PHOTOVOLTAIC SOLAR ENERGY PRODUCTION FOR BRAZILIAN BUILDINGS IN CLIMATE CHANGE SCENARIOS

Carolina Kratsch Sgarbossa[1]
Jorim Sousa das Virgens Filho[2]

[1]Universidade de São Paulo
[2]Universidade Estadual de Ponta Grossa

DOI: 10.47168/rbe.v25i3.476

ABSTRACT

Brazilian cities present a great potential for the use of photovoltaic solar energy. The use of this technology may be a strategy to mitigate the effects of regional climate change. This research aimed to determine the estimation of photovoltaic solar energy production for brazilian single family residences in scenarios of possible climatic changes projected until the end of the 21st century. For the simulation of the climatic scenarios the software PGECLIMA_R was used. To estimate the electrical power produced by the system, daily data of global solar radiation were used. In order to evaluate the data, the Analysis of Variance (ANOVA), with comparison of means (Tukey's test) were used. The simulated global solar radiation data showed a decreasing trend in relation to historical data. All localities indicated annual rates of 98% of system service, which proves that the State of Paraná-Brazil has favorable climatic conditions for the installation of these systems.

Keywords: Global solar radiation; Photovoltaic solar energy; Climate changes; Brazilian single family homes.

RESUMO

As cidades brasileiras apresentam um grande potencial para o uso da energia solar fotovoltaica. O uso dessa tecnologia pode ser uma estratégia para mitigar os efeitos das mudanças climáticas regionais. Esta pesquisa teve como objetivo determinar a estimativa da produção de energia solar fotovoltaica para residências unifamiliares brasileiras em cenários de possíveis mudanças climáticas projetadas até o final do século XXI. Para a simulação dos cenários climáticos foi utilizado o software PGECLIMA_R. Para estimar a energia elétrica produzida pelo sistema, foram utilizados dados diários de radiação solar global. Para avaliação dos dados, foi utilizada a Análise de Variância (ANOVA), com comparação de médias (teste de Tukey). Os dados simulados de radiação solar global apresentaram tendência decrescente em relação aos dados históricos. Todas as localidades indicaram taxas anuais de 98% de serviço do sistema, o que comprova que o Estado do Paraná-Brasil possui condições climáticas favoráveis para a instalação desses sistemas.

Palavras-chave: Radiação solar global; Energia solar fotovoltaica; Mudanças climáticas; Casas unifamiliares brasileiras.

1. INTRODUCTION

The photovoltaic solar energy contributes less than 1% in the Brazilian electrical matrix. Despite of that, Brazilian cities exhibit great potential for the use of solar energy, due to the large area availability and the high incidence of global solar radiation. In addition, coverage of less than 0.04% of the territory with photovoltaic modules could generate more energy than the country's total annual electricity consumption, which is about 500 TWh/year (RÜTHER and SALAMONI, 2011; RÜTHER and ZILLES, 2011). It is estimated that Households represent approximately 21% of total electricity consumption, most part are used for the use of air conditioning, electric shower and refrigeration (ELETROBRÁS, 2007).

The regulation for photovoltaic systems connected to the distribution network was defined by the National Electric Energy Agency (ANEEL) in 2012 and the mechanism for compensation of electric energy was foreseen, that is, a system can inject the surplus in the electric grid, with the possibility of accumulating credits to be compensated in kWh, when the amount of energy generated is lower than the one consumed (PEREIRA et al., 2017).

Furthermore, climate change can affect the energy sector because it is estimated that, by the year 2100, the average global temperature will increase between 1.3 and 4.8ºC, which may lead to a tendency to decrease the demand for heating energy between 36 and 58%, and increase the demand for cooling between 223 and 1050% per year (MARENGO, 2001; FRANK, 2005; IPCC, 2014).

The State of Paraná holds 80.5% of its municipalities with annual average solar radiation above the Brazilian average (2 kWh/m²). From a comparative perspective, in terms of estimated productivity, the total annual average of Paraná is 58.75% higher than Germany, 1.97% to Spain, and 31.28% to France, certifying the viability of the implantation of photovoltaic systems in the State (TIEPOLO et al., 2014).

In view of the foregoing and considering the mitigating and adaptive environmental context for the State of Paraná, this research aimed to determine the estimation of photovoltaic solar energy production for single family homes, in scenarios of possible climatic changes projected towards the end of the 21st century.

2. MATERIALS AND METHODS

Eight localities of the State of Paraná, Figure 1, were selected from climatological data of conventional meteorological stations, Table 1, which are available in the Meteorological Database for Teaching and Research (BDMEP) by the National Institute of Meteorology (INMET).

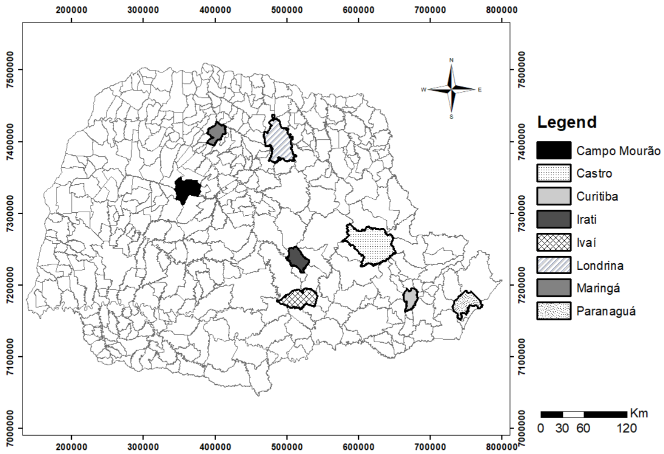


Figure 1 - Selected locations in the State of Paraná

Table 1 - Geographical coordinates of selected locations

ID	Locality	Latitude (S)	Longitude (W)	Elevation (m)
L1	Campo Mourão	-24º05'	-52º36'	616
L2	Curitiba	-24º78'	-50º00'	1009
L3	Castro	-25º43'	-49º26'	924
L4	Irati	-25º46'	-50º63'	837
L5	Ivaí	-25º00'	-50º85'	808
L6	Londrina	-23º31'	-51º13'	566
L7	Maringá	-23º40'	-51º91'	542
L8	Paranaguá	-25º53'	-48º51'	5

The State of Paraná belongs to the region of southern Brazil and is located between the parallels 22º30'58 "and 26º43'00" south latitude and between the meridians 48º05'37 "and 54º37'08" west longitude. According to Köppen's climate classification, the State has two types: Cfa - Subtropical climate and Cfb - Temperate climate.

The daily historical series of insolation and temperatures comprised a period of 31 years (1987-2017). For the simulation of climatic scenarios, the PGECLIMA_R software was used, whose daily climatic data were simulated for two scenarios.

Based on a tendency of decrease of the thermal amplitude for the South Brazil (Marengo and Camargo, 2008; Silva et al., 2015), the simulations projected were: increases of 2.1 ºC in the minimum temperature and 1.3 ºC in the maximum temperature, for the least pessimistic scenario (C1); and increases of 5.9 ºC in the minimum temperature and 3.7 ºC in the maximum temperature, for the most pessimistic scenario (C2).

The estimation method proposed by Chen et al. (2004), Equation 1, was adopted to predict projections for global solar radiation based on the daily temperature range and on the solar radiation at the top of the atmosphere.

$$R_G = R_A \times a \times \ln(\Delta T) + b \tag{1}$$

where,
R_G is global solar radiation;
R_A radiation at the top of the atmosphere;
"a" and "b" are coefficients of the regression equation;
"ΔT" is the thermal amplitude (difference between the maximum and minimum temperatures).

For the hypothetical residence, was defined the value of 75 m² of constructed area and an average monthly consumption of 300 kWh/month.

For the estimation of the electric power produced by a photovoltaic system in a residence, the methodology proposed by Marques et al. (2012) was used. The calculation of the energy generated, in kWh/m2.month by the system (Eg) is expressed in Equation 2.

$$E_g = P_t \times \eta \times n_d \times R_{G\,month} \tag{2}$$

where:
P_t is the nominal installation power, in kWp;
η is the efficiency of the inverter;
n_d is the number of days in the month;
$R_{G\,month}$ is the monthly average of global solar radiation, in kWh/m^2.

In order to verify the availability of global solar radiation in the system implementation, the comparison between the observed averages (historical series) and the simulated averages (2018-2099) were performed by means of statistical analysis. The R_G data were segmented into three periods, P39 (2018-2039), P69 (2040-2069), and P99 (2070-2099).

In the sequence, the data normality was tested by means of the Shapiro-Wilk test. For data with normal distribution, the one-way ANOVA technique was used, with a significance level of 5%. For non-normal data sets, the Kruskal-Wallis test was used, which is a non-parametric one-way ANOVA for one factor.

3. RESULTS AND DISCUSSION

Table 2 shows the average monthly values of RG for the historical period (Hist) and simulated periods P39, P69 and P99, in the scenarios C1 and C2 for the locality of Campo Mourão. It was observed that for C1, the months that presented significant differences during the year were February, April and December, whereas for C2, only the month of November did not present statistical significance in the comparison between the historical and simulated periods. It was found that, although impacted by climate change scenarios, the significant differences found in RG in P39, P69 and P99 were not very significant in magnitude, since the decrease in monthly energy availability was on average of 0.3 kWh/m^2 in C1 and 0.7 kWh/m^2 in C2.

Table 2 - Statistical analysis (ANOVA or KRUSKAL-WALLIS) of the means of RG (kWh/m²) for Campo Mourão-PR

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
Jan	0.0863	-	5.97a	5.78a	5.69a	5.53a
Fev	0.0059	-	5.91a	5.65ab	5.59ab	5.29b
Mar	-	0.1482	5.48a	5.33a	5.27a	5.20a
Apr	0.0354	-	4.68a	4.53ab	4.43ab	4.35b

Table 2 - Continuação

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
May	-	0.1604	3.69a	3.62a	3.49a	3.54a
Jun	0.2430	-	3.22a	3.07a	3.06a	3.19a
Jul	-	0.2720	3.59a	3.44a	3.35a	3.32a
Aug	0.5350	-	4.19a	4.15a	4.06a	4.19a
Sep	0.2980	-	4.85a	4.59a	4.59a	4.61a
Oct	0.8750	-	5.22a	5.24a	5.33a	5.23a
Nov	-	0.3613	6.15a	6.31a	6.19a	6.19a
Dec	0.0005	-	6.62a	6.26ab	6.17b	5.87b
C2						
Jan	0.0000	-	5.97a	5.74a	5.16b	4.93b
Fev	0.0000	-	5.91a	5.63a	5.03b	4.72b
Mar	0.0001	-	5.48a	5.26ab	5.08bc	4.74c
Apr	-	0.0003	4.68a	4.34ab	4.27ab	4.04b
May	0.0028		3.69a	3.63ab	3.28bc	3.25c
Jun	0.0000	-	3.22a	3.09ab	2.84bc	2.73c
Jul	-	0.0016	3.59a	3.32ab	3.40a	2.99b
Aug	0.0004	-	4.19a	4.20a	3.98ab	3.82b
Sep	0.0197	-	4.85a	4.55ab	4.33b	4.35b
Oct	0.0035	-	5.22a	5.20a	4.94ab	4.62b
Nov	0.0975	-	6.15a	6.21a	5.97a	5.84a
Dec	0.0000	-	6.62a	6.15ab	5.65bc	5.38c

Note: Values followed by lower case letters do not differ statistically from each other at the 5% level of significance by the Tukey test

In Figures 2A and 2C, it was observed that for this locality, both the historical and simulated RG in C1 and C2, presented the same pattern of variation among the months of the year, although the simulated values show a tendency of decrease over of the reproduced periods of P39, P69 and P99, in relation to historical values.

Still looking at Figures 2A and 2B we observed the relationship between R_G, understood in this work as available solar energy, and the generated electric energy (E_g) from RG. Those of R_G are presented with a more intense color hue, corresponding to the left axis in the graph, while the columns of less intense color refer to the data of E_g, related to the right axis. It was observed a tendency of decrease of E_g over the periods, as a consequence of the reduction of R_G. It was also observed that the values of R_G and E_g were a little higher in C1 when compared to C2, due to the higher temperature increase in C2. Mean values of R_G for Campo Mourão (Figures 2A and 2C) ranged from 2.7 to 6.6 kWh/m², with an annual average of 4.7 kWh/m², while E_g values were in the range between 184 and 389 kWh/month.

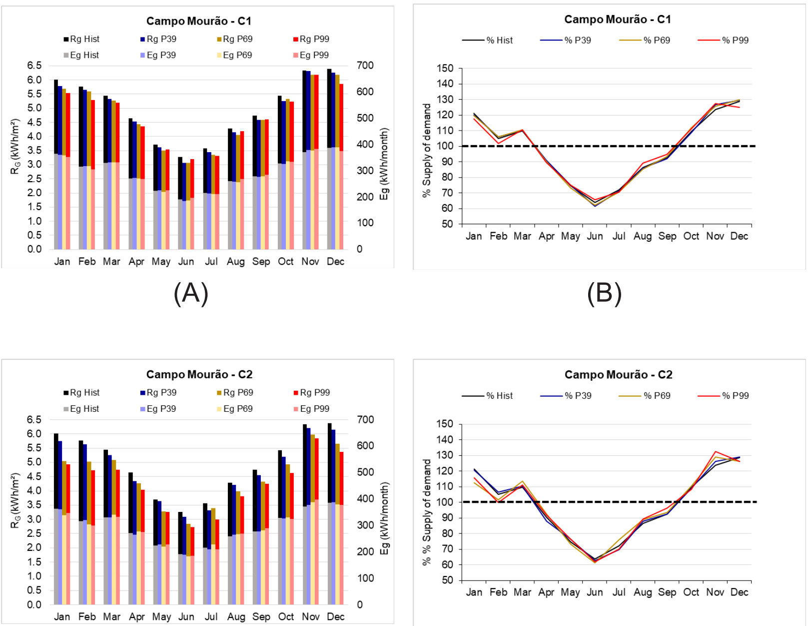


Figure 2 - Available solar radiation (R_G), Electric power generated from R_G (E_g) and Percentage serviced monthly for each residence in the historical period and up to 2099 in scenarios C1 and C2 for Campo Mourão-PR

In Figures 2B and 2D the percentages of energy service are verified in the residence for the historical periods, P39, P69 and P99, in scenarios C1 and C2, in which it was considered the service of 100% of the month whose energy that was generated (Eg) was higher than the established consumption of 300 kWh/month. It was observed that the full attendance occurred in the months from October to March, due to the high RG índices in the period. However, the system deficit period was verified between April and September, and the month that reached the worst energy generation was June, with attendance rates above 60%, while in the best situation, the month of December, provided close service to 130%.

It is possible to consider the percentage of attendance as an annual efficiency metric. When analyzing the annual service, the system presents efficiency of 98%, both for historical periods, P39, P69 and P99 in C1 and for the same periods in C2. That is, in an annual perspective, the residence in this case needs to pay to the concessionaire only 2% of the consumed electric energy. Regarding the number of plates required, the hypothetical residence of the locality of Campo Mourão would require 9 photovoltaic plates in the considered periods and scenarios.

Table 3 - Statistical analysis (ANOVA or KRUSKAL-WALLIS) of the means of RG (kWh/m²) for Castro-PR

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
Jan	0.0001	-	4.94a	4.74a	4.67a	4.38b
Fev	0.0482	-	4.90a	4.67ab	4.61ab	4.53b
Mar	-	0.4626	4.43a	4.28a	4.36a	4.23a
Apr	0.3300	-	3.68a	3.83a	3.77a	3.71a
May	0.0679	-	2.92a	2.87a	2.85a	2.57a
Jun	-	0.5668	2.69a	2.71a	2.59a	2.61a
Jul	0.8310	-	2.94a	2.98a	2.94a	2.87a
Aug	0.2100	-	3.60a	3.66a	3.52a	3.47a
Sep	-	0.8385	3.91a	3.88a	3.80a	3.81a
Oct	0.8590	-	4.22a	4.19a	4.26a	4.14a
Nov	-	0.2113	5.12a	5.13a	5.10a	5.30a
Dec	0.0008	-	5.25a	4.75b	4.89ab	4.58b

Table 3 - Continuação

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C2						
Jan	0.0000	-	4.94a	4.47b	4.10bc	3.82c
Fev	0.0006	-	4.90a	4.62ab	4.38b	4.25b
Mar	0.0023	-	4.43a	4.18ab	3.86b	3.68b
Apr	0.0532	-	3.68a	3.75a	3.57a	3.51a
May	0.0046	-	2.92a	2.71ab	2.45b	2.33b
Jun	-	0.0079	2.69a	2.70ab	2.41ab	2.34b
Jul	0.1220	-	2.94a	3.00a	2.87a	2.73a
Aug	0.0015	-	3.60a	3.58a	3.49a	3.16b
Sep	0.1110	-	3.91a	3.69a	3.71a	3.58a
Oct	0.1480	-	4.22a	4.20a	4.07a	3.92a
Nov	0.0590	-	5.12a	5.26a	5.53a	5.51a
Dec	0.0000	-	5.25a	4.80b	4.59bc	4.40c

Note: Values followed by lower case letters do not differ statistically from each other at the 5% level of significance by the Tukey test

For the locality of Castro, Table 3, it was verified that the estimated values of $R_{G\,n}$ the periods P39, P69 and P99 exhibited significant differences in the C1 for the months of January, February and December, with a small trend of decreasing values, in a period considered of higher temperatures corresponding to the summer season. In the C2 scenario, the months that presented statistical significance were the majority, the months of April, July, September, October and November showing no significant differences in the available energy (R_G) among the periods P39, P69 and P99, demonstrating that the months related to summer tend to show decreases in RG values throughout the century. However, in absolute terms, these differences with a mean decrease of 0.2 and 0.4 kWh/m² in C1 and C2, respectively, do not have a significant impact on energy availability.

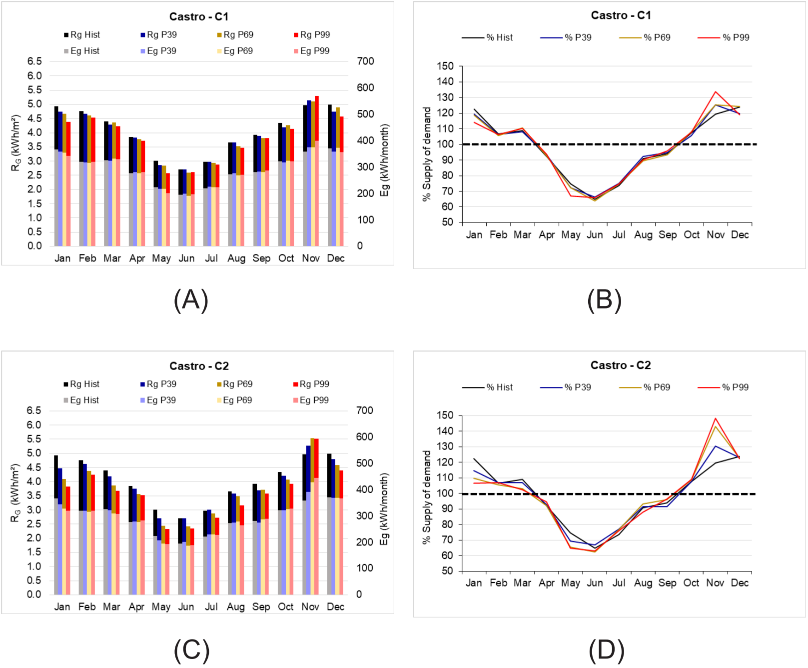


Figure 3 - Available solar radiation (R_G), Electric power generated from R_G (E_g) and Percentage serviced monthly for each residence in the historical period and up to 2099 in scenarios C1 and C2 for Castro-PR

Figures 3A and 3C show that the highest R_G values were between October and March, which comprises approximately the spring and summer seasons, with an average annual value of 3.8 kWh/m² in both scenarios. November has a tendency to increase, with values above 5 kWh/m² in all the evaluated periods. In relation to E_g, values fluctuated between 191 and 445 kWh/month, with the highest generation peak in November, coinciding with the high R_G values for the same month. In general, a trend was found in which values from E_g to C1 (Figure 3A) are higher than for C2 (Figure 3B) in the months between October and March, excluding November, whereas between April and September the values tend to be higher in C2.

In relation to the percentage of monthly attendance (Figures 3B and 3D), the values varied between 62 and 148%, considering the two scenarios (C1 and C2), with the lowest percentages obtained in June and the highest in November. It was observed that the fullness of consumption is supplied by the system in the period from October to March. In the annual scope, the system presented a percentage of attendance of 98% considering all periods and scenarios. As for the number of plates required, the hypothetical residence for the locality of Castro would require 11 plates considering the periods of C1 and 12 plates for C2.

Table 4 - Statistical analysis (ANOVA or KRUSKAL-WALLIS) of the means of RG (kWh/m²) for Curitiba-PR

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
Jan	0.0544	-	5.35a	5.09a	4.94a	4.86a
Fev	-	0.0031	5.39a	4.67b	4.74ab	4.58b
Mar	-	0.2630	4.67a	4.55a	4.37a	4.35a
Apr	-	0.0675	3.69a	3.62a	3.74a	3.38a
May	0.9640	-	3.10a	3.11a	3.07a	3.10a
Jun	-	0.2458	2.76a	2.76a	2.82a	2.73a
Jul	0.0323	-	3.20a	3.12ab	3.01ab	2.89b
Aug	0.7350	-	3.75a	3.76a	3.72a	3.66a
Sep	0.0128	-	4.11a	3.76ab	3.89ab	3.37b
Oct	0.7240	-	4.39a	4.27a	4.30a	4.22a
Nov	0.0548	-	5.26a	5.23a	5.26a	4.79a
Dec	0.2030	-	5.50a	5.33a	5.13a	5.10a
C2						
Jan	-	0.0000	5.35a	4.94a	4.59ab	3.96b
Fev	0.0000	-	5.39a	4.75b	4.46b	3.76c
Mar	0.0003	-	4.67a	4.40ab	4.10bc	3.76c
Apr	0.0027	-	3.69a	3.64a	3.34ab	3.18b
May	-	0.0018	3.10a	3.02a	2.90ab	2.74b
Jun	-	0.0512	2.76a	2.81a	2.71a	2.63a
Jul	0.0036	-	3.20a	2.99ab	2.77b	2.73b
Aug	-	0.0167	3.75a	3.71a	3.55ab	3.39b
Sep	0.0000	-	4.11a	3.83a	3.29b	3.12b
Oct	0.0034	-	4.39a	4.47a	4.16ab	3.94b
Nov	0.0000	-	5.26a	5.13ab	4.75bc	4.37c
Dec	0.0001	-	5.50a	5.03ab	4.64b	4.51b

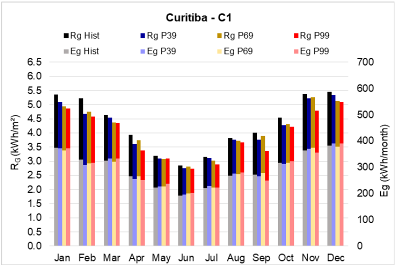
Note: Values followed by lower case letters do not differ statistically from each other at the 5% level of significance by the Tukey test

Table 4 presents the values for the Curitiba locality, where there is a trend of decreasing the energy available until the end of the century. In C1, only the months February, July and September have statistical significance, with an average decrease of 0.3 kWh/m² between the historical period and P99. Conversely, for C2, only the month of June did not show a significant decrease in RG, and the mean reduction was 0.8 kWh/m² in absolute values between the historical period and P99.

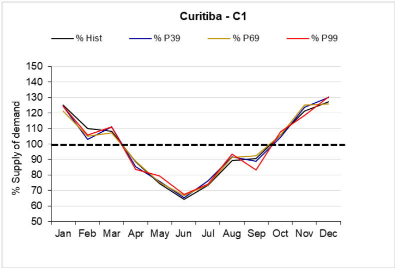
The medium R_G values for Curitiba (Figures 4A and 4C) varied between 2.7 and 5.5 kWh/m², with an annual average of 3.9 kWh/m², and in C1 the values (darker hue) are higher compared to C2. The variation of the energy availability between the historical period and P99 was more accentuated in C.

The values of E_g, considering the two scenarios, were in the range between 192 and 391 kWh/month and are slightly higher in C2, however, comparing the monthly values, in the month of December in all periods of scenario C1, there was a higher power generation.

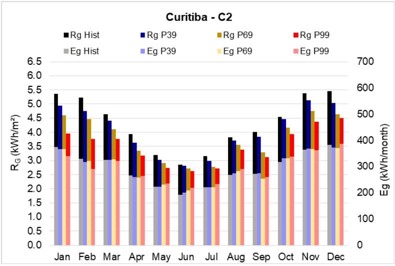
The attendance of the system in the two scenarios varied between 64 and 130% for this locality, and it was verified that this percentage increased about 5% in the worst month considered (June), in C2, when compared to C1. For the periods evaluated in scenario C1, 11 plates will be needed, while for C2, 12.



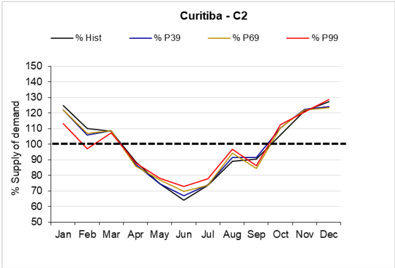
(A)



(B)



(C)



(D)

Figure 4 - Available solar radiation (R_G), Electric power generated from R_G (E_g) and Percentage serviced monthly for each residence in the historical period and up to 2099 in scenarios C1 and C2 for Curitiba-PR

About the monthly average values of RG or the historical period (Hist) and simulated periods P39, P69 and P99, in the scenarios C1 and C2, for the Irati locality (Table 5), it was observed that for C1, the months which presented significant differences during the year were February, June and December, whereas for C2, only the months of April and May did not present statistical significance in the comparison between the historical and simulated periods. It was found that the decline in monthly energy availability over the year in C1 and C2 was on average 0.2 and 0.6 kWh/m², respectively, and these differences in energy terms are not considered expressive.

Table 5 - Statistical analysis (ANOVA or KRUSKAL-WALLIS) of the means of RG (kWh/m²) for Irati-PR

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
Jan	-	0.3272	5.48a	5.26a	5.10a	5.18a
Fev	0.0087	-	5.29a	4.89ab	4.71b	4.63b
Mar	-	0.1282	4.64a	4.68a	4.38a	4.42a
Apr	0.0704	-	3.78a	3.80a	3.60a	3.54a
May	-	0.8994	3.07a	3.12a	3.09a	3.09a
Jun	0.0079	-	2.76ab	2.85a	2.66b	2.74ab
Jul	-	0.8351	3.12a	3.11a	3.08a	3.06a
Aug	0.6670	-	3.74a	3.77a	3.69a	3.68a
Sep	-	0.1511	4.09a	4.01a	4.16a	4.01a
Oct	0.7410	-	4.49a	4.56a	4.47a	4.38a
Nov	-	0.2651	5.37a	5.42a	5.28a	5.20a
Dec	0.0237	-	5.67a	5.52ab	5.35ab	5.31b
C2						
Jan	0.0001	-	5.48a	5.16ab	4.92bc	4.60c
Fev	0.0000	-	5.29a	4.52b	4.02bc	3.57c
Mar	-	0.0034	4.64a	4.52a	4.31ab	3.95b
Apr	0.0569	-	3.78a	3.79a	3.58a	3.49a
May	0.2730	-	3.07a	3.09a	3.00a	2.95a
Jun	0.0004	-	2.76a	2.67a	2.62ab	2.46b
Jul	0.0037	-	3.12a	2.82ab	2.71b	2.57b
Aug	-	0.0117	3.74a	3.67ab	3.70a	3.50b
Sep	0.010	-	4.09a	4.11a	3.89ab	3.74b
Oct	-	0.0115	4.49ab	4.54a	4.09ab	3.99b
Nov	-	0.0056	5.37a	5.24ab	5.12ab	4.88b
Dec	0.0000	-	5.67a	5.25b	5.14bc	4.84c

Note: Values followed by lower case letters do not differ statistically from each other at the 5% level of significance by the Tukey test

In Figures 5A and 5C, a downward trend over the reproduced periods of P39, P69 and P99 was observed for this locality, in relation to historical values. The average monthly RG for Irati ranged from 2.4 to 5.6 kWh/m², with the annual average being about 4.0 kWh/m².

It was found that the values of Eg were in the range between 187 and 394 kWh/month, with the peak of generation in the month of December. It was also observed that the values of RG and Eg are shown to be slightly higher in C1 when compared to C2 due to the higher temperature increase in C2.

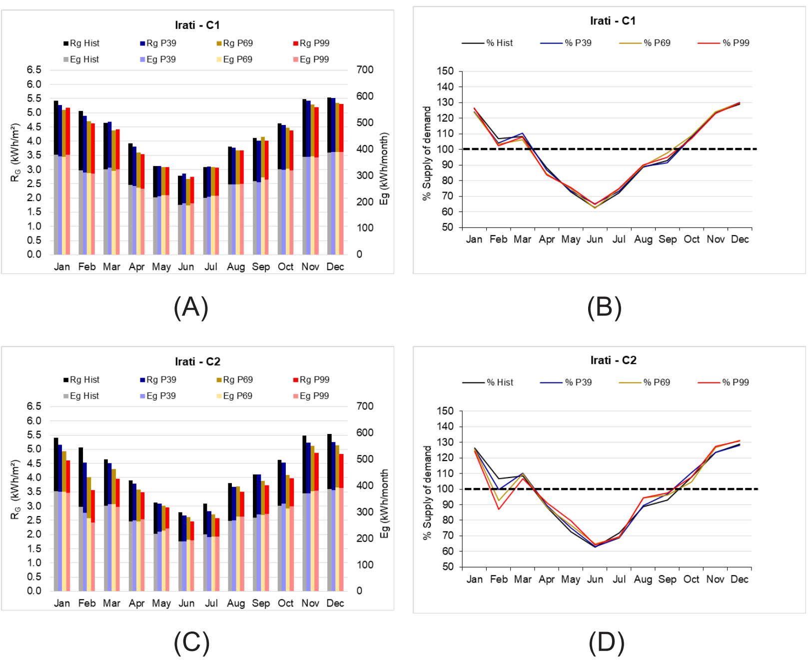


Figure 5 - Available solar radiation (R_G), Electric power generated from R_G (E_g) and Percentage serviced monthly for each residence in the historical period and up to 2099 in scenarios C1 and C2 for Irati-PR

Moreover, according to Figures 5B and 5D, it was observed that, for C1, the fullness of care occurred in the months of October to March, while the deficit period of the system was verified between April and September, being the month that reached the worst power generation was June, with average attendance percentages of 64%. However, in C2, the month of February did not reach this totality, with average E_g

values of 279 kWh/month, equivalent to 93%. When analyzing the annual service, the system presents efficiency of 98%, for all periods and scenarios. Regarding the number of plates required, the hypothetical residence of Irati locality requires 10 photovoltaic plates in the periods evaluated for scenario C1 and 11 plates for C2.

Table 6 shows the results for the locality of Ivaí, where the average monthly values of R_G for the historical period (Hist) and simulated periods P39, P69 and P99, in scenarios C1 and C2 tend to decrease over the period. It was observed that for C1, the months that presented significant differences were March and June, whereas for C2, the months of May, October and November did not present statistical significance in the comparison between the historical and simulated periods. It was found that this reduction in RG values, in absolute terms, averaged 0.1 kWh/m² for C1, and 0.3 kWh/m² for C2.

Table 5 - Statistical analysis (ANOVA or KRUSKAL-WALLIS) of the means of RG (kWh/m²) for Ivaí-PR

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
Jan	-	0.5585	5.62a	5.63a	5.56a	5.49a
Fev	0.8150	-	5.35a	5.43a	5.27a	5.31a
Mar	0.0098	-	5.26a	5.14ab	4.80b	4.82b
Apr	-	0.2014	4.21a	4.14a	4.05a	3.99a
May	0.9970	-	3.49a	3.48a	3.49a	3.49a
Jun	-	0.0191	2.79a	2.68ab	2.68ab	2.57b
Jul	0.0823	-	3.23a	3.03a	3.09a	2.91a
Aug	0.3560	-	4.04a	4.08a	3.90a	4.00a
Sep	0.9070	-	4.50a	4.48a	4.49a	4.43a
Oct	0.2410	-	4.74a	4.95a	4.94a	4.94a
Nov	0.9600	-	5.82a	5.86a	5.88a	5.89a
Dec	0.0500	-	6.02a	5.84a	5.78a	5.80a
C2						
Jan	-	0.0099	5.62a	5.45a	5.34ab	5.17b
Fev	0.0084	-	5.35a	5.28a	5.02ab	4.77b
Mar	0.0000	-	5.26a	4.85b	4.66b	4.18c
Apr	0.0361	-	4.21a	4.04ab	3.94ab	3.80b
May	0.8030	-	3.49a	3.49a	3.52a	3.54a
Jun	0.0101	-	2.79a	2.62ab	2.63ab	2.39b
Jul	-	0.0003	3.23a	2.98ab	2.66b	2.60b
Aug	0.0314	-	4.04a	3.98ab	3.94ab	3.79b

Table 5 - Continuação

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C2						
Sep	0.0392	-	4.50a	4.41ab	4.29ab	4.19b
Oct	0.3220	-	4.74a	4.95a	4.88a	4.80a
Nov	0.8780	-	5.82a	5.86a	5.90a	5.93a
Dec	0.0124	-	6.02a	5.79ab	5.78ab	5.72b

Note: Values followed by lower case letters do not differ statistically from each other at the 5% level of significance by the Tukey test

By means of Figures 6A and 6C, it was noted that monthly average values of R_G for Ivai varied between 2.3 and 6.0 kWh/m², and that the annual average is about 4.4 kWh/m². It was found that the values of E_g were delimited between 164 and 408 kWh/month. It is important to note that it was during this period and scenario that both the worst (June of P99) and the best (November of P99) value of generation of E_g of the locality were recorded. Therefore, the monthly peak of energy generation was recorded in December when considering all periods and scenarios.

According to Figures 6B and 6D, the fullness of care was observed between the months of October to March, and the period of system deficit between the months of April and September. However, it was noted that, for C2, the month of March did not reach the total of service in P99, with E_g of 297 kWh/month, equivalent to a percentage of 98%. The month of June was the one that reached the worst generation of energy, with average attendance percentages of 57%. It is important to note that, for Ivaí in C2, the month of February did not present an expressive surplus generation, which occurred in the other localities, and this surplus was on average 5%

For all periods and scenarios, the annual efficiency of the system is 98%. In relation to the number of plates required, the hypothetical residence of the locality of Ivaí requires 9 photovoltaic plates in the periods of C1 and 10 plates in the scenario C2.

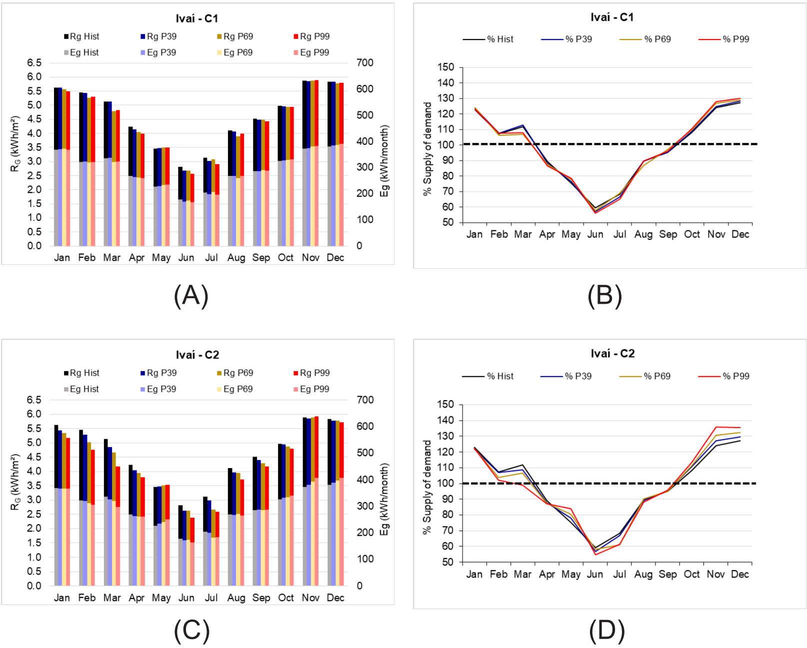


Figure 6 - Available solar radiation (R_G), Electric power generated from R_G (E_g) and Percentage serviced monthly for each residence in the historical period and up to 2099 in scenarios C1 and C2 for Ivaí-PR

Table 7 shows the R_G values for the Londrina locality, where there is a downward trend towards the end of the century. In the C1, only the month of December has statistical significance, with an average decrease of 0.1 kWh/m² between the historical period and P99. For C2, January, February, May, June, November and December showed a significant decrease in R_G with a mean reduction of 0.3 kWh/m² in absolute values between the historical period and P99. For this scenario and locality, winter was the only season of the year in which no month obtained a significant decrease of R_G.

It was observed that, despite being impacted by climate change scenarios, the average reduction values of R_G in both C1 and C2 do not energetically represent a restriction to be considered.

Table 7 - Statistical analysis (ANOVA or KRUSKAL-WALLIS) of the means of RG (kWh/m²) for Londrina-PR

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
Jan	-	0.1306	5.75a	5.70a	5.59a	5.40a
Fev	0.9640	-	5.98a	5.74a	5.71a	5.68a
Mar	0.8320	-	5.67a	5.59a	5.58a	5.58a
Apr	-	0.3658	4.76a	4.80a	4.76a	4.74a
May	0.1070	-	3.80a	3.57a	3.62a	3.51a
Jun	0.9680	-	3.54a	3.47a	3.49a	3.39a
Jul	-	0.2240	3.79a	3.78a	3.77a	3.76a
Aug	0.4400	-	4.54a	4.59a	4.58a	4.49a
Sep	-	0.9220	5.22a	5.12a	5.12a	5.12a
Oct	0.7490	-	5.48a	5.58a	5.61a	5.61a
Nov	0.5210	-	6.15a	6.11a	6.06a	6.01a
Dec	0.0019	-	6.30a	5.96b	5.89b	5.88b
C2						
Jan	0.0002	-	5.75a	5.71ab	5.22bc	4.93c
Fev	0.0003	-	5.98a	5.69ab	5.50b	5.38b
Mar	-	0.0500	5.67a	5.58a	5.57a	5.57a
Apr	-	0.0825	4.76a	4.74a	4.69a	4.65a
May	0.0017	-	3.80a	3.63ab	3.40bc	3.27c
Jun	-	0.0141	3.54a	3.46a	3.45ab	3.33b
Jul	-	0.3343	3.79a	3.75a	3.75a	3.73a
Aug	0.3170	-	4.54a	4.58a	4.48a	4.47a
Sep	0.8240	-	5.22a	5.12a	5.13a	5.14a
Oct	0.5030	-	5.48a	5.59a	5.66a	5.67a
Nov	0.0048	-	6.15a	6.05a	5.91ab	5.75b
Dec	-	0.0003	6.30a	5.98ab	5.78bc	5.67c

Note: Values followed by lower case letters do not differ statistically from each other at the 5% level of significance by the Tukey test

The average R_G values for Londrina (Figures 7A and 7C) varied between 3.2 and 6.3 kWh/m², with an annual average of 5.0 kWh/m², and in C1 the values are higher in comparison to C2. It was observed that the values of E_g were between 200 and 360 kWh/month, for the months of June and December, respectively. Therefore, the peak energy generation was registered in December for all the periods and scenarios, although the highest R_G values were in the month of November.

The system attendance (Figures 7B and 7D) varied between 67 and 120% for this location. The month of June was the one that reached the worst level of energy generation, with average attendance rates of 68% considering all the three periods and scenarios. It was observed that the integrality of the system is reached in the months between October to March. Despite the fact that February showed sufficient performance (above 100%), it was noticed that there was a decrease in generation of E_g and, consequently, a drop in attendance of around 9% in relation to January and March. It is important to note that this behavior was not verified in relation to R_G data.

For all periods and scenarios, the annual efficiency of the system was 98%. Likewise, considering the hypothetical defined residence, in the locality of Londrina the need for photovoltaic panels would be 8 considering all the analyzed periods and scenarios.

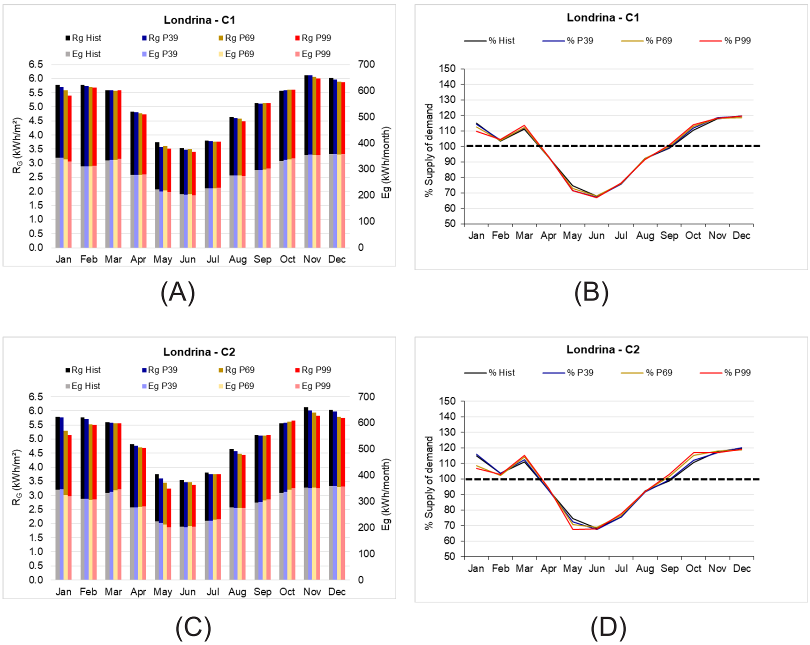


Figure 7 - Available solar radiation (R_G), Electric power generated from R_G (E_g) and Percentage serviced monthly for each residence in the historical period and up to 2099 in scenarios C1 and C2 for Londrina-PR

In the locality of Maringá, according to the results shown in Table 8, it was generally perceived that the average monthly values of

R_G for the historical period (Hist) and simulated periods P39, P69 and P99, in scenarios C1 and C2 tend to decrease throughout the century. A safeguard should be made only for the month of April, which, for both scenarios, showed a slight increase of an average of 0.06 kWh/m².

It was observed that for C1, the months that presented significant differences were in March, June and December, whereas in C2, every month presented statistical significance in the comparison between the historical and simulated periods. It was found that this reduction of R_G values, in absolute terms, averaged 0.4 kWh/m² for C1 and 0.8 kWh/m² for C2.

Table 8 - Statistical analysis (ANOVA or KRUSKAL-WALLIS) of the means of RG (kWh/m²) for Maringá-PR

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
Jan	0.3090	-	5.99a	5.80a	5.82a	5.65a
Fev	-	0.1125	6.15a	5.89a	5.85a	5.76a
Mar	-	0.0247	5.63a	5.37ab	5.13ab	4.91b
Apr	-	0.1751	4.85a	4.84a	4.82a	4.88a
May	0.9150	-	3.86a	3.72a	3.65a	3.58a
Jun	-	0.00061	3.62a	3.32ab	3.28ab	3.00b
Jul	0.0701	-	3.96a	3.82a	3.77a	3.76a
Aug	0.1100	-	4.55a	4.35a	4.32a	4.19a
Sep	-	0.2892	5.09a	4.82a	4.53a	4.55a
Oct	0.5490	-	5.51a	5.40a	5.36a	5.23a
Nov	0.5750	-	6.30a	6.16a	6.21a	6.11a
Dec	0.0015	-	6.53a	6.07b	6.04b	6.03b
C2						
Jan	0.0002	-	5.99a	5.79ab	5.32bc	5.10c
Fev	0.0000	-	6.15a	5.86ab	5.54bc	5.38c
Mar	0.0000	-	5.63a	4.99b	4.68b	4.05c
Apr	-	0.0020	4.85b	4.85b	4.91ab	4.94a
May	0.0076	-	3.86a	3.60ab	3.51b	3.51b
Jun	0.0000	-	3.62a	3.29ab	3.15bc	2.93c
Jul	0.0002	-	3.96a	3.84ab	3.64bc	3.60c
Aug	0.0000	-	4.55a	4.28ab	4.10b	3.50c
Sep	-	0.0002	5.09a	4.38ab	4.34ab	3.74b

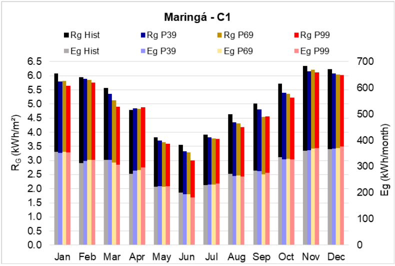
Table 8 - Continuação

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C2						
Oct	-	0.0001	5.51a	5.52a	4.89b	4.47b
Nov	0.0008	-	6.30a	6.12ab	5.82bc	5.66c
Dec	0.0000	-	6.53a	6.02b	5.72b	5.31c

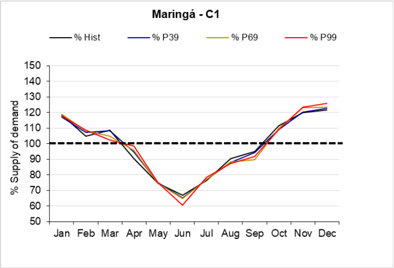
Note: Values followed by lower case letters do not differ statistically from each other at the 5% level of significance by the Tukey test

From Figures 8A and 8C, it was verified that mean monthly R_G values for Maringá ranged from 2.9 to 6.5 kWh/m², with the annual average being around 4.8 kWh/m², whose extreme values of interval refer to the months of June and December, respectively. It was observed that E_g values were between 182 and 379 kWh/month, which refer to the months of June and November, respectively. Generally speaking, peak power generation was recorded in December for all periods and scenarios, although the highlight month for this location for R_G was November.

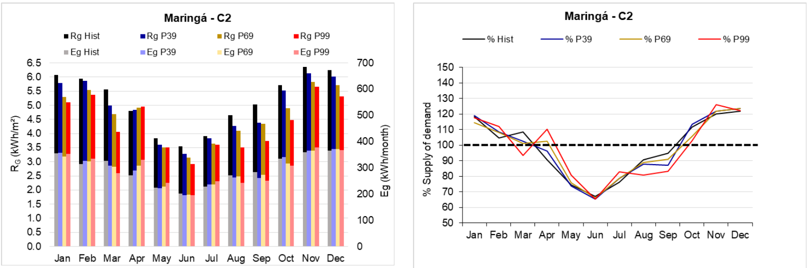
According to Figures 8B and 8D, it was observed that the percentage of attendance varied between 60 and 126%, and the fullness occurred between October and March, with the system deficit period between April and September. However, it was found that for C2, the month of March did not reach the total service, in P99, with E_g of 280 kWh/month, equivalent to a percentage of 93%. On the other hand, the month of April, which in all localities was insufficient to generate energy, for this period and scenario (P99/C2), had full and surplus service, with E_g of 331 kWh/month, corresponding to 110% of service. The month of June was the one that reached the worst generation of energy, with average attendance percentages of 65%. For all periods and scenarios, the annual efficiency of the system was 98%. The number of plates required, for the hypothetical residence in the locality of Maringá is 10 photovoltaic plates in all the evaluated periods and scenarios.



(A)



(B)



(C) (D)

Figure 8 - Available solar radiation (R_G), Electric power generated from R_G (E_g) and Percentage serviced monthly for each residence in the historical period and up to 2099 in scenarios C1 and C2 for Maringa-PR

It was verified that the R_G values for the Paranaguá locality (Table 9) show a decreasing tendency until the end of the century, except for the months of January, April, May and December, that do not have or have a slight tendency of increase. For these months, the mean increase was 0.1 kWh/m² in C1 and 0.2 kWh/m² in C2, while for other months, the average reduction in R_G was 0.2 in C1 and of 0.3 kWh/m² in C2, between the historical period and P99. In C1, only the month of September presented statistical significance with decrease, in the monthly average of 0.33 kWh/m² between the historical period and P99. However, for C2, the months of January, March, May, August, September and December showed statistical significance of R_G. It was noticed that the mean values of both reduction and R_G increase were not expressive.

Table 9 - Statistical analysis (ANOVA or KRUSKAL-WALLIS) of the means of RG (kWh/m²) for Paranaguá-PR

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
Jan	0.2290	-	4.92a	5.05a	5.10a	5.18a
Fev	0.3290	-	5.10a	4.91a	4.90a	4.89a
Mar	0.0571	-	4.48a	4.23a	4.16a	4.16a
Apr	-	0.3334	3.72a	3.72a	3.71a	3.72a
May	-	0.9623	2.94a	3.04a	3.04a	3.04a
Jun	-	0.4157	2.60a	2.58a	2.56a	2.52a

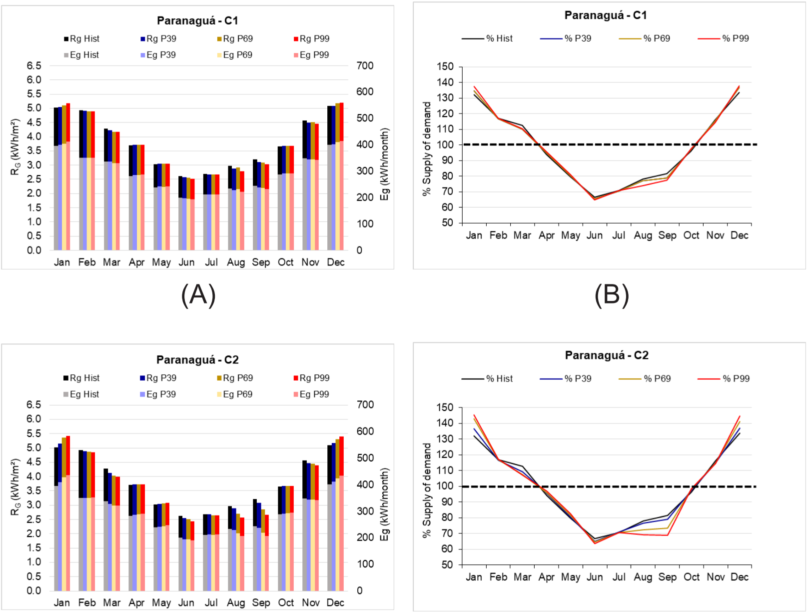
Table 9 - Continuação

Scenario/Month	p-Anova	p-KW	Hist	P39	P69	P99
C1						
Jul	0.9850	-	2.69a	2.67a	2.67a	2.67a
Aug	0.2520	-	3.04a	2.88ab	2.92ab	2.79b
Sep	0.0385	-	3.35a	3.12ab	3.09ab	3.02b
Oct	-	0.1224	3.75a	3.67a	3.68a	3.67a
Nov	0.9380	-	4.49a	4.50a	4.51a	4.45a
Dec	0.4940	-	5.18a	5.08a	5.18a	5.20a
C2						
Jan	-	0.0007	4.92c	5.15bc	5.36ab	5.42a
Fev	0.1910	-	5.10a	4.88a	4.86a	4.84a
Mar	0.0013	-	4.48a	4.12b	4.03b	3.99b
Apr	-	0.1136	3.72a	3.72a	3.72a	3.74a
May	-	0.0156	2.94a	3.04b	3.06ab	3.08a
Jun	0.2130	-	2.60a	2.54a	2.50a	2.44a
Jul	0.8590	-	2.69a	2.67a	2.65a	2.63a
Aug	0.0001	-	3.04a	2.90ab	2.71bc	2.57c
Sep	0.0000	-	3.35a	3.08ab	2.84bc	2.65c
Oct	-	0.1742	3.75a	3.67a	3.67a	3.66a
Nov	0.8070	-	4.49a	4.48a	4.45a	4.40a
Dec	-	0.0133	5.18a	5.17b	5.30a	5.39a

In Figures 9A and 9C, it was observed that the mean monthly RG values for Paranaguá varied between 2.4 and 5.4 kWh/m², and that the annual average was around 3.8 kWh/m², whose lower limit of interval belongs to the month of June, while the upper limit refers to the months of January and December. It was verified that the values of Eg were between 190 and 436 kWh/month, referring to June and January, respectively. Therefore, peak power generation was recorded in the months of January and December for the periods and scenarios analyzed, with values very close in these two months.

According to Figures 9B and 9D, it was observed that the percentage of attendance varied between 63 and 145% in this locality, where it was found that the totality of attendance of the system occurred between the months between November and March, and the month of October falls within the deficit period, along with the months of April to September. The average efficiency of the month of October for all periods and scenarios is 97%. The month of June was the one that reached the worst generation of energy, with average attendance percentages of 65%.

It was noticed that for this locality, the autumn-winter months showed a tendency of decrease in E_g values and, consequently, in the percentage of attendance during the periods, within each scenario. On the other hand, the months belonging to the spring-summer period tended to increase these values, and the percentage of attendance for these months may exceed up to 40% of the consumption need. For all the periods and scenarios, the annual efficiency of the system was 98%. Regarding the number of plates required, the hypothetical residence for the locality of Paranaguá requires 11 photovoltaic plates in all the considered periods and scenarios.



(A) (B)

(C) (D)

Figure 9 - Available solar radiation (R_G), Electric power generated from R_G (E_g) and Percentage serviced monthly for each residence in the historical period and up to 2099 in scenarios C1 and C2 for Paranaguá-PR

In general, for all localities, it was observed that the simulated R_G values showed a decreasing trend over the simulated periods of P39, P69 and P99, in relation to historical values. This pattern can be attributed to the model used for estimating R_G (CHEN et al., 2004), which is based on the daily thermal amplitude (ΔT), in which the climatic scenarios, with a minimum temperature increase of the maximum temperature, caused the decrease of this amplitude, which causes a reduction tendency of the R_G values.

Similarly, Bierhals et al. (2017) found that, for the State of Rio Grande do Sul, climate scenario models have shown that global solar radiation values tend to decline to 60% of the year through 2100. In addition, Huber et al. (2016) concluded that global solar radiation in the future (2035-2039) is likely to be reduced when compared to historical values (1995-1999), and that this decline is around 5% for regions in Africa. Similarly, Ohunakin et al. (2015) also observed a reduction of global solar radiation by the end of the century in Nigeria for the period from 2041 to 2070, whose range was in the range of 0.11 to 3.39%.

Tiepolo et al. (2014) found that even in winter periods of low solar intensity, the RG values found in Paraná-Brazil (3.61 kWh/m²) were higher than those found in Germany (between 2.16 and 2, 98 kWh/m²) and in Belgium (between 2.33 and 2.74 kWh/m²), and close to the values found in France (between 2.26 and 4.11 kWh/m²), which shows that even in this period, the State of Paraná has significant potential for the installation of photovoltaic systems.

On the other hand, Kopp and Lean (2011) warn of the complexity of establishing the magnitude of long-term changes in global solar radiation, or of alleviating the conflicting claims of radiation variations that have driven significant climate change in recent decades, since the current database is too short and inaccurate for this purpose.

It is important to note that the highest values of RG verified in this research refer to the months between October and March, coinciding with the spring and summer seasons, when the sun's rays illuminate the southern hemisphere brighter. With similar justification, the lowest values refer to the months from April to September, belonging to fall and winter, when the days are shorter and the solar rays have lower intensity, due to the apparent movement of the sun in relation to the Earth, due to the solar declination.

As a consequence of the decrease in the simulated RG values, a decrease trend of the values of EG over the periods was observed, which confirms that the daily energy supplied by the panel is proportional to the solar radiation incident on the panel plane, also found by Gnoatto et al. (2008), to the city of Cascavel (PR). In all the localities, it was verified that there is a period of the year in which the attendance of the system does not reach the fullness, however, although in the period that includes the fall and the winter one has the impression to occur an energy debt, this does not mean that the system does not meet the annual energy demand.

Because the system is connected to the public electricity grid and there is the mechanism of energy compensation, the surplus in the spring and summer months is made available to the network, which can be reimbursed by means of credits, to be redeemed when the attendance of the system is not full. That is, the credit available at intervals in which Eg is greater than the demand for the residence can be reversed in the period in which the system does not meet the total need.

It was noted that, despite the impacts of climate change, the efficiency of the system did not change over time, reaching 98% of service for all locations, or a subtle increase of service was observed over the period with increasing temperature. This behavior was also perceived by Michels et al. (2010), who verified, for the city of Medianeira-PR, that the temperature increase in a photovoltaic system can negatively alter its power and efficiency. This situation was also found by Gnoatto et al. (2008), who, when analyzing the efficiency of a photovoltaic system, in the city of Cascavel-PR, pointed out that the lowest energy production occurred in May, and the highest in March. Analyzing the seasonal mean, the highest energy production occurred in the summer and the lowest in the winter, while in the spring and autumn production was equivalent.

It is important to highlight that in systems installed in Florianópolis-SC, studied by Urbanetz et al. (2011), showed an annual efficiency of 88%, and the service only supplied the demand and generated surplus energy in the months from November to February, a behavior attributed to this locality, characterized as the Brazilian capital with the lowest incidence of solar radiation. On the other hand, Singh and Banerjee (2015) have found that a system installed on the roof of a residence in Mumbai, India, can provide 12-20% of average daily demand and 31-60% of peak morning demand for many diferente months.

In relation to climate, changes in solar radiation do not directly affect the regional and global climate but may affect changes in absorbed solar radiation, which directly influences energy production. However, contrary to Huber et al. (2016) argued that photovoltaic systems are unlikely to be affected by climate change.

From a Brazilian perspective, Monteiro et al. (2017) point out that since the South region of Brazil has a high energy consumption in the summer and imports energy from the southeast and center-west regions, where the solar energy supply is the highest among all Brazilian regions, the insertion of photovoltaic energy in the South region can result in great benefit to the national electricity system, as well as socioeconomic advantages, such as the generation of jobs in the area of renewable energy.

4. CONCLUSION

It was verified that the estimation of the production of solar energy in function of the regionality and possible scenarios of climate change are important aspects to evaluate the viability of installation of integrated systems of photovoltaic energy in the residences.
The popularization of solar systems in Brazilian homes can bring benefits to users, the environment, and government. On the other hand, there is a lack of public incentive policies, such as the reduction of taxes, in order to promote the adoption of solar energy systems for residential use.

REFERENCES

BIERHALS, E. E.; PEREIRA, F.; BRAZIL, C.; ROSSINI, E. Solar radiation projections of Cmip5 models for South of Brazil. Contemporary Urban Affairs, v. 1, n. 3, p. 1-6, 2017.

CHEN, R.; ERSI, K.; YANG, J.; LU, S.; ZHAO, W. Validation of five global radiation models with measured daily data in China. Energy Conversion and Management, v. 45, p. 1759-1769, 2004.

ELETROBRAS. Pesquisa de posse de equipamentos e hábitos de uso, ano base 2005: classe residencial relatório Sul. Rio de Janeiro: Eletrobras/Procel, 2007.

FRANK, T.H. Climate change impacts on building heating and cooling energy demand in Switzerland. Energy and Buildings, v. 37, p. 1175-1185, 2005.

GNOATTO, E.; DALLACORT, R.; RICIERI, R. P.; SILVA, S. L.; FERRUZI, Y. Eficiência de um conjunto fotovoltaico em condições reais de trabalho na região de Cascavel. Acta Scientiarum Technology, Maringá, v. 30, n. 2, p. 215-219, 2008.

HUBER, I.; BUGLIARO, L.; PONATER, M.; GARNY, H.; EMDE, C.; MAYER, B. Do climate models project changes in solar resources? Solar Energy, v. 129, p. 65-84, 2016.

IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Genebra: IPCC, 2014.

KOPP, G.; LEAN, J. L. A new, lower value of total solar irradiance: evidence and climate significance. Geophysical Research Letters, v. 38, p. 1-7, 2011.

MARENGO, J.A.; CAMARGO, C.C. Surface air temperature trends in Southern Brazil for 1960–2002. International Journal of Climatology, v. 28, p. 893-904, 2008.

MARQUES, D.D.; BRITO, A.U.; CUNHA, A.C.; SOUZA, L.R. Variação da radiação solar no Estado do Amapá: estudo de caso em Macapá, Pacuí, Serra do Navio e Oiapoque no período de 2006 a 2008. Revista Brasileira de Meteorologia, v. 27, n. 2, p. 127-138, 2012.

MICHELS, R. N.; GNOATTO, E.; SANTOS, J. A. A.; KAVANAGH, E.; HALMEMAN, M. C. A influência da temperatura na eficiência de painéis fotovoltaicos em diferentes níveis de incidência da radiância solar. Revista Agrogeoambiental, dez. 2010.

MONTEIRO, N.S.C.; MONTEIRO, R.A.B.; MARIANO, J.D.A.; URBANETZ JUNIOR, J.; ROMANO, C.A. Brazil market outlook for photovoltaic solar energy: A survey study. British Journal of Applied Science & Technology, v. 21, n. 5, p. 1-11, 2017.

OHUNAKIN, O.S.; ADARAMOLA, M. S.; OYEWOLA, O. M.; MATTHEW, O. J.; FAGBENLE, R. O. The effect of climate change on solar radiation in Nigeria. Solar Energy, v. 116, p. 272-286, 2015.

PEREIRA, E.B.; MARTINS, F.R.; GONÇALVES, A.R.; COSTA, R.S.; LIMA, F.J.L.; RÜTHER, R.; ABREU, S.L.; TIEPOLO, S.M.; PEREIRA, S.V.; SOUZA, J.G. Atlas brasileiro de energia solar. 2.ed. São José dos Campos: INPE, 2017.

RÜTHER, R.; SALAMONI, I. O potencial dos setores urbanos brasileiros para a geração de energia solar fotovoltaica de forma integrada às edificações. Fórum Patrimônio, Belo Horizonte, v. 4, n. 2, p. 84-94, 2011.

RÜTHER, R; ZILLES, R. Making the case for grid-connected photovoltaics in Brazil. Energy policy, v. 39, n. 3, p. 1027-1030, 2011.

SILVA, W. L.; DERECZYNSKI, C.; CHANG, M.; FREITAS, M.; MACHADO, B. J.; TRISTÃO, L.; RUGGERI, J. Tendências observadas em indicadores de extremos climáticos de temperatura e precipitação no Estado do Paraná. Revista Brasileira de Meteorologia, v.30, n.2, p. 181-194, 2015.

SINGH, R.; BANERJEE, R. Estimation of rooftop solar photovoltaic potential of a city. Solar Energy, v. 115, p. 589-602, 2015.

TIEPOLO, G.M.; URBANETZ JUNIOR, J.; CANCIGLIERI JUNIOR, O.; VIANA, T. Photovoltaic generation potential of Paraná State, Brazil – a comparative analysis with European countries. Energy Procedia, v. 57, p. 725-734, 2014.

URBANETZ, J.; ZOMER, C.D.; RÜTHER, R. Compromises between form and function in grid-connected, building-integrated photovoltaics (BIPV) at low-latitude sites. Building and Environment, v. 46, p. 2107-2113, 2011.

VIRGENS FILHO, J.S.; OLIVEIRA, R.B.; LEITE, M.L.; TSUKAHARA, R.Y. Desempenho dos modelos CLIGEN, LARS-WG e PGECLIMA_R na simulação de séries diárias de temperatura máxima do ar para localidades do estado do Paraná. Engenharia Agrícola, Jaboticabal, v. 33, n. 3, p. 538-547, maio/jun. 2013.