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PHOTOVOLTAIC GENERATORS: USE BY RURAL CUSTOMERS IN MATO GROSSO STATE

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Keywords:
Agribusiness
Rural customers
Distributed generation
Photovoltaic systems

ABSTRACT

In the current Brazilian energy scenario, the use of photovoltaic systems for generating energy is an excellent choice, as it combines electricity savings and energy production with less harmful impact on the environment. Mato Grosso is a state of great importance for agricultural production, in a country where agribusiness has a large share in the Gross Domestic Product (GDP). The aims of this study are to investigate the growing use of distributed photovoltaic system by rural customers in the state of Mato Grosso and compare it with the number of installations implemented in other consumer classes to eventually evaluate the participation in the state energy matrix and its applications. The analysis was carried out with data up to 2020 available from the registration system of the distributed generation of the National Electric Energy Agency (ANEEL) and the local electricity company Energisa Mato Grosso (EMT). The number of consumer units having photovoltaic generation systems in the state has grown on average 342% since 2015, when the first units were installed. When analyzing only rural facilities, this percentage rises to 347%. Although the participation of rural customers in the total number of installations is 7.04%, which are less significant than the other consumer classes, these systems are 6.44 times larger than residential systems, with a participation in the total state installed power of 21.74%.

Palavras-Chave:
Agronegócio
Consumidores rurais
Geração distribuída
Sistemas Fotovoltaicos

GERADORES FOTOVOLTAICOS: UTILIZAÇÃO POR CLIENTES RURAIS NO ESTADO DE MATO GROSSO

RESUMO

No atual cenário energético brasileiro a utilização de sistemas fotovoltaicos para geração de energia é uma excelente escolha, pois concilia a economia com tarifas de eletricidade a produção de energia com menor impacto prejudicial ao meio ambiente. O estado de Mato Grosso representa grande importância no cenário de produção agrícola, em um país que o agronegócio possui grande participação em seu Produto Interno Bruto (PIB). Desta forma, este trabalho objetiva analisar e discutir a crescente utilização de geração distribuída fotovoltaica em clientes rurais do estado de Mato Grosso, comparando-a com o número de instalações das demais classes de consumo, avaliando sua participação no cenário estadual e aplicações. A análise considera os dados disponibilizados até o ano de 2020 pelo sistema de registro de geração distribuída da Agência Nacional de Energia Elétrica e da concessionária de energia local, Energisa Mato Grosso. O número de unidades consumidoras portadoras de sistemas de geração fotovoltaica no estado cresceu em média 342% desde 2015, quando houveram as primeiras instalações. Quando analisado somente as instalações rurais este percentual é de 347%. Embora sua participação no número total de instalações seja de 7,04%, sendo menos significativo que as demais classes de consumo, estes sistemas são 6,44 vezes maiores em relação aos sistemas residenciais, tendo uma participação na potência total estadual instalada de 21,74%.

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INTRODUCTION

Agribusiness is among the world´s highly valued market sectors due to its growth potential. It plays a fundamental role in the economic development of Brazil, accounting for a quarter of the country´s Gross Domestic Product (GDP) (KURESKI *et al.*, 2020). Gilio and Rennó (2018) point out that over the last decade its performance has been growing, with job and income generation, despite all the political, economic and climate crises the country has been facing.

Data from the Brazilian Institute of Geography and Statistics (IBGE) (2015) show that the Midwest region stands out in the national crop production with 87.6 million tons of grain. The state of Mato Grosso is the main responsible for the increase in production, ranking first as the largest Brazilian producer of cotton, corn and soybean.

Strengthening the main Brazilian production chain positively impact all other segments of society. Costa *et al*. (2013) found that the percentage of rural electricity consumption is among the 22 variables analyzed as factors determining agricultural development in municipalities, and pointed out the importance of public investment for the promotion of this sector.

The evolution of industrial processes in the 20th century systematically increased the demand for energy in all sectors of society. Energy became essential for the development and was not limited to urban regions, because it was vital for the growth of the agricultural sector and had technological advances that expanded the production chains (CARDOSO, 2012).

In this context, with increasing consumption of energy, the use of fossil fuels must be rethought. Besides being exhaustible natural resources, they are also harmful to the environment, which leads to the rational use of these resources and makes space for research on more sustainable and efficient processes aimed to increase production and diversify the existing energy matrix using renewable energy sources (SCARPETTA, 2014).

The Normative Resolution No. 482/2012 of the National Electric Energy Agency (ANEEL, 2012) established the conditions for the Distributed Generation (DG). This Resolution allowed captive consumers to produce their own energy through renewable sources and qualified cogeneration, promoting financial savings, self-sustainability and socio-environmental awareness. In addition, it brings the generating source near where it will be used, reducing losses along transmission lines and transformers that are very common in rural distribution grids far from large cities (ANEEL, 2012).

In addition, a revision to the previous resolution, the Normative Resolution No. 687/2015 was an important milestone for the sector. It increased the range of the target customers and allowed the installation in multiple consumer units. It created the so-called "remote self-consumption", where it is possible to use the electricity credits generated in one location to reduce the consumption of consumer units of the same holder in another location. The same resolution also gave rise to the so-called "shared generation", which allowed several interested parties gather into a consortium or cooperative, to install a distributed generation center and use the energy produced to reduce the bills of its members (ANEEL, 2015).

The technology for converting sunlight into electricity through photovoltaic effect has advanced since it was first conceived and is currently the fastest growing energy generation technology in the world (NETO *et al*., 2018). The Brazilian potential for energy production from this source is excellent, and according to Pereira *et al.* (2017), it is estimated between 1,550 and 2,350 kWh m^{-2} per year. Brazil´s Midwest resides in the second best region in the country for the global average radiation index (5.08 kWh m^{-2} day^{-1}) and shares the rank of best global average radiation on inclined surfaces because throughout the year, climatic conditions provide a stable regime of low cloudiness and high solar radiation for this semiarid region (TSURUDA *et al*., 2017).

This study presents an analysis of the increasing use of Distributed Photovoltaic Generation (DPVG) by rural customers in the state of Mato Grosso, using data on the number of installations in recent years and comparing the installed power with other consumer classes. The Electricity Supply Continuity indicators were analyzed to assess the quality after the generating plants come into operation. The amount of energy generated was estimated to understand its effect on the decarbonization of the energy matrix and measure its participation in the state's energy demand.

MATERIAL AND METHODS

The research data in this study, referring to number of installations of photovoltaic generators, total installed power, and consumer classes in the state of Mato Grosso, from 2015 to 2020, are drawn from the distributed generation registration system of the National Electric Energy Agency (ANEEL, 2021), aiming to investigate the growth of these systems and their participation in the state's energy matrix. In addition, the percentage of consumer units with distributed photovoltaic generation was computed from the number of consumer units within the territory of Mato Grosso until the end of 2020 that was supplied by the local company Energisa Mato Grosso (EMT), using data disclosed in the ANEEL´s Management Information Report.

The criteria established by Module 8 of the ANEEL´s Distribution Procedures (PRODIST) allows the assessment of the quality of services provided by distributors based on interruptions in the electricity supply using collective continuity indicators (DEC and FEC) and individual continuity indicators (DIC, FIC, DMIC and DICRI), as described as follows:

• DEC: Equivalent interruption duration per consumer unit (hours);

• FEC: Equivalent interruption frequency per consumer unit (number of interruptions);

• DIC: Duration of individual interruption per consumer unit. It is the time during the calculation period, in which there is discontinuity in the electricity distribution in each consumer unit or connection point (in hours);

• FIC: Frequency of individual interruption per consumer unit. It represents the number of interruptions in each consumer unit or connection point during the calculation period (in number of interruptions);

• DMIC: The maximum duration of continuous interruption per consumer unit or connection point. It is the time of maximum continuous electricity interruption at a consumer unit or connection point (in hours);

• DICRI: Duration of individual interruption occurring in a critical day per consumer unit or connection point (in hours).

Therefore, the limits of the individual continuity indicators were confirmed by the electricity production sets existing in the state of Mato Grosso aiming to assess the difference in acceptable tolerance between urban and non-urban areas using the monthly observation period for the year 2020. Additionally, data from the ANEEL system on collective continuity indicators of the last 10 years of the state of Mato Grosso were used to analyze the quality of electricity supply over time.

The energy generated (E) through the installed photovoltaic generators can be estimated using the methodologies by Marinoski *et al*. (2004) and Masutti *et al*. (2016), which is given by multiplying the installed power (P_i), the average local irradiation (IM), the photovoltaic generator efficiency (*RGFV*) and the time period (*t*) in days, as shown in equation 1.

$$E = P_i \times \mathrm{IM} \times RGFV \times t \quad (1)$$

This estimate shows the participation of the electric energy generated by these systems within the energy demand of the rural environment and its contribution to reducing the emission of carbon dioxide (CO_2) into the atmosphere. The quantification of CO_2 avoided emissions in the production of electricity using the solar source complies with the project Clean Development Mechanism (CDM), which is an integral part of the Kyoto Protocol (UNFCC, 2016), in which its estimate was confirmed by the methodologies adapted by Campos (2015), Buiatti *et al*. (2016), and Sanquetta *et al*. (2017), as described in equation 2.

$$R_{CO2} = E \times M_c \quad (2)$$

In equation 2, the reduction in CO_2 (R_{CO2}) emission is calculated by multiplying the estimated energy of the photovoltaic generators (E) by the combined margin (M_c), which is a parameter calculated from the records of generation of the centralized dispatch plants members of the National Electric System Operator (ONS) and the National Interconnected System (SIN). The calculation is based on the methodology defined in the CDM projects, since it considers the combination of the operating margin emission factor, which quantifies the emissions associated with the energy dispatched in the SIN, and the build margin factor, which comprises the emissions associated with the recently built power plants (CAMPOS, 2015).

The calculation of the combined margin applied in photovoltaic systems considers 75% of the operating margin plus 25% of the build margin (BUIATTI *et al*., 2016), where the emission factors of the operating margin and build margin are provided by the annual reports of the Ministry of Science, Technology and Innovation (MCTI). Table 1 presents the data examined in this study.

Table 1. Estimation of the combined margin parameter from the build margin and operating margin

Year	Build margin	Operating margin	Combined margin
2016	0.1581	0.6228	0.507
2017	0.0028	0.5882	0.442
2018	0.137	0.539	0.439
2019	0.102	0.5181	0.414
2020	0.098	0.4539	0.365

RESULTS AND DISCUSSION

Although captive consumers can use distributed generation to generate electricity, since the regulation published by ANEEL in 2012, the first photovoltaic systems in the state of Mato Grosso were installed in 2015, seeing that the technology was still high costly and few companies sold these systems. By the end of 2020 a total of 21,204 photovoltaic generators connected to the local companies´ grid had been registered, and of these, 1,492 units (7.04%) were installed in rural areas.

Few Distributed Photovoltaic Generation (DPVG) systems were installed for rural consumers until 2018 and, basically, they were small with low power generation potential. With technology consolidation and reduction in prices, from 2019 onwards, this number grew remarkably, as seen in Figure 1.

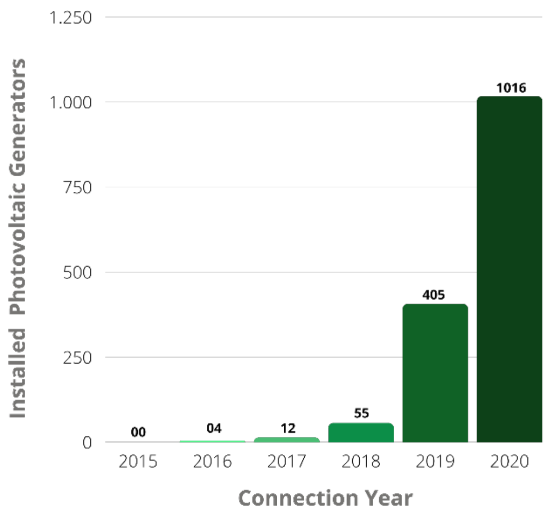

Figure 1. DPVG systems installed by rural consumers per year in the state of Mato Grosso

The average growth of Consumer Units (CUs) having distributed generation in the state of Mato Grosso from 2015 was 342%, and when we analyze only rural areas, the figure is 349%. The number of generator installations per consumer class in the state of Mato Grosso was predominant in the class of residential consumers, according to the percentages in Figure 2 and the numbers in Table 2.

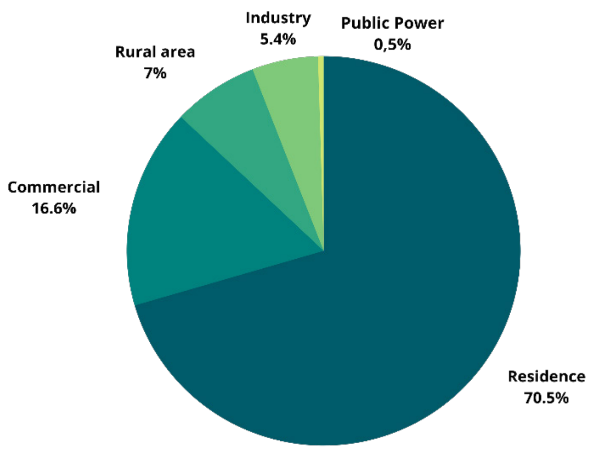

Figure 2. Percentage of DPVG installations per consumer class in Mato Grosso

Table 2 shows that the average power of systems installed in rural areas is 6.44 times greater than that of the residential class. It is clear that the percentages of total power of the installations per consumer class are less different than the number of installations mentioned above, this is because the residential class has lower consumption than that of the other classes and has limited installation capacity.

Therefore, the analysis of the total installed power of each consumer class (Figure 3) shows that the rural consumers with DPVG hold approximately one-fifth of all production potential installed in Mato Grosso. When observing the number of consumer units supplied by the local energy company Energisa Mato Grosso (EMT) separated into their respective consumer classes and relate them to the number of units that have DPVG, we obtain the percentage of penetration of these systems in the grid, as seen in Table 3.

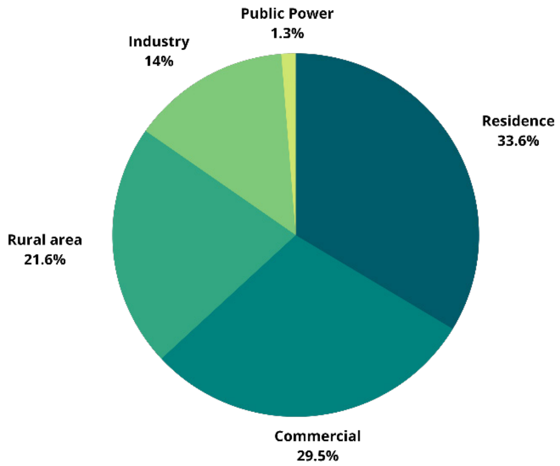

Figure 3. Percentage of installed DPVG power per consumer class in Mato Grosso

Until the end of 2020, the percentage of CUs having DPVG systems was extremely low, which represented a vast possibility of implantation of distributed photovoltaic generation in the state. According to data from ANEEL, to the date of this study, there were 29 thermoelectric power plants (TPPs) totaling 11,925.75 kW installed in the state of Mato Grosso. Figure 4 shows the percentage comparison between the power of DPVG installations and the power of TPPs installed in the state of Mato Grosso.

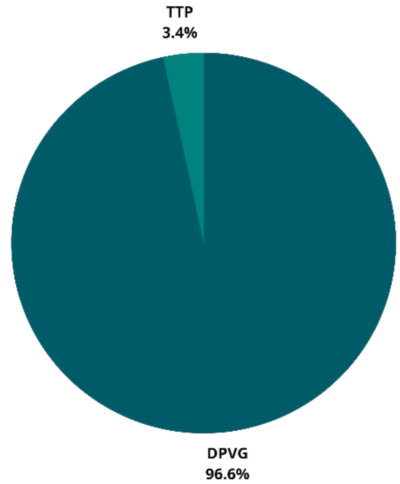

Figure 4. Percentage of installed capacity of DPVG and TTP in Mato Grosso

Table 2. Number of Installations and Total Power of DPVG per consumer class in Mato Grosso

Consumer class	Total CUs with DPVG	Total UCs with DPVG (%)	Total DPVG Installed Power	Total DPVG Installed Power (%)r	Average Installed Power
Residential	14,943	70.50%	114.212.54	33.60%	7.64
Commercial	3,520	16.60%	100.064.03	29.50%	28.43
Rural	1,492	7.00%	73.465.27	21.60%	49.24
Industrial	1,151	5.40%	47.597.04	14.00%	41.35
Public Power	98	0.50%	4.306.31	1.30%	43.94
Total	21,204	100%	339.645.19	100%	170.60

Table 3. Number of CUs in Mato Grosso per consumer class and percentage of them having DPVG

Consumer class	Total number of CUs in the State	Total CUs with DPVG	Percentage of CUs with DPVG
Residential	187,102,552	14,943	0.0080%
Commercial	18,031,643	3,520	0.0195%
Rural	3,672,989	1,151	0.0313%
Industrial	28,884,547	1,492	0.0052%
Public Power	2,632,456	98	0.0037%
Total	240,324,187	21,204	0.0088%

The electricity system of the EMT company in the state of Mato Grosso has 94 electricity production sets that supply the 141 municipalities in the region, with a varied scope, they can supply more than one municipality and at the same time some municipalities may have more than one set. The limits of individual continuity indicators of energy distribution were provided by ANEEL for the monthly period of 2020, as presented in Table 4.

Table 4. Individual continuity indicators for the state of Mato Grosso

Electricity production set	DIC		FIC		DMIC		DICRI	
	Urban	Non Urban	Urban	Non Urban	Urban	Non Urban	Urban	Non Urban
Água Boa	6.27	11.74	3.86	8.27	3.71	6.49	12.22	16.60
Alta Floresta	6.47	11.94	4.59	9.01	3.80	6.59	12.22	16.60
Alta Floresta_34.5kv	10.73	16.32	5.07	9.48	5.63	8.76	12.22	16.60
Alto Boa Vista Ii_34.5	10.04	15.61	6.02	10.42	5.33	8.41	12.22	16.60
Araputanga	6.87	12.35	3.67	8.04	3.97	6.79	12.22	16.60
Aripuanã	9.64	15.20	5.54	9.95	5.16	8.21	12.22	16.60
Barra Do Bugres	6.03	11.45	3.80	8.19	3.54	6.29	12.22	16.60
Barra Do Garças	5.19	10.44	3.30	7.59	2.94	5.58	12.22	16.60
Barra Do Garcas_34.5kv	9.24	14.80	3.92	8.34	4.99	8.01	12.22	16.60
Barra Do Peixe - São Domingos	8.05	13.57	3.42	7.74	4.48	7.40	12.22	16.60
Barro Duro	4.95	10.15	3.23	7.52	2.77	5.38	12.22	16.60
Beira Rio	5.19	10.44	3.36	7.67	2.94	5.58	12.22	16.60
Boa Esperança	10.73	16.32	5.07	9.48	5.63	8.76	12.22	16.60
Brasnorte	7.26	12.76	4.11	8.54	4.14	6.99	12.22	16.60
Cáceres	5.31	10.58	3.73	8.12	3.03	5.68	12.22	16.60
Caceres_34.5kv	11.72	17.34	5.30	9.71	6.05	9.27	12.22	16.60
Campo Novo Parecis - Nova	6.15	11.59	3.67	8.04	3.63	6.39	12.22	16.60
Campo Verde	6.03	11.45	3.48	7.82	3.54	6.29	12.22	16.60
Campo Verde 34.5kv	13.7	19.38	5.78	10.18	6.90	10.28	12.22	16.60
Canarana	6.87	12.35	3.80	8.19	3.97	6.79	12.22	16.60
Chapada	8.85	14.39	3.67	8.04	4.82	7.8	12.22	16.60
Chapada_34.5kv	10.73	16.32	4.35	8.77	5.63	8.77	12.22	16.60
Cidade Alta	5.19	10.44	3.36	7.67	2.94	5.58	12.22	16.60
Cidade Alta_34.5kv	10.73	16.32	5.78	10.18	5.63	8.76	12.22	16.60
Claudia	8.05	13.57	3.99	8.42	4.48	7.40	12.22	16.60
Colíder	6.87	12.35	3.86	8.27	3.97	6.79	12.22	16.60
Comodoro	7.66	13.17	3.99	8.42	4.31	7.20	12.22	16.60
Confresa	7.26	12.76	5.07	9.48	4.14	6.99	12.22	16.60
Confresa_34.5kv	11.72	17.34	6.67	11.06	6.05	9.27	12.22	16.60
Couto Magalhaes	7.66	13.17	3.73	8.12	4.31	7.20	12.22	16.60
Coxipó	5.19	10.44	3.30	7.59	2.94	5.58	12.22	16.60
CPA	5.19	10.44	3.30	7.59	2.94	5.58	12.22	16.60
Cristo Rei	5.07	10.29	3.30	7.59	2.86	5.48	12.22	16.60
Diamantino	6.03	11.45	3.73	8.12	3.54	6.29	12.22	16.60
Distrito Cuiabá	5.43	10.73	3.30	7.59	3.11	5.78	12.22	16.60

Ferronorte	6.27	11.74	3.73	8.12	3.71	6.49	12.22	16.60
Guarantã	10.73	16.32	5.30	9.71	5.63	8.76	12.22	16.60
Guariba	9.64	15.20	5.54	9.95	5.16	8.21	12.22	16.60
Ipiranga Do Norte	8.45	13.98	4.83	9.24	4.65	7.60	12.22	16.60
Itanorte	8.85	14.39	4.11	8.54	4.82	7.80	12.22	16.60
Jaciara	5.55	10.87	3.48	7.82	3.48	7.82	12.22	16.60
Jaciara_34.5kv	9.64	15.20	4.59	9.01	5.16	8.21	12.22	16.60
Jangada	10.73	16.32	5.78	10.18	5.63	8.76	12.22	16.60
Juara	6.03	11.45	3.67	8.04	3.54	6.29	12.22	16.60
Juara_34.5kv	9.24	14.80	4.11	8.54	4.99	8.01	12.22	16.60
Juína	5.79	11.16	3.55	7.89	3.37	6.08	12.22	16.60
Juina_34.5kv	8.45	13.98	4.11	8.54	4.65	7.60	12.22	16.60
Lucas do Rio Verde	6.47	11.94	4.35	8.77	3.80	6.59	12.22	16.60
Lucas do Rio Verde_34.5kv	10.04	15.61	5.07	9.48	5.33	8.41	12.22	16.60
Matupá	10.73	16.32	5.30	9.71	5.63	8.76	12.22	16.60
Mineradora	8.85	14.39	3.86	8.27	4.82	7.80	12.22	16.60
Nobres	10.73	16.32	3.80	8.19	5.63	8.76	12.22	16.60
Nortelândia	7.66	13.17	4.83	9.24	4.31	7.20	12.22	16.60
Nova Canaã	8.45	13.98	4.11	8.54	4.65	7.60	12.22	16.60
Nova Monte Verde	10.04	15.61	4.83	9.24	5.33	8.41	12.22	16.60
Nova Mutum	6.47	11.94	3.67	8.04	3.80	6.59	12.22	16.60
Nova Olimpia	5.31	10.58	3.55	7.89	3.03	7.89	12.22	16.60
Nova Xavantina	5.91	11.30	3.55	7.89	3.46	7.89	12.22	16.60
Nova Xavantina_34.5kv	11.72	17.34	5.78	10.18	6.05	9.27	12.22	16.60
Paranaíta	10.73	16.32	5.54	9.95	5.63	8.76	12.22	16.60
Paranatinga	12.71	18.36	5.78	10.18	6.48	9.77	12.22	16.60
PCH Paranatinga II	10.04	15.61	5.07	9.48	5.33	8.41	12.22	16.60
Poconé	8.85	14.39	3.86	8.27	4.82	7.80	12.22	16.60
Pontes e Lacerda	5.55	10.87	3.55	7.89	3.20	5.88	12.22	16.60
Pontes e Lacerda_34.5kv	12.71	18.36	5.07	9.48	6.48	9.77	12.22	16.60
Primavera do Leste	5.43	10.73	3.55	7.89	3.11	5.78	12.22	16.60
Primavera do Leste_34.5kv	10.04	15.61	4.83	9.24	5.33	8.41	12.22	16.60
Quatro Marcos	5.79	11.16	3.55	7.89	3.37	7.89	12.22	16.60
Quatro Marcos_34.5kv	12.71	18.36	6.67	11.06	6.48	9.77	12.22	16.60
Querência do Norte	8.45	13.98	4.83	9.24	4.65	7.60	12.22	16.60
Rodoviária	5.19	10.44	3.30	7.59	2.94	5.58	12.22	16.60
Rondolandia	9.64	15.20	5.54	9.95	5.16	8.21	12.22	16.60
Rondonópolis Centro	5.19	10.44	3.30	7.59	2.94	5.58	12.22	16.60
Rondonópolis 1	5.07	10.29	3.30	7.59	2.86	5.48	12.22	16.60
Rondonópolis 1_34.5kv	10.73	16.32	3.99	8.42	5.63	8.76	12.22	16.60
Santa Carmem	8.45	13.98	4.65	8.42	4.65	7.60	12.22	16.60
Sapezal	5.79	11.16	3.55	7.89	3.37	6.08	12.22	16.60
Sapezal_34.5kv	9.24	14.80	4.59	9.01	4.99	8.01	12.22	16.60
Sinop	5.55	10.87	3.67	8.04	3.20	5.88	12.22	16.60
Sinop Centro	5.55	10.87	3.67	8.04	3.20	5.88	12.22	16.60

Sorriso	5.67	11.01	3.86	8.27	3.29	5.98	12.22	16.60
Sorriso-Terciário ELN	10.73	16.32	5.54	9.95	5.63	8.76	12.22	16.60
Sozinho	7.66	13.17	3.86	8.27	4.31	7.20	12.22	16.60
Tangara da Serra	5.43	10.73	3.42	7.74	3.11	5.78	12.22	16.60
Tapurah	10.04	15.61	5.07	9.48	5.33	8.41	12.22	16.60
Terra Nova Do Norte	7.26	12.76	4.59	9.01	4.14	6.99	12.22	16.60
Trevo do Lagarto	5.31	10.58	3.30	7.59	3.03	5.68	12.22	16.60
Trevo do Lagarto_34.5kv	9.24	14.80	4.83	9.24	4.99	8.01	12.22	16.60
UT São Jose Rio Claro	5.91	11.30	3.42	7.74	3.46	6.19	12.22	16.60
UT São Jose Rio Claro_34.5kv	8.05	13.57	3.61	7.97	4.48	7.40	12.22	16.60
Várzea Grande	5.31	10.58	3.36	7.67	3.03	5.68	12.22	16.60
Várzea Grande_34.5kv	9.24	14.80	3.92	8.34	4.99	8.01	12.22	16.60
Vila Rica Nova	6.87	12.35	5.07	9.48	3.97	6.79	12.22	16.60
Vila Rica Nova_34.5kv	7.26	12.76	6.02	10.42	4.14	6.99	12.22	16.60
Average	7.95	13.42	4.29	8.67	4.36	7.34	12.22	16.60

The acceptable limits for the non-urban zone are greater than the limits for the urban zone, which, on average, are about 1.68 times greater for DIC; 2.02 times for FIC; 1.68 times for DMIC, and 1.36 times for DICRI than in urban areas. Interruption of supply can lead to losses in agricultural and animal production, and the rates can be improved with the decentralized production of electricity and customer proximity, as is the case of photovoltaic generators. This would contribute to the reduction of these problems in rural areas with higher incidence, promoting energy security and ensuring that demand is met (OLIVEIRA *et al.*, 2021).

In addition, the collective indices (DEC and FEC) were analyzed for the state of Mato Grosso in the last 10 years. Data are presented in Table 5 and graphs of Figures 5 and 6.

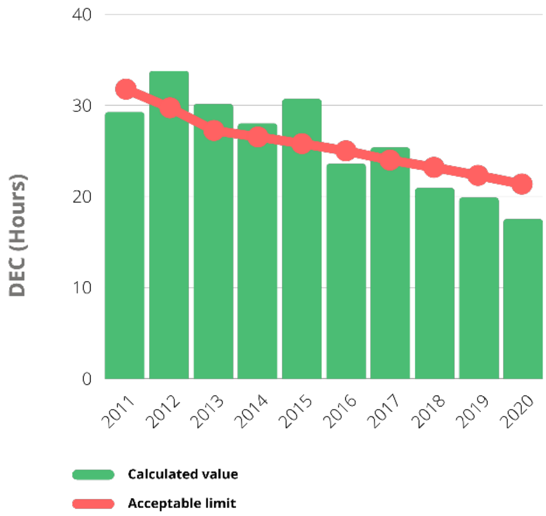

Figure 5. Bar chart of DEC indicator in the last 10 years for the state of Mato Grosso

Table 5. Collective continuity indicators for the state of Mato Grosso

Year	DEC calculated	DEC limit	FEC calculated	FEC limit
2011	29.23	31.24	20.79	26.31
2012	33.75	29.32	24.22	24.57
2013	30.12	26.98	23.48	22.59
2014	27.99	26.32	20.61	22.33
2015	30.67	25.63	24.31	21.67
2016	23.56	24.89	14.26	20.93
2017	25.35	23.94	12.49	19.85
2018	20.9	23.19	9.14	19.05
2019	19.85	22.36	8.2	18.07
2020	17.48	21.47	7.77	17.05

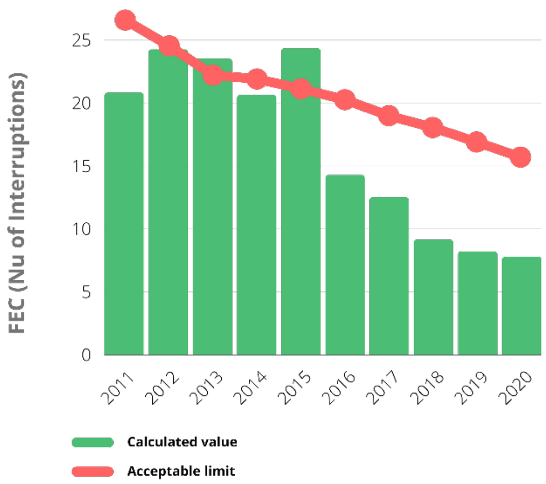

Figure 6. Bar chart of FEC indicator in the last 10 years for the state of Mato Grosso

The chart of the DEC indicator in Figure 5 shows that the limit of hours of interruptions was exceeded in 2012, 2013, 2014, 2015 and 2017, while the number of interruptions for the FEC indicator violated the limits in 2013 and 2017. Both indicators showed a marked reduction in the rates from 2016, when the first photovoltaic generators began to be installed in the state.

To estimate the total energy generated by the photovoltaic systems installed for rural class costumers, the average irradiation for the central west region was 5.08 kWh m^{-2} day^{-1} (PEREIRA *et al.*, 2017) and the performance rate of the photovoltaic generator was 75%. The estimates were obtained from equation 1 as shown in Table 6.

From that metric, the positive impact of the implantation of photovoltaic systems for electricity generation was estimated, resulting in a reduction of more than 52 thousand tons of CO_2 emission into the atmosphere during the study period. Moreover, as the number of these installations increases, society becomes less dependent on combustion generators to supply energy demands such as turning on thermoelectric power stations.

According to the 2021 Electric Energy Statistical Yearbook published by the public company attached to the Ministry of Mines and Energy, the Energy Research Company (EPE, 2021), the electricity consumption of costumers in the state of Mato Grosso was 9,800 GWh in 2020, representing an increase of 3.6% over the previous year. Of this total, 1,503 GWh is demanded only by rural class customers, representing 15.33% of the total consumption.

The estimate of the total energy produced by the photovoltaic generators installed for rural consumers in the state (Table 6) accounts for 6.3% of all energy demanded by rural consumers in 2020, as shown in Figure 7. This percentage is still relatively low, but based on the evident growth of generator installations in recent years the trend is for this number to increase even more.

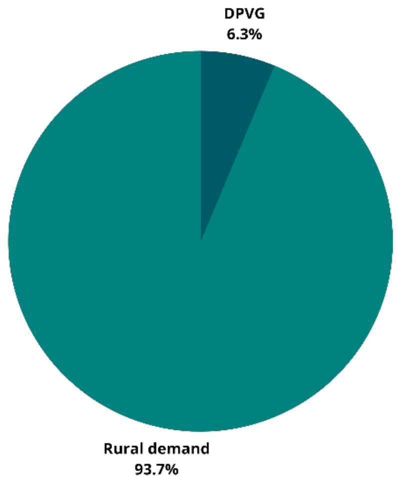

Figure 7. Percentage of participation of energy generated by DPVG in the rural demand of the state

Table 6. Estimated CO_2 emission reduction for the state of Mato Grosso

Year	Installed Power (kW)	Estimated generated energy (MWh)	Estimated CO_2 reduction ($_tCO_2/year^{-1}$)
2016	24.40	33.47	16.96
2017	594.61	815.57	360.36
2018	3.797.09	5208.09	2283.75
2019	23.404.62	32101.78	13292.54
2020	73.465.27	100764.96	36771.65
	Total		52725.26

CONCLUSIONS

- The distributed photovoltaic generation in the state of Mato Grosso has been growing in all consumer classes, with an emphasis on residential applications, due to their higher rates. However, these applications are restricted to the residential area available, which implies in lower power systems. Rural systems, on the other hand, have more extensive space, enabling the application of larger plants installed in vast sheds or on the ground, allowing for more convenient and frequent maintenance and cleaning of the panels, hence increasing the production of the system.
- The collective indicators of continuity from the year 2016 onwards showed a significant improvement in the values, no longer exceeding the established limit, which happens simultaneously with the significant installation of photovoltaic generators, being able to indicate participation in improving continuity of supply.
- In addition, reduction in carbon dioxide emission into the atmosphere, estimated at more than 52,000 tons from the generation of energy by these systems, has contributed to the decarbonization of the state's energy matrix, which still has a small share of only 6.3% of all energy demanded by rural consumers.
- The technical visits showed that rural properties have more larger installations, because there is greater energy demand such as storage and drying of grains in silos or in poultry and swine farms that need electrical systems to control temperature.
- Compared to other types of distributed generation (DG), photovoltaic systems have lower maintenance cost, not requiring technicians to operate the system, in addition to having several credit lines with attractive interest rates. Thus, the application of photovoltaic generators for energy production in the rural sector, in addition to growing, has proven to be advantageous and have great potential for expansion, since only 0.0052% of consumer units have this type of generation.

AUTHORSHIP CONTRIBUTION STATEMENT

HOLZBACH, M.: Data curation, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing; **RESENDE, A.S.:** Conceptualization, Supervision, Visualization, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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