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Meteorological influences on solar energy production in a coastal Amazon region

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ABSTRACT

A study was conducted with a photovoltaic distributed generation system in São Luís, Brazil, to determine the influence of meteorological variables on the generation of energy. The methodology is composed of three stages: the first corresponds to the obtaining, organization, and treatment of the data; the second involves the application of mathematical models to determine the yield, operating temperature, nominal power, and estimated power; and the third is to generate the correlations obtained between the monitored climatic variables, whether on an hourly, daily, monthly, or annual scale. For an average temperature of 27.50ºC in March, it was verified that the ultraviolet radiation was 5.06, while the average of the total radiation was 481.01 W.m^{-2}. The maximum peak temperature was 27.88°C at noon, while the ultraviolet radiation was 8.55 and total radiation was 794.97 W.m^{-2}. At this average temperature variation of 0.38°C, there is a variation of 313.96 W.m^{-2}. It is concluded that, because São Luís is very close to the equator, the conditions to produce the system are favorable, mainly because, on average, there were no abrupt changes in temperature and radiation for the period studied. Even in the wintry period, the production behaved within the parameters designed.

Keywords: Climate change; Energetic risk; Climatic risk

1 INTRODUCTION

The effect of photovoltaic (PV) power generation was discovered in 1839 by Becquerel while studying the effect of light on electrolytic cells. A long period of research was necessary to reach a sufficiently high efficiency in solar cells. In the 1950s, leveraged by space programs for use in satellites, and then in the 1970s energy crisis, technologies for PV energy production have made significant headway, especially with the commercial-scale use of silicon crystalline (c-Si), polycrystalline silicon (pc-Si), and amorphous silicon (a-Si), which made possible the current advancement of the use of this technology (FEDRIZZI; SAUER, 2002).

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The electrical performance of solar cells depends on the electrical-system constituents and environmental variables (DUBEY; SARVAIYA; SESHADRI, 2013), and, although several studies have addressed climate influences on PV systems, the use of PV systems is scarce in regions of tropical forest, such as the Amazon Basin, where the climate conditions are unique, and the implementations of these technologies are increasing.

The efficiency of the PV technologies is still widely and ambiguously discussed, because the systems are evaluated with the same Standard Test Conditions (STCs). Although the normal operating cell temperature can express the relation between STC and real outdoor conditions (HEGEDOUS, 2013), the intra-annual and inter annual variability can financially compromise the project because of an unexpected decrease in PV system efficiency.

Several studies have shown that the efficiency of PV systems decreases with increasing ambient temperature (ZHOU *et al*., 2017), affecting mainly the operating temperature, which that plays a key role in the PV conversion process because of the increase in the internal rates of recombination of carriers (electrons or gaps) caused by the increase of the concentrations. The performance rate decreases with latitude because of high temperature, except in regions with higher altitudes with low temperature and high solar irradiation (SWAPNIEL; NAROTAM; BHARATH, 2012).

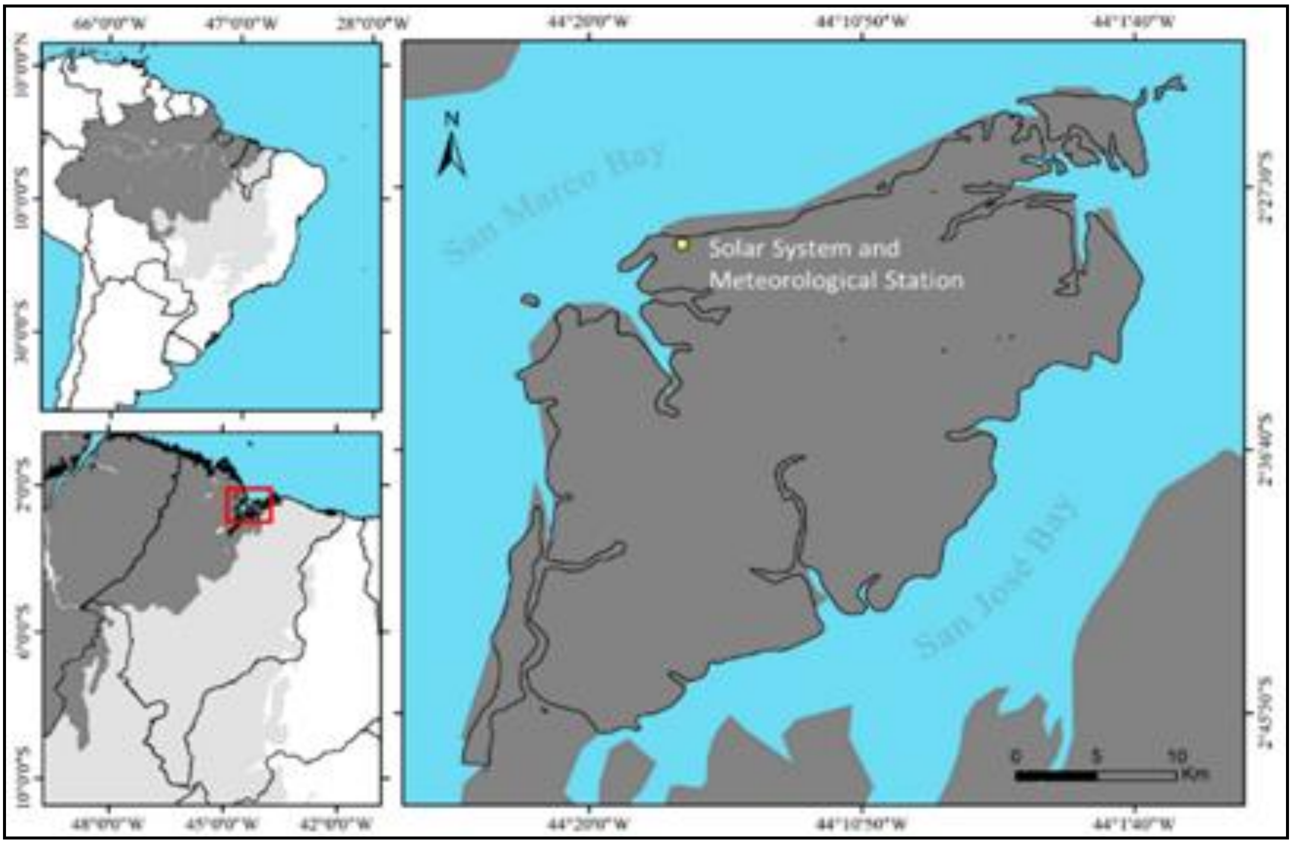
Tropical forest regions, such as the Amazon forest, have high cloud presence, and, in the Amazon coastal zone, at least six months in the year have a clear sky probability of less than 30% (SANO *et al*., 2007; MARTINS *et al*., 2018). However, the average maximum daily temperature exceeds 30^{0}C throughout the year. In this scenario, Silva *et al*. (2016) pointed to the increase in temperature as evidence of climate change in the Amazon coastal zone.

In a scenario of climate uncertainty, it is necessary to acquire knowledge to support the design of efficient PV system projects in humid, warm climate regions with a tendency for significant increases in ambient temperature, such as the rainforest regions. The focus of this study was on the following questions. 1. What is the variation of energy production during a climatic year in a region of tropical forest? 2. How does variability affect solar energy production in the Amazon coastal region? Therefore, the aim of this work was to evaluate PV energy generation in relation to climatic variation in the Amazon coastal region.

2 MATERIAL AND METHODS

The PV system used in this work was installed in a building on the Island of São Luís at the geographic coordinates of latitude 2^{0}29'29.4"S and longitude 44^{0}16'52.5"W (Figure 1).

Figure 1 - Location of the area where the PV system studied was implanted



The PV power generation system was composed of polycrystalline silicon (p-Si) cells, consisting of 16 plates totaling an area of 25.76m^2. The nominal power of the system was 4 kWp, the power of the board was 250Wp, with a DC voltage of the panel of 30.1V and DC current of the panel of 8.3A. The connection arrangement was of a series type (1 × 16), the power of the inverter being 4 kW, connection on grid, with a nominal voltage of the system of 220V in single-phase connection and a yield of 95.7% (Figure 2a). The acquisition of meteorological data was performed using a weather station Weather WS-2902 WiFi OSPREY Solar Powered Wireless, where the data were stored on hourly and daily time scales (Figure 2a). The data monitored were wind speed (m/s), temperature (°C), rainfall (mm), air pressure (mmHg), air humidity (%), ultraviolet (UV) irradiation, and solar irradiation (W.m^{-2}).

Figure 2 - (a) Photovoltaic system and (b) weather station view

The operating temperature of the PV cells is a key variable for the energy production, strongly influenced by weather conditions. In this work, the operating temperature was estimated by integration of the meteorological variables related to wind speed (Vf), ambient temperature (Ta), global irradiance (GT), and mounting coefficient (ω) (SKOPLAKI *et al*., 2008) — see Equation 1.

$$T_c = T_a + \omega\left(\frac{0{,}32}{8{,}91+2{,}0V_f}\right)G_T \quad (1)$$

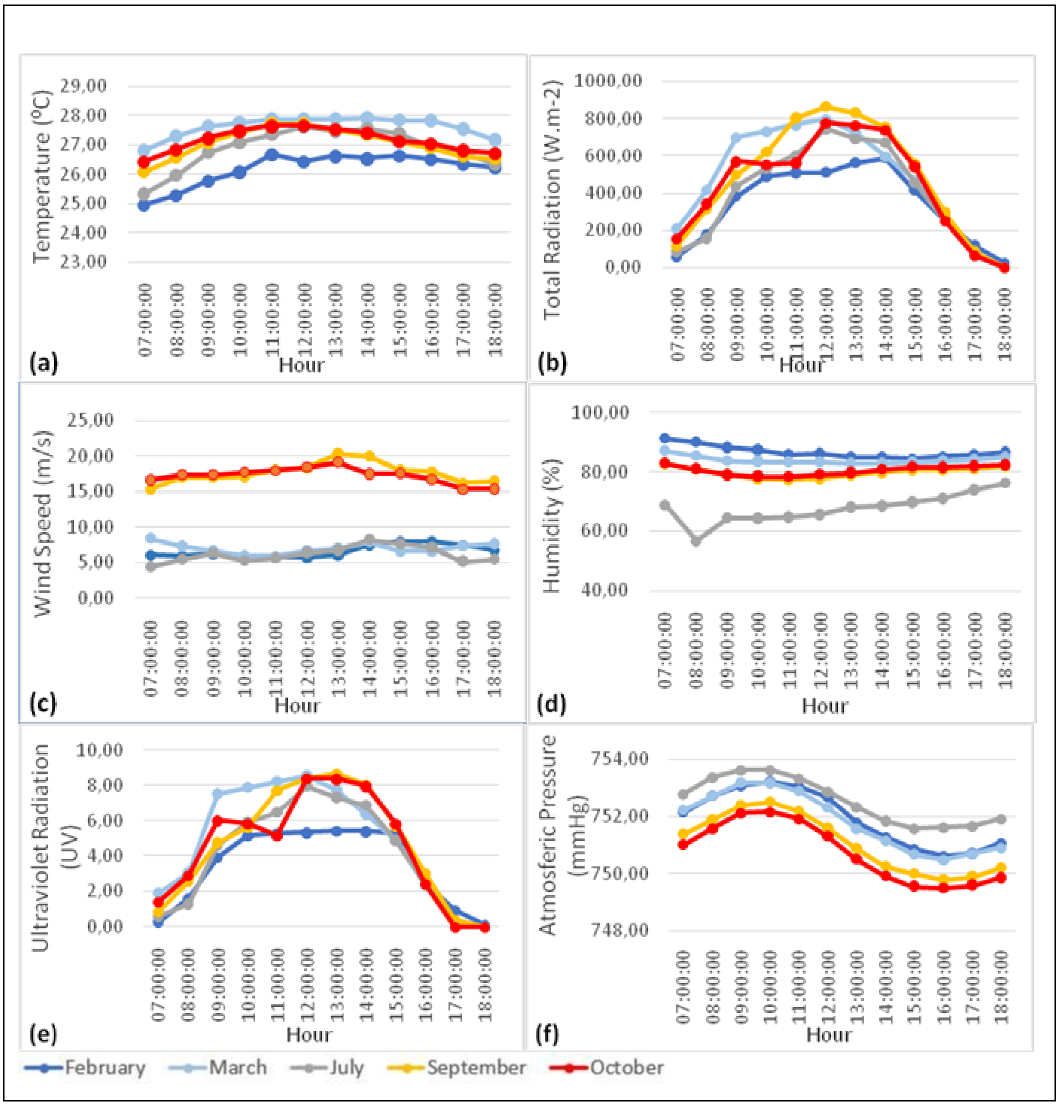
The Pearson correlation analysis was used to evaluate the correlation among the meteorological variables, and a linear regression analysis was used to evaluate the relationships between the meteorological variables and the energy production of the system in different seasons. These analyses were performed with hourly and daily time-scale data, during the rainy season (February), transition from rainy to dry (July), and dry (September).

3 RESULTS AND DISCUSSION

3.1 Characterization of climate variables

The climatic variables and solar energy production were evaluated only in the period between 7 a.m. and 18 p.m., because this was the most relevant interval of energy production. Figure 3 shows the hourly averages of climate variables for each month evaluated.

Figure 3 - Hourly averages of (a) temperature, (b) total radiation, (c) Wind Speed, (d) Humidity, (e) Ultraviolet Radiation, (f) Atmospheric Pressure



These data indicated that March (wet season) was an atypical climate month, with the temperature highest than October (dry season). The temperature data reveal low daily thermal amplitude in all seasons, with a maximum daily amplitude in July of

2.31ºC, representing a low intraseason thermal amplitude. In the wet season (February), the minimum hourly temperature was 25.35ºC, and, in the dry season, the minimum hourly temperature was 26.44ºC, an amplitude of 1.09ºC. The hourly thermal amplitude of the maximum temperature was 0.96ºC. As well as temperature, atmospheric pressure presented low amplitude values.

The wind speed had allowed hourly amplitude and high intraseason amplitude, with the highest values occurring in the dry season (17.65 m/s^2) and low values occurring in the wet season (7.96 m/s^2). The total and UV radiation showed high intraseason amplitudes. The average hourly total radiation at 2:00 p.m. was 593.03 Wm^{-2} in the wet season (February) and 861.62 Wm^{-2} in the dry season (October).

In the hour time scale, the correlation analysis among the weather variables revealed a moderate correlation between total radiation, UV radiation, temperature, and atmospheric pressure (Table 1). These results show that temperature is moderately influenced by the other variables, and the wind speed has no influence on ambient temperature. Thus, the ambient temperature in this study area has low variation throughout the day.

Table 1 - Correlation between climatic variables based on hourly data: bold values are statistically significant at 5%

	Wind	Temperature	Rain	Pressure	Humidity	UV Radiation
Temperature	0.19					
Rain	-0.10	-0.32				
Pressure	**-0.40**	-0.17	0.11			
Humidity	-0.09	**-0.53**	0.27	-0.08		
UV Radiation	0.13	**0.52**	-0.12	0.15	-0.30	
Total Radiation	0.16	**0.53**	-0.13	0.17	-0.31	**0.97**

In the daily time scale, the correlation analysis among the weather variables reveals a strong correlation among total radiation, UV radiation, temperature, and pressure (Table 2). Unlike the hourly timescale, in the monthly timescale, the temperature is more influenced by the other meteorological variables. Probably this behavior can be explained by the fact that the temperature is only influenced by atmospheric conditions that last for days.

Table 2 - Correlation between climatic variables based on daily data: bold values are statistically significant at 5%

	Wind	Temperature	Rain	Pressure	Humidity	UV Radiation
Temperature	0.24					
Rain	-0.23	**-0.62**				
Pressure	**-0.63**	**-0.30**	0.12			
Humidity	-0.09	**-0.44**	**0.50**	-0.08		
UV Radiation	0.21	**0.75**	**-0.57**	-0.23	-0.35	
Total Radiation	0.28	**0.73**	**-0.57**	-0.26	-0.33	**0.97**

In the monthly time scale, the correlation analysis among the climatic variables reveals a strong correlation just between temperature and radiation (Table 3). Therefore, in daily and monthly scales, the largest forcing temperature is radiation.

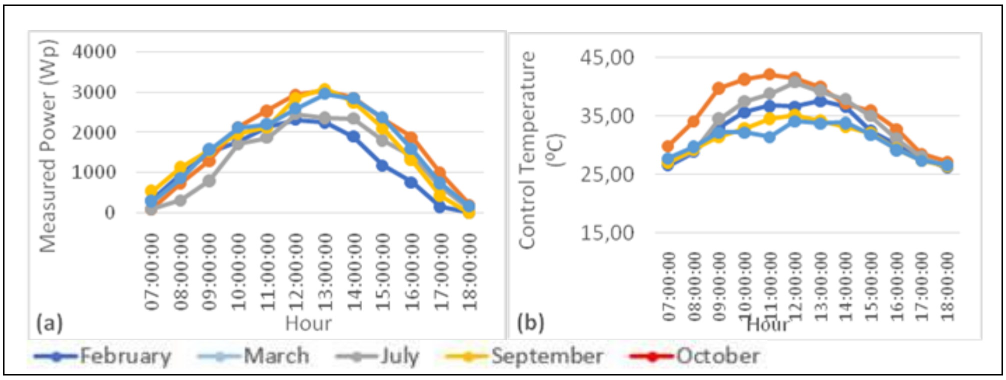
Table 3 - Correlation among weather variables based on months data: bold values are statistically significant at 5%

	Wind	Temperature	Rain	Pressure	Humidity	UV Radiation
Temperature	0.19					
Rain	-0.38	-0.35				
Pressure	**-0.54**	-0.03	0.35			
Humidity	0.13	-0.09	**0.38**	-0.34		
UV	0.15	**0.70**	-0.08	0.25	-0.14	
Total Radiation	0.17	**0.70**	-0.08	0.25	-0.14	**0.99**

3.2 Characterization of the system power data and the operating temperature of the PV cells

The highest averages of solar power generation occurred in March, September, and October, and the lowest in February and July. The highest peak occurred in September at 1:00 p.m. (3076.35 Wp) and the lowest peak in February at 12:00 p.m. (2456.06 Wp), considering the best production period that is from 9:00a.m. to 3:00p.m. The periods of lower production were always recorded between 7:00 a.m. and 9:00 a.m. and after 4:00 p.m. (Figure 4a). The hourly average of the operating temperature (Figure 25b) was higher in the month of March, followed by the months of July, February, October, and September.

Figure 4 - Hourly (a) average power measured and (b) average control temperature



3.3 Influence of climatic variables on energy production

The regression analysis at different time scales revealed the radiation as the mean weather variable to determine the solar power generation (Tables 4 and 5). The daily time scale presented the best adjustment for the estimation of PV energy production.

Table 4 - Regression analysis components corresponding to the linear coefficient (a), angular coefficient (b), coefficient of determination (R^2), and p-value, between meteorological data and total photovoltaic energy production in the evaluated system, at hour time scale

Months	**Weather Variables**	**Coefficients**			
		a	**b**	**R^2**	**p-value**
February (Wet Season)	Wind Speed	-18.32	1394.4	0.0038	0.2961
	Temperature	426.04	-9874.6	0.2839	<0.0001
	Humidity	-84.65	8618.1	0.2715	0.0001
	UV Radiation	279.76	314.32	0.6852	<0.0001
	Total Radiation	3.176	194.74	0.6948	<0.0001
July (Transition Season)	Wind Speed	110.23	641.34	0.0694	0.0004
	Temperature	541.72	-13238	0.3857	<0.0001
	Humidity	-41.566	4190.6	0.1059	<0.0001
	UV Radiation	225.28	404.76	0.6017	<0.0001
	Total Radiation	2.5005	335.42	0.5836	<0.0001
September (Dry Season)	Wind Speed	53.274	717.51	0.0669	<0.0001
	Temperature	1070.5	-27295	0.4348	<0.0001
	Humidity	-127.4	11833	0.1603	<0.0001
	UV Radiation	252.12	484.05	0.7383	<0.0001
	Total Radiation	2.8921	237.55	0.786	<0.0001

Table 5 - Regression analysis corresponding to the linear coefficient (a), angular coefficient (b), coefficient of determination (R^2), and p-value, between meteorological data and total photovoltaic energy production in the evaluated system, at daily time scale

Months	**Weather Variables**	**Coefficients**			
		a	**b**	**R^2**	**p-value**
February (Wet Season)	Wind Speed	22.19	1088.10	0.0066	0.7053
	Temperature	354.85	-8047.40	0.4790	0.0002
	Humidity	-83.10	8440.10	0.6295	<0.0001
	UV Radiation	349.67	33.05	0.9174	<0.0001
	Total Radiation	3.90	-87.45	0.9095	<0.0001
July (Transition Season)	Wind Speed	18.94	1202.40	0.0088	0.7393
	Temperature	257.69	-5605.60	0.3978	0.0117
	Humidity	-33.93	3627.20	0.3828	0.0139
	UV Radiation	266.27	238.47	0.9238	<0.0001
	Total Radiation	3.37	-6.35	0.9154	<0.0001
September (Dry Season)	Wind Speed	15.46	1381.70	0.0377	0.3315
	Temperature	139.77	-2126.00	0.0327	0.3665
	Humidity	-15.65	2904.60	0.0231	0.4491
	UV Radiation	240.37	535.66	0.7331	<0.0001
	Total Radiation	2.60	409.28	0.7303	<0.0001

4 DISCUSSION

The issues addressed in this work concern the analysis of climatic variables and their effects on the energy production of PV panels in the city of São Luís. To support the analysis, the Pearson correlation was used to correlate the climatic variables between themselves and with the energy production of the PV system. In the correlation of the climatic variables, the temperature has a very strong correlation with the UV radiation and the total irradiation. For an average temperature of 27.50°C, in the month of March, the UV irradiation was 5.06, while the average of the total irradiation was 481.01 W.m^{-2}. The maximum peak temperature was 27.88°C at noon, while UV irradiation was 8.55 and total irradiation was 794.97 W.m^{-2}. At this mean temperature variation of 0.38°C, there was a variation of 313.96 W.m^{-2}.

Rain, humidity, and pressure had a direct and strong correlation; however, rainfall and wind behavior were inversely correlated.

The pressure was directly related to solar irradiation and UV irradiation, but inversely related to temperature. The operating temperature had a direct influence on the voltage levels produced on the board or system. For the determination of this variable, Skoplak *et al*. (2008), in Equation (1), used the ambient temperature, wind speed, and total irradiation, in addition to the system assembly coefficient. According to Griffith *et al*. (2018), the mentioned variables can be classified in descending order of sensitivity in the results — irradiance, wind speed, and ambient temperature.

The results of this correlation indicate that the effects of temperature rise and irradiation on energy production have an inverse influence on system performance.

The effects of temperature and irradiation on the PV plates are important for understanding the behavior of voltage (volts) and current (amperes) (RAZKOV *et al*., 2010). While the temperature contributes to the production of voltage, the excess can destabilize; just as the irradiation contributes to the production of electric current, the excess also contributes to the compromise of the energy produced by the system. Adjustment of this situation is dealt with by aligning cells and plates in serial or parallel bonding systems.

The power produced by the system is more subject to a variation of amplitude of the irradiation than of the temperature, because, in absolute terms, a variation of 5% in the average of the temperature can represent a variation of 40% for the irradiation — that is, this component has greater influence on the energy production of the system.

5 CONCLUSION

An attempt was made to explain how much the climatic variables can influence, in an isolated or grouped way, the determination of the energy production of a plate or of a PV system. Part of the answer is that the main variables that contribute to the production are the irradiation and temperature; however, they only do not respond for all the variation of the system.

The established correlations between the climatic variables and the energy production demonstrate that the oscillation in production is related to the variation of temperature and irradiation.

The effect of wind speed on the boards is highlighted by their ability to cool the modules and possibly reduce the damaging effect that excess heat can have on the system. At temperatures closer to nominal, 25ºC, the energy production is lower because of the lower irradiance. In the period from 9:00 a.m. to 3:00 p.m., considering the average full-sun period, the temperature and irradiation are at their maximum peaks, and the system performance is lower, and this inverse effect is reflected in the behavior of energy production.

Energy production can change dramatically if climatic conditions change rapidly, such as the effects of humidity (cloudiness) and rainfall, which act to reduce the production of the system.

It can be concluded from the results of the question that, although São Luís is in a transition region between the Cerrado and the Amazon, which is very close to the equator, the conditions for the production of the system are favorable, mainly because, on average, there were no abrupt changes in temperature and radiation for the period studied. Even in the wintry period, the production behaves within the parameters for which it was designed.

In relation to the integrated influence of the meteorological variables in the production of PV energy, the answer is “yes”; however, it should be emphasized that this conclusion comes from the correlation already discussed. To better answer the question, a multivariate analysis is planned, based on two univariate and multivariate analyses.

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REFERENCES

ANGONESE, A. R.; Campos, A. T.; ZACARKIM, C. Eb.; MATSUO, M. S.; CUNHA, F. Energy efficiency of pig production system with waste treatment in biodigestor. Brazilian Journal of Agricultural and Environmental Engineering, v.10, n.3, p.745-750, 2006.

ARVIZU, D. *et al*. Direct Solar Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011.

BEZERRA JÚNIOR, J. T; BEZERRA JÚNIOR, J. T. The market of distribution of electric energy in Maranhão: a study on environmental proactivity, 2013.

BRAUN, P.; SANTOS, I. P.; ZOMER, C. D.; RÜTHER, R. The integration of solar photovoltaic systems at six Brazilian airports using different solar cell technologies. Brazilian Journal of Solar Energy. v.1, n.1, p.12-22, 2010.

DUBEY, S.; SARVAIYA, J. N.; SESHADRI, B. Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world - A review. Energy Procedia, v. 33, p. 311–321, 2013.

EVANS, D. L. Simplified method for predicting photovoltaic array output. Solar Energy, v. 27, pp. 555-560, Jul. 1981.

EVANS, D. L.; FLORSCHUETZ, L. W. Cost studies on terrestrial photovoltaic power systems with sunlight concentration. Solar Energy, v. 19, n. 3, p. 255-262, 1977.

FEDRIZZI, M. C.; SAUER, I.L. Photovoltaic solar pumping, historical, features and projects. University of Sao Paulo. Program Interunidades of Post-Graduation in Energy, 2002.

FERREIRA, T. D. V. G.; OLIVEIRA, L. H. D. Individual decentralized non-potable water system: the need for quality and quantity management. AmbienteConstruído, v. 18, n. 1, p. 379-392, 2018.

GARG, H.P., AGARWAL, R.K. “Some aspects of a PV/T collector/forced circulation flat plate solar water heater with solar cells”. Energy Conversion and Management, v. 36, p. 87–99, Out. 1994.

GRIFFITH, J. S.; RATHOD, N. S.; PASLASKI, J. Some tests of flat plate photovoltaic module cell temperatures in simulated field conditions. Proc. 15th IEEE PhotovoltaicSpecialists Conf. Kissimmee, EUA, p. 822-30, 1981.

GUERRA, Hélvio Neves. I Workshop OSTSEV: Operação de Sistemas Fotovoltaicos em Condições Ambientais e Climáticas. 2017.

GUERRA, S.M.G.; FANTINELLI, J.T. The approach between technology and economy: the emerging roles of energy. Journal of Social Studies. Year 3, n. 5, p.33-58, 2001.

HAMAKAWA, S.; HIBINO, T.; IWAHARA, H. Electrochemical Hydrogen Permeation in a Proton-Hole Mixed Conductor and Its Application to a Membrane Reactor. Journal of the Electrochemical Society, v. 141, n. 7, p. 1720-1725, 1994.

HART, G. W.; RAGHURAMAN, P. Simulation of thermal aspects of residential photovoltaic systems. MIT Report DOE/ET/20279-202, 1982.

HEGEDUS, S. Review of photovoltaic module energy yield (kWh/kW): Comparison of crystalline Si and thin film technologies. Wiley Interdisciplinary Reviews: Energy and Environment, v. 2, n. 2, p. 218–233, 2013.

HERNÁNDEZ-Moro, J.; MARTÍNEZ-Duart, J. M. Analytical model for solar PV and CSP electricity costs: Present LCOE values and their future evolution. Renewable and Sustainable Energy Reviews, v. 20, p. 119-132, 2013.

LAVRATTI, Paula Cerski; PRESTES, VanescaBuzelato. Diagnosis of the legislation: identification of the norms with incidence in mitigation and adaptation to the climatic changes. Institute the right for a green planet, 2010.

MARTINS, V. S.; NOVO, E. M. L. M.; LYAPUSTIN, A.; ARAGÃO, L. E. O. C.; FREITAS, S. R.; BARBOSA, C. C. F. Seasonal and interannual assessment of cloud cover and atmospheric constituents across the Amazon (2000–2015): Insights for remote sensing and climate analysis. ISPRS Journal of Photogrammetry and Remote Sensing, v. 145, p. 309–327, 2018.

RAZIKOV, T.M; FEREKIDES, C.S.; MOREL, D.; STEFANAKOS, E.; HULLAL, H.S.; UPADHYAYA, H.M. Solar photovoltaic electricity: Current status and future prospects. Solar Energy, v. 85, p. 1580-1608, 2011.

SALLA, D. A.; FURLANETO, F.P.B.; CABELLO, C.; KANTHACK, R.A.D. Energy analysis of cassava ethanol production systems (Manihot esculenta Crantz). Brazilian Journal of Agricultural and Environmental Engineering, v.14, n. 4, p. 444-448, 2010.

SANO, E. E.; FERREIRA, L. G.; ASNER, G. P.; STEINKE, E. T. Spatial and temporal probabilities of obtaining cloud-free Landsat images over the Brazilian tropical savanna. International Journal of Remote Sensing, v. 28, n. 12, 2739–2752, 2007.

SCHULER, M.; GREEN, D. R. Mechanisms of p53-dependent apoptosis, 2001.

SILVA, F. B.; SANTOS, J. R. N.; FEITOSA, F. E. C. S.; SILVA, I. D. C.; ARAÚJO, M. D.; GUTERRES, C. E.; NERES, R. L. Evidências de mudanças climáticas na região de transição Amazônia-Cerrado no estado do Maranhão. Revista Brasileira de Meteorologia, v. 31, n. 3, p. 330-336, 2016.

SINGH, P.; RAVINDRA, N.M., Temperaturedependenceof solar cell performance ananalysis. Solar Energy Materials & Solar Cells, v. 101, p. 36–45, 2012.

SKOPLAKI, E.; BOUDOUVIS, A.G.; PALYVOS, J.A. A simple correlation for the operating temperature of photovoltaic modules of arbitrary mounting. Solar Energy Materials & Solar Cells, v. 92, p. 1393– 1402, Mai. 2008.

SKOPLAKI, E.; PALYVOS, J.A. On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. Solar Energy, v. 83, n. 5, p. 614–624, Mai. 2009.

SKOPLAKI, E.; PALYVOS, J.A. Operating temperature of photovoltaic modules: A survey of pertinent correlations. Renewable Energy, v. 34, p. 23–29, Jun. 2008.

SOUSA, T.A.; PREGITZER R.L.; MARTINS, J.S.; AFONSO, J.L. Study of the Panorama of Renewable Energy in the European Union and Suggestions for Portugal. Conference on RenewableEnergiesandEnvironment in Portugal Figueira da Foz, Portugal, p. 1.87-1.92. 201. 2015.

TOLMASQUIM, Mauricio T.; GORINI, Ricardo. Brazilian energy matrix: a prospective. New studies. - CEBRAP, São Paulo, n. 79, p. 47-69, Nov. 2007.

TRIGOSO, F.M.; QUAGLIA, R. B.; MORAES, A. M.; OLIVEIRA, S.H.F. Panorama of distributed generation in Brazil based on the use of Photovoltaic Solar technology. Revista Brasileira de Energia Solar, v. 1, n. 2, p. 127-138, 2010.

VEISSID, Nelson; BARUEL, Mário Ferreira. Solar Energy and its Application in Satellites. São José dos Campos: SindCT, 2012. Available at www.sindct.org.br/files/celulassolares.pdf. Accessed 05/02/2018.

VON ROEDERN, B.; KENNETH, Zweibel; HARIN, S. Ullal. The role of polycrystalline thin-film PV technologies for achieving midterm market-competitive PV modules. Photovoltaic Specialists Conference, 2005. Conference Record of the Thirty-first IEEE. IEEE, 2005.

ZOLPER, J. C.; NARAYANAN, S.; WENHAM, S. R.; GREEN, M. A. 16.7% efficient, laser textured, buried contact polycrystalline silicon solar cell. AppliedPhysicsLetters, v. 55, n. 22, p. 2363-2365, 1989.