficiency of photovoltaic cells is still quite low and influenced by temperature, solar irradiance and, consequently, by meteorological elements. Despite this, few studies evaluate the meteorological variables that are related to the efficiency of electric power generation.

Climatic conditions play a crucial role in solar energy generation, as the excess or lack of specific phenomena can impact energy capture. A climate with high humidity and no wind can generate excessively hot conditions near the cells, which impairs energy production, and, in addition, humidity can create precipitation and clouds that cover up and make it difficult to absorb solar radiation. Wind is one of the key elements, as it moves air masses, pushing moisture and clouds and cooling the photovoltaic system (Navntoft *et al.*, 2019).

This study is justified by the excellent opportunity for research work to assess the influence of meteorological elements on the efficiency of electricity generation by photovoltaic cells, aiming to enable the increased participation of solar power plants in electricity generation. With this objective in mind, among other subjects, the primary sources of electricity generation, the respective greenhouse gas emissions and how meteorological elements can affect the generation of energy by photovoltaic cells will be analysed.

Methodology

For the development of research and analysis of the influence of meteorological elements on the efficiency of electricity generation using photovoltaic cells, the study was divided into the following stages: measurement of electricity generation using photovoltaic cells; compilation of meteorological elements and panel temperature; relationship between the generation of electricity through photovoltaic cells and the other parameters, and parameters for improving the efficiency of clean energy generation.

Study area

The study was carried out in the city of Itajaí (Figure 1), located on the north coast of the state of Santa Catarina (Latitude 26° 55' 51" S and Longitude 048° 41' 05" W), on the right bank of the mouth of the Itajaí-Açu river, in the southern region of Brazil.



Figure 1 - Location of the Municipality of Itajaí.

Source: Map generated from Interactive Map information - GeoSEUC / Unofficial basemap, © OpenStreetMap contributors.

Measurement of electricity generation using photovoltaic cells

The measurement of local electricity generation was conducted from December 2022 to April 2023. For this measurement, a solar energy generator kit with photovoltaic cells, model CS6U-325P, manufactured by Canadian Solar, was used. It was installed in the Northwest direction (282° NW).

The kit was attached to the Sanches prototype meteorological station (2020), with wind direction (HMC-5883 sensor), wind speed (Hall sensor - US-1881), relative humidity (HDC-1080 sensor), atmospheric pressure and temperature sensors (BMP-180), as well as UV sensors ML8511, Type K Thermocouple Temperature Sensor of the

solar cell and data transmission via RS485 communication cable to USB with reading software installed.

The set, comprising mechanical and electrical-electronic structures, was installed in a free area on a roof, approximately 12 meters above the ground.

The electro-electronic structure is composed of an XTRA4210N-XDS2 battery charge and discharge controller and 40A flow current with

MPPT (Maximum Power Point Tracking) technology, together with a bank of 03 Model 12MN105 batteries, the Model IP2000-22 inverter module and the protection system with circuit breakers, earthing and lightning protection devices.

Figure 2 demonstrates the layout scheme formed by the photovoltaic cell system, weather station and protection devices.

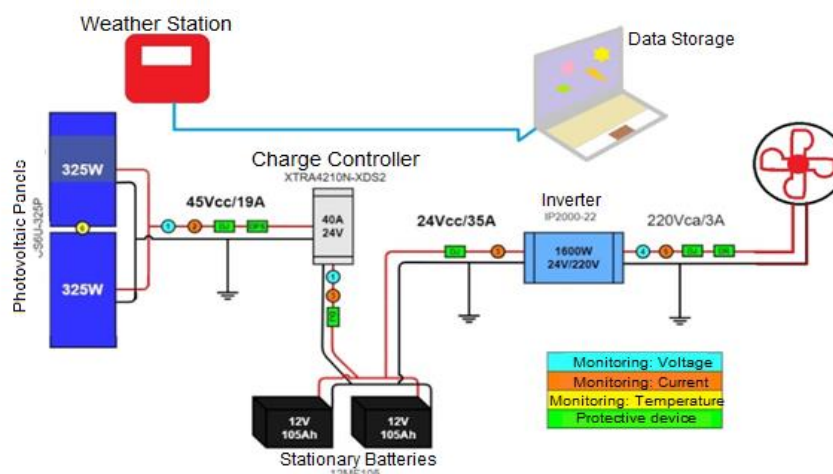


Figure 2 - Sensor installation scheme.

Source: Author.

The power generation set was installed and later calibrated by checking the voltage and current at the input and output of the controller using a multimeter (ET-1002 Minipa). This verification ensured that the voltage (37.0 V) and current (8.0 V, 78 A) were adequate, and consequently, power was generated (325 W). The system operates off-grid (i.e., it is not connected to the official energy distributor's network) and is connected to consumer equipment with approximately 500W of power during the entire period of energy generation. The reading of the generated voltage (V), current produced (A), and calculated power (W) was performed every 10 minutes using the XTRA4210N-XDS2 charge controller, which is available in real time on a display and in LandStar B software (LS-B).

Subsequently, the voltage, current, and power reading data were correlated with the meteorological elements and panel temperature.

Compilation of meteorological elements and panel temperature

The meteorological station performed readings of meteorological elements, including wind speed and direction, relative humidity, atmospheric pressure, air temperature, UV radiation, and panel temperature, synchronised with the reading of the charge controller (electricity) every 10 minutes.

The meteorological station utilised an electronic prototyping platform featuring free hardware and a single-board microcontroller (Arduino) that employs the C++ programming language. This platform generated a database of the parameters above.

Relationship between the generation of electricity through photovoltaic cells and the other parameters

After measuring and compiling the data obtained in C++ and LS-B (Embedded) programming languages, Table 1 was formatted, along with correlation graphs for discussion and analysis of the influence of

meteorological elements on energy generation.

In this step, the power generated by the panel was correlated with meteorological elements (wind speed and direction, relative humidity, atmospheric pressure, temperature, and

ultraviolet radiation) and panel temperature to assess the efficiency of the photovoltaic cells in generating electric energy. Such correlations, as well as basic statistics, were obtained using Minitab, with support from Spearman's Rho method.

Table 1 - Relationship between the generation of electricity through photovoltaic cells and the other parameters.

DT	H	GER	PT	T	RH	UV	WS	WD	AP
d/m/y	h:m:s	W	°C	°C	%	Index	m/s	°	mmHg

Where: DT = Date, H = Time, GER = Generation, PT = Panel Temperature, T = Ambient Temperature, RH = Relative Humidity of Air, UV = Ultraviolet, WS = Wind Speed, WD = Wind Direction, AP = Atmospheric Pressure,

Source: Author.

The analysis first considered the average generation of the four quadrants of the wind direction (WD), between 0 and 360°, of the third quartile (above 175 W of photovoltaic energy generation) and, subsequently, it was possible to identify more specifically the wind directions (330-360°) that had the highest mean power generation for the third quartile. From these data, correlations were made between the variables wind speed, relative humidity, atmospheric pressure, temperature, radiation (UV) and panel temperature.

Parameters for improving the efficiency of clean energy generation

Through the interpolation of the relationship of the parameters, the hypothesis of use was generated in relation to the installation position and the meteorological elements to obtain the best efficiency of the photovoltaic cells, providing the reduction of the use of electric energy generated by hydroelectric and thermoelectric plants and, consequently, predicting their influence on the environmental impact and the generation of greenhouse gases (GHG).

The effect of improving the efficiency of clean energy generation on the environment was measured through a survey of the possible reduction of hydroelectric plants and by the decrease in fuel consumption (oil, biomass and coal) in thermoelectric plants and, consequently, the emission of GHG.

For the evaluation of the reduction of GHG emissions in this study, three scenarios were proposed (Table 2), in addition to the current scenario. The scenario categorised as current is based on the percentage of electricity generation in Brazil in 2018. The other scenarios were determined with gradual reductions in the percentage of use of hydroelectric (hydraulic) and thermoelectric (biomass, oil and coal) plants. Based on the proposed scenarios, GHG emission reductions were calculated using the emission factors for each emission source.

To estimate CO₂ emissions in hydraulic, wind, natural gas, oil, coal and nuclear energy generation, the emission factors estimated by Miranda¹ (2012) were considered.

The biomass and solar emission factors were obtained from the Low Carbon Study for Brazil² - Land Use, Land Use Change and Forests by Soares Filho *et al.* (2010) and the Covenant of Mayors for Climate and Energy³ by Neves *et al.* (2016), respectively (Table 3). For the case of energy in hydroelectric plants, Life Cycle Assessment studies were considered that encompass stages of construction, generation, and emissions from reservoirs, as these have significant emissions and characterise the operation phase of the plant. Additionally, the total installed capacity of electricity-generating sources in Brazil is 164,187 MW.

Table 2 - Proposed scenarios for analysis of greenhouse gas emissions (%).

Percentage of energy generation by type of source									
Scenario	Hydraulics	Biomass	Wind	Natural gas	Oil	Coal	Nuclear	Solar	Total
Current (2018)	63.7	9.0	8.8	8.0	6.1	2.2	1.2	1.0	100
1	63.2	8.8	8.8	8.0	6.0	2.0	1.2	2.0	

2	62.6	8.7	8.8	8.0	5.9	1.8	1.2	3.0
3	62.0	8.6	8.8	8.0	5.8	1.6	1.2	4.0

Source: ANEEL, 2018

Table 3 - GHG emission factors from generation sources.

	Hydraulics ¹	Biomass ²	Wind ¹	Natural Gas ¹	Oil ¹	Coal ¹	Nuclear ¹	Solar ³
Factor (gCO _{2eq} /kWh)	86	1580	16	518	829	1144	14	50

Source: Author.

The methodology for calculating carbon emissions for energy generation sources (E_{GHG}) is based on the installed energy production capacity (CP_{PLANT}) and the GHG emission factor (F_{GHG}), and the calculation can be represented by Equation 1:

$$E_{GHG} = (CP_{PLANT} \times F_{GHG}) \quad (1)$$

Where:

E_{GHG} - Estimate of GHG generation (ton CO_{2eq})

CP_{PLANT} - Installed Energy Production Capacity (kWh)

F_{GHG} - GHG emission factor (gCO_{2eq}/kWh)

To calculate the reduction in the area of the hydroelectric reservoir due to the decrease in generation through this source, Equations 2 and 3 are used.

$$E_{GHG \text{ at}} = (E_{GHG} \times A_{RES \text{ CUR}}) \quad (2)$$

Where:

$E_{GHG \text{ at}}$ - GHG generation in hydroelectric plants for the total flooded area (ton CO_{2eq});

E_{GHG} - GHG emissions ton CO_{2eq} per km²;

$A_{RES \text{ CUR}}$ - Total reservoir area in the current scenario (km²).

$$R_{ARES} = (A_{RES \text{ CUR}} - A_{RES \text{ SCEN3}}) \quad (3)$$

Where:

R_{ARES} - Reduction of hydroelectric reservoir area (km²);

$A_{RES \text{ CUR}}$ - Area of the hydroelectric reservoir in the current scenario (km²);

$A_{RES \text{ SCEN3}}$ - Hydroelectric reservoir area in scenario 3 (km²).

Results and discussions

Measurement and relationship of electricity generation with other parameters

Figure 3 shows scatter plots between power generation and wind direction in four different situations. One can observe the increasing trend of generations as the wind direction approaches the fourth quadrant (Figure 3a). By filtering the data for the third quartile of generation, that is, where the highest generation of energy occurs, it is also possible to perceive the increasing trend of the data (Figures 3b and 3c), which makes it possible to observe a higher average generation of energy in the wind direction of 330 - 360° (Figure 3d).

Table 4 shows the average energy generation (general data) of 100.18 W, and Table 5 shows the energy generation correlations with the other parameters, with the most significant values of UV and panel temperature, 0.483 and 0.442, respectively.

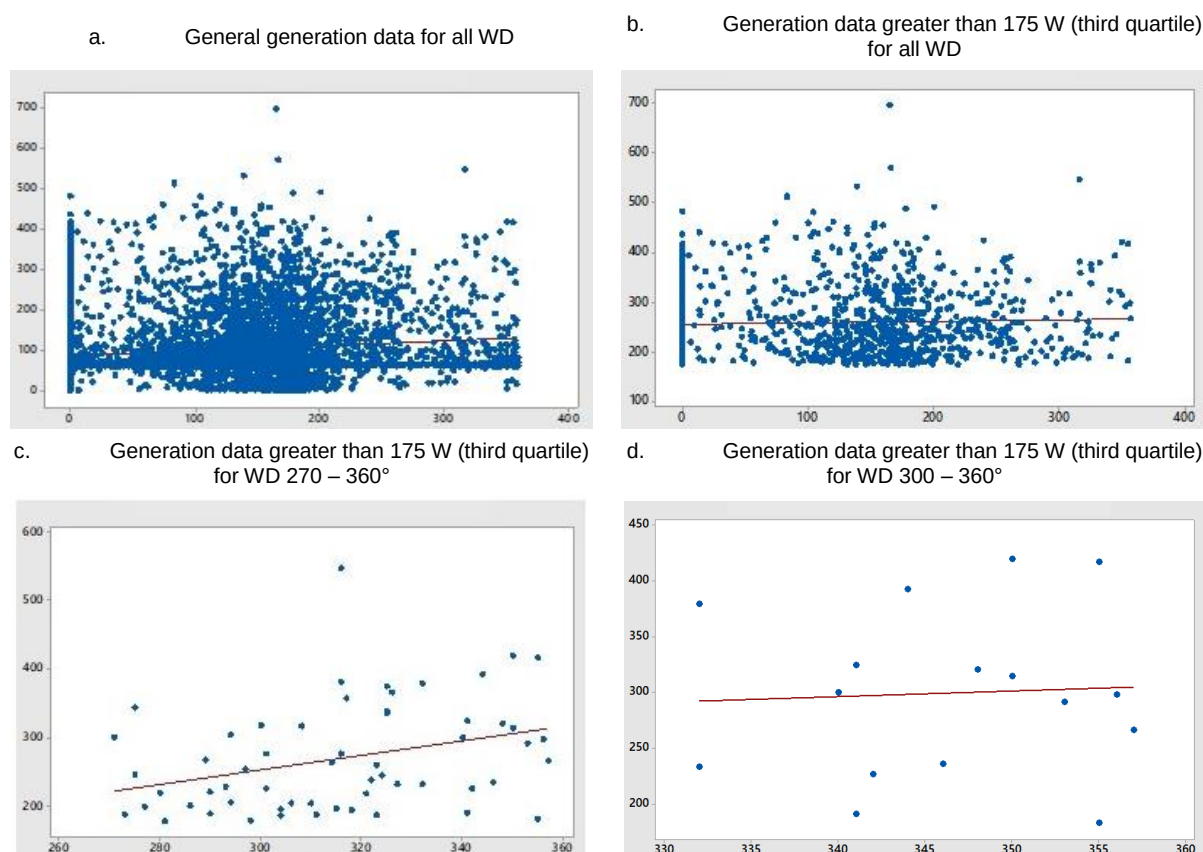


Figure 3 - Scatter charts with trend line.

Table 4 - Mean values (general data) of the analysed parameters.

GER (W)	PT (°C)	T (°C)	RH (%)	UV (mW/c)	WS (m/s)	WD (°)	AP (mmHg)
100.18	227.33	29.04	59.00	7.00	0.16	98.44	1,012.30

Table 5 - Correlations between generation and other parameters.

	PT	T	RH	UV	WS	WD	AP
Generation	0.442	0.371	-0.338	0.483	0.068	0.157	0.044
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

With the fractionation of the historical series of energy generation in subsamples, using the third quartile of the wind direction as a filter, that is, dividing 25% of the data of the largest generations into four quadrants of wind performance, where 0 to 90° constitute the first sample, between 90 and 180° the second sample, and so on, it is observed in Table 6 that the average power generation is 258.79 W between 0 and 90° (first quadrant), 257.36 W in the second quadrant, 257.47 W in the third quadrant and 270.00 W in the fourth quadrant, resulting in a slight increase in generation efficiency in the last quadrant in relation to the other quadrants.

After surveying the averages of electric energy generation in the third quartile in relation to each quadrant of wind direction, the range of analysis can be adjusted for the highest average of energy generations and, with that, it was identified that the wind direction between 330 and 360° has the highest average generation of the third quartile, with a value of 299.6 W (Table 7), resulting in an increase in energy generation efficiency of approximately 11% in relation to the average of the fourth quadrant.

Employing the correlations (Tables 8 to 12) between the values obtained by reading the meteorological elements and the generation

data and panel temperature, a more detailed observation of these data can be initiated. It can be observed that, in general, the correlations between energy generation and

wind direction, panel temperature and ultraviolet radiation provide more significant values concerning the other elements.

Table 6 - Mean values of parameters analysed in the third quartile in relation to wind direction.

a. Generation greater than 175 W and WD between 0 and 90°										
Variable	N	N*	Average	SE average	Standard deviation	Minimum	Q1	Median	Q3	Maximum
Generation	465	0	258.79	3.07	66.22	175.07	205.90	244.70	296.13	513.47
PT	465	0	30,130	0.182	3,923	20,660	29,650	29,650	32,360	43,250
T	465	0	31,163	0.125	2,685	20,610	31,790	31,790	33,330	41,530
RH	465	0	51,829	0.438	9,434	30,240	50,970	50,970	51,175	86,800
UV	465	0	7.2224	0.0262	0.5640	6.0400	7.1400	7.1400	7,5500	9.9100
WS	465	0	0.0594	0.0064	0.1389	0.0000	0.0000	0.0000	0.1000	0.9100
WD	465	0	12.13	1.18	25.50	0.00	0.00	0.00	0.00	90.00
AP	465	0	1012.7	0.161	3.48	101.4	1013.5	1013.5	1015.4	1020.5
b. Generation greater than 175 W and WD between 90 and 180°										
Variable	N	N*	Average	SE average	Standard deviation	Minimum	Q1	Median	Q3	Maximum
Generation	495	0	257.36	3.30	73.49	175.00	200.85	237.19	297.84	696.47
PT	495	0	29,923	0.206	4,583	16,770	26,980	29,410	32,160	44,180
T	495	0	30,514	0.143	3,172	17,240	28,560	30,710	32,450	39,920
RH	495	0	51,900	0.404	8,978	26,920	45,330	51,400	57,970	79,370
UV	495	0	7.2905	0.0259	0.5768	6.1300	6,9000	7,1800	7,6700	9,8700
WS	495	0	0.1737	0.0072	0.1612	0.0200	0.0500	0.1200	0.2400	0.8700
WD	495	0	148.32	1.14	25.34	90.00	129.00	152.00	170.00	180.00
AP	495	0	1013.3	0.158	3.51	1003.6	1011.0	1013.9	1015.8	1020.4
c. Generation greater than 175 W and WD between 180 and 270°										
Variable	N	N*	Average	SE average	Standard deviation	Minimum	Q1	Median	Q3	Maximum
Generation	238	0	257.47	3.95	60.90	175.12	206.36	244.71	297.44	491.49
PT	238	0	29,350	0.262	4,049	16,770	26,488	29,155	31,595	40,330
T	238	0	30,673	0.221	3,413	17,240	28,212	31,140	33,245	37,570
RH	238	0	51,617	0.549	8,475	36,460	45,863	50,045	56,438	78,870
UV	238	0	7.2196	0.0325	0.5015	5.6400	6.9300	7.1400	7.5200	9.0200
WS	238	0	0.1441	0.0076	0.1181	0.0200	0.0500	0.11000	0.2000	0.5900
WD	238	0	215.95	1.79	27.64	180.00	191.00	212.00	241.25	270.00
AP	238	0	1011.5	0.244	3.76	1003.6	1008.3	1011.2	1013.9	1020.5
d. Generation greater than 175 W and WD between 270 and 360°										
Variable	N	N*	Average	SE average	Standard deviation	Minimum	Q1	Median	Q3	Maximum
Generation	58	0	270.0	10.2	77.4	177.7	203.8	250.2	318.6	546.2
PT	58	0	31,868	0.568	4,323	23,270	29,260	31,050	34,255	45,860
T	58	0	32,664	0.416	3,166	25,250	31,248	32,475	34,487	42,290
RH	58	0	46.16	1.12	8.53	31.15	40.45	44.91	50.54	73.22
UV	58	0	7.4891	0.0733	0.5579	6.5700	7.0200	7.5300	7,8000	9.3400
WS	58	0	0.1895	0.0210	0.1602	0.0200	0.0700	0.1450	0.2775	0.7700
WD	58	0	315.57	3.21	24.45	271.00	296.25	316.00	334.00	357.00
AP	58	0	1011.6	0.545	4.15	1004.4	1007.6	1012.0	1014.8	1019.9

Table 7 - Mean values of parameters analysed in the third quartile in relation to wind direction between 330 and 360°.

Variable	N	N*	Average	SE average	Standard deviation	Minimum	Q1	Median	Q3	Maximum
Generation	16	0	299.6	18.8	75.3	182.7	233.8	299.1	365.7	419.7
PT	16	0	31,737	0.828	3,314	26,500	29,343	31,240	33,295	39,700
T	16	0	33,180	0.898	3,591	26,600	30,782	32,285	35,907	40,730
RH	16	0	46.09	2.45	9.81	34.62	39.17	06.43	52.23	72.64
UV	16	0	7.917	0.160	0.638	6,940	7,630	7,755	8,287	9,340
WS	16	0	0.2650	0.0542	0.2167	0.0200	0.1250	0.2100	0.4050	0.7700
WD	16	0	346.38	2.00	8.02	332.00	341.00	347.00	354.50	357.00
AP	16	0	1011.1	0.883	3.53	1004.4	1009.2	1012.0	1012.9	1016.4

In the third quadrant (Table 10), the highest correlation between ultraviolet radiation and power generation can be found, reaching a value of 0.401, considered moderate. There

is still an inverse proportional relationship in relation to relative humidity of -0.313. Given these numerical factors, one can, empirically, have an impression of this being the quadrant

that presents the most positive results for the study.

However, when establishing a correlation by observing the concentration of data with higher generation values, it is identified that

there is a range of coordinates in the northwest direction, 330 to 360° (Table 12), which presents average values of generation (299.6 W) that are higher (Figure 4).

Table 8 - Correlation of 1st wind direction quadrant (0 to 90°) and generation greater than 175 W.

	PT	T	RH	UV	WS	WD	AP
Generation	0.308	0.223	-0.284	0.308	0.180	0.184	-0.093
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 9 - Correlation of 2nd wind direction quadrant (90 to 180°) and generation greater than 175 W.

	PT	T	RH	UV	WS	WD	AP
Generation	0.228	0.207	-0.181	0.292	0.063	-0.019	-0.096
p-value	0.000	0.000	0.000	0.000	0.162	0.674	0.032

Table 10 - Correlation of 3rd wind direction quadrant (180 to 270°) and generation greater than 175 W.

	PT	T	RH	UV	WS	WD	AP
Generation	0.397	0.315	-0.313	0.401	0.132	0.066	-0.132
p-value	0.000	0.000	0.000	0.000	0.043	0.314	0.041

Table 11 - Correlation of 4th wind direction quadrant (270 to 360°) and generation greater than 175 W.

	PT	T	RH	UV	WS	WD	AP
Generation	0.115	-0.018	0.077	0.253	0.082	0.333	-0.119
p-value	0.392	0.892	0.567	0.053	0.540	0.011	0.375

Table 12 - Correlations for wind direction (330 to 360°) and generation greater than 175 W.

	PT	T	RH	UV	WS	WD	AP
Generation	-0.112	-0.271	0.315	-0.231	-0.021	0.010	0.253
p-value	0.680	0.311	0.425	0.389	0.940	0.970	0.345

To make data analysis more accurate, it can be observed that, in addition to the wind direction between 330 and 360°, there is a punctual estimate for the highest average, the lower limit for the average generation estimate, in this wind direction interval, nearly exceeds the upper bound for the average

generation estimates for all other quadrants. The statistical test in this range rejects equality with a p-value of 0.07, which is very close to 95% reliability.

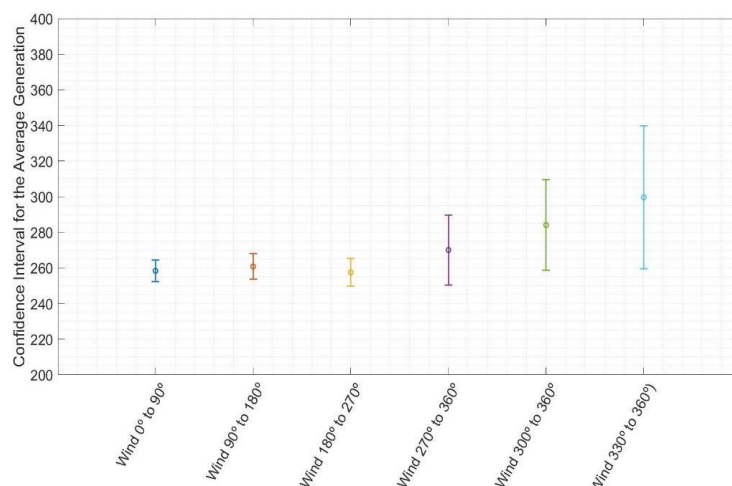


Figure 4 - Reliability Ratio for Energy Generation.

Thus, it can be observed that energy generation is a function of a composition of variables, which may differ in each region or location of installation of photovoltaic panels and, in this case in particular, higher generation occurs in wind directions between 330 and 360°, where the panel temperature, ambient temperature, ultraviolet radiation and wind speed are higher than in the other directions. Atmospheric pressure is maintained in all directions, and relative humidity is lower than in other directions.

According to *Matin et al.* (2020), the generation efficiency of photovoltaic cells is still relatively low and influenced by temperature and solar irradiance and, consequently, by meteorological elements. Such specificity may be related to the characteristic geographic position of the observation site in the municipality of Itajaí, where the collector side of the photovoltaic panels is installed at 282° NW. The northwest wind is drier, originating from within the state of Santa Catarina, leaving the sky with less cloudiness and increasing the ultraviolet radiation, which falls within an optimal range for energy generation.

Climatic conditions play a crucial role in solar energy generation, as the excess or lack of certain phenomena can directly affect energy capture. A climate characterised by high humidity and a lack of wind can result in excessively hot conditions around solar cells, significantly impairing energy production. Additionally, the presence of moisture can lead to the formation of precipitation and clouds that cover and hinder the efficient

absorption of solar radiation. The wind, in turn, is an essential element, as it has the role of moving air masses, displacing moisture and dispersing clouds. Furthermore, it plays a crucial role in cooling the PV system, thereby contributing to its overall efficiency and performance.

According to the sensitivity analysis conducted by *LV et al.* (2014), based on solar power generation measurement data in 2011, from a comprehensive perspective of daily and monthly power generation, the top five climate variables of importance are solar radiation time (i.e. solar radiation), speed wind, relative humidity, cloud cover and outside temperature.

The power generated by photovoltaic modules is linearly dependent on irradiance, except for small values of irradiance when the output power is zero. The efficiency of the photovoltaic plant not only strongly depends on the irradiance, but also depends on the module temperature (*Chokmajirov et al.*, 2006).

In this study, no significant variations were identified between the panel temperature and the ambient temperature (Table 6), including the average temperature of the panel around 1°C lower than the ambient temperature. This fact may be related to the location and position of the panel's installation, as the photovoltaic set is elevated above the roof, allowing for air circulation and convection on the panels.

According to *Hamrouni et al.* (2008), for several solar radiations ranging from 100 to 1000 W/m² and for a constant temperature

equal to 25 °C, there is an increase in generation with an increase in radiation and a maximum global efficiency of the photovoltaic system for 300 W/m² of radiation.

According to research by Kaldellis *et al.* (2014), as wind speed increases, the working temperature of photovoltaic cells gradually approaches ambient temperature, which affects the efficiency of power generation. Thus, the photovoltaic conversion process, in addition to instantaneous solar radiation, also depends on the temperature of the modules. The module temperature, in turn, is influenced by climatic conditions, as well as by the technical characteristics of the photovoltaic panels.

Solar irradiance has the most significant impact on the output power of a photovoltaic system (Diaf *et al.*, 2008). In addition to irradiance, weather conditions such as ambient temperature, along with several other factors (e.g. angle of incidence [AOI], dust, etc.) (Kaldellis *et al.*, 2012) can also affect the power output and energy production of a photovoltaic module. To this end, the module temperature is influenced by the ambient temperature, cloud patterns and wind speed (Buday, 2011), while the temperature change rate also depends on the PV material and frame position.

Normally, the impact of free convection is quite limited, while the radiation mechanism is dominant during low wind speed values (Kaldellis *et al.*, 2014).

The photovoltaic conversion process, in addition to instantaneous solar radiation, also depends on the temperature of the modules. The module temperature, in turn, depends on climatic conditions (such as ambient temperature, solar irradiance, and wind speed) and the technical characteristics of the photovoltaic panels (including material, type, assembly, and ventilation) (Kaldellis *et al.*, 2014).

For a better characterisation and prediction of photovoltaic module performance under a wide variety of climatic conditions, several detailed studies have been carried out (Jacques *et al.*, 2013; Armstrong *et al.*, 2010) and several models have been proposed, with most of them based on only indoor measurements (for example,

controlling the wind flow over the panel surface with fans).

Parameters for improving the efficiency of clean energy generation

Calculation of gas emissions from the various generation sources

Based on the results of improving the efficiency of photovoltaic energy generation, it is possible to perceive the potential for reducing greenhouse gas (GHG) emissions from hydroelectric and thermoelectric plants, thereby enhancing the use of solar energy.

Tables 13 and 14 show the values of energy generation and emissions calculated using Equation 1, by type of energy generation and for each proposed scenario. In these scenarios, the values referring to energy related to wind, natural gas, and nuclear were kept constant, while energy from hydraulic and thermal power plants (biomass, coal, and oil) was reduced, and energy from solar sources was increased.

In the current scenario, there is a total gas emission of $28,609 \times 10^6$ ton CO_{2eq}, while in the proposed scenarios 28,170; 27,592 and $27,078 \times 10^6$ ton CO_{2eq} are generated, that is, a reduction of approximately $1,531 \times 10^6$ ton CO_{2eq} in Scenario 3 compared to the current scenario, which results in a 5.3% reduction.

According to the IPCC special report (2021), it is crucial to reduce greenhouse gas (GHG) emissions by 45% by 2030, compared to 2010 levels, to limit the increase in global average temperature to 1.5°C above pre-industrial levels. This reduction is necessary to avoid more serious consequences of climate change.

Although a 5.3% reduction in emissions, related to the generation of electricity in Brazil, is not enough to generate a significant impact on the increase in global average temperature, it is one more factor to be considered for mitigating global warming, and it is fundamental to recognise that this phenomenon is complex and influenced by several factors. Therefore, in addition to this progress, a significantly greater effort is needed, in terms of electricity generation sources, to achieve the global warming mitigation targets established by the IPCC and prevent significant and irreversible impacts.

Table 13 - Energy generation for each scenario and each generation source.

Power generation (MW)									
Scenario	Hydraulics	Biomass	Wind	Natural gas	Oil	Coal	Nuclear	Solar	Total
Current (2018)	104,587	14,776	14,448	13,134	10,015	3,612	1,970	1,641	164,187
1	103,766	14,448	14,448	13,134	9,851	3,283	1,970	3,283	
2	102,781	14,284	14,448	13,134	9,687	2,955	1,970	4,925	
3	101,795	14,120	14,448	13,134	9,522	2,626	1,970	6,567	

Table 14 - GHG emissions for each scenario.

Emissions (x 10 ⁶ ton CO _{2eq})										
Scenarios	Hydraulics	Biomass	Wind	Natural gas	Oil	Coal	Nuclear	Solar	Total	Reduction (%)
Current (2018)	9,016	12	233	6,805	8,302	4,132	27	82	28,609	-
1	8,945	11	233	6,805	8,166	3,756	27	164	28,107	1.7
2	8,860	11	233	6,805	8,030	3,380	27	246	27,592	3.5
3	8,775	11	233	6,805	7,894	3,005	27	328	27,078	5.3

Calculation of fuel consumption reduction

Due to the reduction in energy generation from thermoelectric plants, there is a

reduction in consumption (Table 15) of fuels (coal, oil and biomass), reaching a maximum reduction of 27% for coal and approximately 5% for oil and biomass.

Table 15 - Reductions in fuel used in thermoelectric plants.

Fuel consumption (kg)					
Fuel	Current scenario	Scene 1	Scenario 2	Scenario 3	Reduction (%) Scenario 3 x Current scenario
Coal	1,242,795	1,129,814	1,016,832	903,851	27.3
Oil	2,549,874	2,508,072	2,466,271	2,424,470	4.9
Biomass	7,628,195	7,458,679	7,373,921	7,289,164	4.5

Calculation of reservoir area reduction by reducing generation in hydroelectric plants

By reducing the percentage of energy generation through hydraulic sources, biomass, oil and coal (Table 14), maintaining energy generation through wind, natural gas and nuclear sources and expanding energy generation through solar source, in addition to a reduction in CO₂ emissions from the generation itself, there is also a possibility of reducing emissions from the generation of CH₄ due to the anaerobic decomposition of

organic matter present in the hydroelectric lakes (Barros *et al.*, 2021).

Zanoni *et al.* (2015) analysed the characteristics of the flooded soil and the CH₄ production that is produced at the bottom of the reservoirs by the anaerobic decomposition of the organic matter and emitted in the water-air interface, through bubbles or diffusion, demonstrating that the local factors of the flooding influence the amount of CH₄ produced.

According to some authors (Louis *et al.*, 2000; Pueyo *et al.*, 2011), the average methane emission rate in hydroelectric plants can vary

from 20 to 300 mg of CH₄ /m² per day, depending on local conditions.

According to the method presented by Santos *et al.* (2008), CH₄ emission is 18.29 kg.km⁻².day⁻¹, which corresponds to an annual emission of 0.36 ton x 10⁶ in 55,000 km² of reservoir area, resulting in 2.06 ton x 10⁶ CO_{2eq} year, considering a CH₄ GWP of 21.

Considering GHG generation in Hydroelectric Power Plants for the total flooded area (E_{GHGat}), for the current scenario, at 9,016 x 10⁶ ton CO_{2eq} (Table 14) and the total reservoir area of 55,000 km², the GHG emission per km² (E_{GHG}) can be calculated using Equation 2.

$$E_{GHGat} = (E_{GHG} \times A_{RESCUR})$$

$$9.016 \times 10^6 = (E_{GHG} \times 55.000)$$

$$E_{GHG} = 163.927 \frac{\text{ton CO}_{2eq}}{\text{Km}^2}$$

From the issuance of scenario 3 (8,775 x 10⁶ ton CO_{2eq} - Table 14), the final area of the reservoir can then be calculated.

$$E_{GHGat} = (E_{GHG} \times A_{RES SCEN3})$$

$$8.775 \times 10^6 = (163.927 \times A_{RES SCEN3})$$

$$A_{RES SCEN3} = 53.529,84 \text{ km}^2$$

And, through Equation 3, it is possible to calculate its consequent reduction in area (approximately 2.7%), due to the reduction in energy generation through hydroelectric plants.

$$R_{ARES} = (A_{RES CUR} - A_{RES SCEN3})$$

$$R_{ARES} = (55.000 - 53.529,84)$$

$$R_{ARES} = 1.470,16 \text{ km}^2$$

These equations are a simplified way of estimating the generation of greenhouse gases in hydroelectric power plants and, it is important to remember that the emission factor may vary according to the characteristics of each plant and that other factors may influence emissions, such as the type of vegetation removed during the construction of the reservoir and the type of soil present in the region.

According to the ANEEL, there are approximately 220 hydroelectric power plants in operation in Brazil, with a total installed

capacity of more than 104 gigawatts (GW) as of 2022. The ANEEL provides detailed information about each of these plants, including the size of dams, the area flooded and the volume of water stored.

Through studies by the Ministry of Mines and Energy of Brazil, it is possible to verify that in the year 2020 there was a significant consumption of energy from hydroelectric plants, totalling 396,381 GWh (MME, 2022). The substantial amount of energy generated by hydroelectric plants underscores the importance of this sector in the national energy matrix, highlighting its crucial role in supplying electricity to the country.

However, it is worth remembering that the hydroelectric plants in operation in Brazil have a total area of dams of approximately 55,000 km² (ANEEL, 2022) and it is also worth noting that the size of dams of hydroelectric plants in Brazil is subject of debate and controversy due to the socio-environmental impacts that these undertakings cause. Several organisations and social movements have questioned the construction of large dams, arguing that they cause the loss of forest areas, the displacement of traditional communities, and the forced relocation of riverside populations (Fearnside, 2020).

Amaral *et al.* (2019) conducted an environmental assessment of hydroelectric power plants in Brazil, employing life cycle analysis and inventory methodologies. Based on this, the authors calculated greenhouse gas (GHG) emissions and other environmental impact categories, considering the plant's power density to differentiate emissions per km² of flooded area. The results indicated that power density was a significant factor in determining GHG emissions, with notable variations between the evaluated power plants. The study emphasised the importance of considering power density as a key factor in the environmental assessment of hydroelectric power plants. The estimation of greenhouse gas emissions associated with hydroelectric energy generation can be performed using a simplified equation that considers the plant's energy generation capacity, the reservoir area, and the emission factor.

The works by Miranda (2012) and Amaral (2019) address the assessment of the

environmental performance of hydroelectric power plants, focusing on the analysis of greenhouse gas (GHG) emissions. Both studies employ the life cycle approach to assess GHG emissions throughout the life cycle of power plants, from construction to end of life.

While Miranda (2012) emphasises the importance of considering the plant's power density in assessing GHG emissions, Amaral (2019) utilises this concept to calculate GHG emissions per square kilometre of flooded area. This approach enables a more accurate assessment of the environmental performance of various hydroelectric plants, taking into account the unique characteristics of each project. By combining these approaches, it is possible to obtain a more comprehensive assessment of the environmental performance of hydroelectric plants.

In addition, it is essential to note that the National Electric Energy Agency (ANEEL), in its Annual Report on the Inspection of the Use of the Union's Heritage (2022), uses electricity generation capacity and the total area of dams in Brazil as references to estimate greenhouse gas emissions. This approach considers the diversity of existing plants and dams in the country, which have different operational characteristics and environmental impacts. However, it is important to point out that this methodology can be improved with the inclusion of specific emission factors for each plant, as proposed by Miranda and Amaral.

Final considerations

By analysing the influence of wind direction and speed, ambient temperature, relative humidity, atmospheric pressure, ultraviolet radiation and panel temperature on the efficiency of photovoltaic energy generation and its climate effect, it can be identified that:

- The efficiency of photovoltaic energy generation can be influenced by the composition of meteorological elements and panel temperature, and may vary in each region or location where photovoltaic panels are installed.
- In the specific case of this study, there is an average generation 11% higher

in wind directions between 330 and 360°, since the collector face of the photovoltaic panels is installed at 282° NW and the northwest wind is a drier wind, coming from within the state of Santa Catarina, leaving the sky with less cloudiness, expanding ultraviolet radiation to within a range of excellent standards for energy generation.

- The proposition of scenarios with an increase in the percentage of energy generation by photovoltaic panels results in a reduction in greenhouse gas emissions of up to 5.3%.
- The reduction in energy generation through hydroelectric plants, proposed in the scenarios, allows for a 2.7% reduction in the area of the reservoirs.
- The reduction in energy generation through thermoelectric plants, proposed in the scenarios, makes it possible to reduce the consumption of coal, oil and biomass by 27.3%, 4.9% and 4.5%, respectively.

The study provides one more factor to consider for mitigating global warming, and it is essential to recognise that this phenomenon is complex and influenced by several components.

References

- AMARAL, TR, NAVEIRA-COTTA, CP, NASSER, LS, BEZERRA, BS, SANTOS, AM, & LIMA, RP (2019). Environmental performance of hydropower plants: A Brazilian case study. *Journal of Cleaner Production*, 232, 751-763.
- ANEEL. (2008). *Atlas of Electrical Energy*. National Electric Energy Agency, Brasília.
- ANEEL. (2018). *Performance Report for Centrally Dispatched Thermoelectric Power Plants – Types IE liad*. National Electric Energy Agency, Brasília.
- ANEEL. (2022). *Generation Information Bank*. National Electric Energy Agency, Brasília.
- ARMSTRONG, S., & HURLEY, W. (2010). A thermal model for photovoltaic panels under varying atmospheric conditions. *Appl Therm Eng*, 30, 11-12.
- BARROS, N.E. (2021). Greenhouse gas emissions from hydroelectric reservoirs: what knowledge do we have and what needs to be

- done? *Renewable and Sustainable Energy Reviews*, 147, 111-131.
- BUDAY, M. (2011). *Measuring irradiance, temperature, Corkishe and angle of incidence effects on photovoltaic modules in Auburn Hills*. Michigan: University of Michigan.
- CHOKMAVIROJ, S., WATTANAPONG, R., & SUCHART, Y. (2006). Performance of a 500 kWp Grid-Connected Photovoltaic System at Mae Hong Son Province, Thailand. *Renewable Energy*, 31, 19.
- DIAF, S., NOTTON, G., BELHAMEL, M., HADDADI, M., & LOUCHE, A. (2008). Design and technoeconomical optimisation for hybrid PV/wind system under various meteorological conditions. *Applied Energy*, 85, 968-987.
- FEARNSIDE, PM (2020). Large hydroelectric dams in Brazilian Amazonia: A flawed climate solution?. *Environmental Science & Policy*, 112, 215-225.
- JACQUES, S; CALDEIRA, A; REN, Z; SCHELLMANN, A; BATUT, N. Impact of the cell temperature on the energy efficiency of a single glass PV module: thermal modelling in steady-state and validation by experimental data. In: *Proceedings of the international conference on renewable energies and power quality 2013 (ICREPQ'13)*, Bilbao, Spain.
- HAMROUNI, N., JRAIDI, M., & CHÉRIF, A. (1995). Solar radiation and ambient temperature effects on the performance of a PV pumping system. *Revue des Energies Renouvelables*, pp. 95 – 106.
- HANIFI, HP (2018). A Practical Optical and Electrical Model to Estimate the Power Losses and Quantification of Different Heat Sources in Silicon-Based PV Module. *Renewable Energy*, pp. 602-612.
- KHOLOD, Yana et al. Excitation Energy Transfer Pathways in Light-harvesting Proteins: Modelling with PyFREC. *Journal of Computational Chemistry*, v. 39, no. 8, p. 438-449, 2018. Available at: <https://onlinelibrary.wiley.com/doi/abs/10.1002/jcc.25101>. Epub.
- LOUIS, VL ST.; KELLY, CLA; DUCHEMIN, É.; RUDD, JWM; ROSENBERG, DM Reservoir surfaces as sources of greenhouse gases to the atmosphere: a global estimate. *BioScience*, v. 50, no. 9, p. 766-775, 2000.
- HAYAT, MB, Ali, D., MONYAKE, KC, ALAGHA, L., & AHMED, N. (2019). *Solar Energy: A Look into Power Generation, Challenges, and A Solar-Powered Future*. *J. Energy Res.*, pp. 1049–1067.
- IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Intergovernmental Panel on Climate Change.
- JAIN, Sachin, DHARA, Sumon, AGARWAL, Vivek. A Voltage-Zone Based Power Management Scheme With Seamless Power Transfer Between PV-Battery for OFF-Grid Stand-Alone System. *IEEE Transactions on Industry Applications*, v. 57, no. 1, p. 754-763, 2021. Available at: <https://ieeexplore.ieee.org/document/9319219>. Epub.
- KALDELLIS, JK, KAVADIAS K., ZAFIRAKIS D. Experimental validation of the optimum photovoltaic panels' tilt angle for remote consumers. *Renew Energy* 2012; 46: 179 and 91.
- KALDELLIS, JK; KAPSALI, M.; KAVADIAS, KA. Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece, *Renewable Energy* 66 (2014) 612–624.
- LV, JWX; ZHU, H.; SONG, Y. The influence of meteorological factors on the photovoltaic daily generation (2014). DOI:10.13941/j.cnki.21-1469/tk.2014.10.001.
- MATIN, MA et al. Bi(1-y)SmyFeO3 as potential photovoltaic materials. *Bull Mater Sci*, v. 43, p. 167, 2020. <https://doi-org.ez130>.
- MIRANDA, MM (2012). Emission factor of greenhouse gases from electricity generation in Brazil: implications of applying the Life Cycle Assessment. 162p. Dissertation (Master). Engineering School of São Carlos. University of São Paulo. 2012.
- MME - Ministry of Mines and Energy. National Energy Plan 2050. (2018). <https://www.mme.gov.br/documents/10584/1102077/PNE+2050+-+vers%C3%A3o+final.pdf/3e3d0dbb-bf14-0c48-c287-0d4f3e33df44>.
- NAVNTOFT, LC, CRISTÓFALO, MP, CUCCORESE, S., DEFFERRARI, IR, & ROMERO, I. (2019). *Distributed Solar Photovoltaic Generation Manual (1st revised ed.)*. Secretariat of the Government of Energy.

NEVES, A; BLONDEL, L; BRAND, K; HENDEL, B.S; RIVAS, CS; IANCU, A; MELICA, G; KOFFI, L.B; ZANCANELLA, P; KONA, A. Guide for presenting the results of the Covenant of Mayors for Climate and Energy, 2016, EUR 28160 PT, DOI: 10.2790/717311.

PUEYO, S.; FEARNSIDE, PM GREENHOUSE GAS EMISSIONS FROM HYDROELECTRIC RESERVOIRS: IMPLICATIONS OF A POWER LAW. *Oecologia Australis* 15(2): 199-212, June 2011 DOI:10.4257/oeco.2011.1502.02.

RAZA. A, Syed J, Muhammad Ali F, et al. Incidence of vitamin D Deficiency in Different Seasons in the Adult Karachi Population Presenting in the Medical Outpatient Department with Generalized Body Ache. *Cureus*, v. 11, no. 7, p. e5167, 2019. DOI: 10.7759/cureus.5167.

SANCHES, SR Meteorological Data Transmission System in Real Time for Marina Users' Cell Phones. Florianopolis: IFSC, 2020.

SANTOS, MA; ROSA, LP; MATVIENKO, B.; SANTOS, EO; D'ALMEIDA ROCHA, CHE; SIKAR, E.; SILVA, MB & JUNIOR, AMPB 2008. Greenhouse gas emissions from hydroelectric reservoirs. *Oecologia Brasiliensis*, 12: 116-129.

SOARES FILHO et al. Low Carbon Study for Brazil - Land Use, Land Use Change and Forests, 2010. International Bank for Reconstruction and Development.

WOLFE, Philip R. "What Is Photovoltaics?" In: *The Solar Generation*. 1st ed. Hoboken, NJ, USA: Wiley, 2018. p. 9-24.

ZANONI, Maria MV, Josiléia A. Zanatta, Jeferson Dieckow, Akemi Kan, and Carlos B. Reissmann. "Methane Emissions from Decomposition of Flooded Forestry Waste." *Brazilian Journal of Agricultural and Environmental Engineering* 19.2 (2015): 173-79.