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Planning For Distributed Photovoltaic Microgeneration In Brazil – The Regulatory Framework And The Projection Of The National Expansion Plan (PNE) For 2050

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Abstract:
Background: *The search for the development and expansion of the national energy matrix in a renewable and sustainable way is the subject of constant studies and corroborates the potential use of photovoltaic generation. In this work, the effects of Federal Law No. 14,300/2022 for photovoltaic self-generators were analyzed and the contribution of Distributed Photovoltaic Microgeneration (MGFD) on the national load curve projected for 2050 was simulated. This article explains long-term energy planning in Brazil and seeks to contribute in the following sectors: Demand forecasting; Sustainable development; Decision support; Education and awareness of use; Planning the national energy matrix; and Solution or adaptation to local supply conditions.*
Materials and Methods: *The study was focused on consumption in the residential sector and its reduction with energy produced by MGFD, from a planning perspective for this sector. For this, historical data on electricity consumption in Brazil was used, extracted from the National Energy Balance (BEN); and the energy sector growth rates projected by the Energy Research Company (EPE), contained in the National Energy Expansion Plan for 2050 (PNE-2050), were adopted.*
Results: *The results showed the growth of MGFD in the years 2021 to 2023, demonstrating consolidation of photovoltaic solar energy in Brazil. This progress was the result of the bill that provided for the end of the existing tax incentive for the acquisition of MGFD. They also demonstrated that the demand for energy by 2050 will be three times higher than today, with the MGFD being able to reduce 72.22% of the country's residential demand.*
Conclusion: *Forecasts of increased national demand justify the need for public and private incentives for the dissemination of photovoltaic solar energy. Installing this energy source can significantly alleviate future demand in the residential sector. This decision impacts planning for the expansion of the current national energy matrix and government investment to meet future energy demand.*
Key Word: *Alternative energies; Distributed renewable energy systems; Energy matrix; Energy development; Public policies; Renewable sources.*

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I. Introduction

Brazil presents increasing energy consumption every year. According to data presented by the Energy Research Company (EPE), the demand for electrical energy has been driven - mainly - by population growth and urbanization. Since the industrial, commercial, and residential sectors have different hourly electricity consumption profiles, these profiles are constructed by the instantaneous hourly demand of consumer units in the country (EPE,2023).

The United Nations (UN) established the 2030 Agenda with objectives for the sustainable management of natural resources in economic development - the Sustainable Development Goals (SDGs), among which - among them - the following are part of this study: SDG 7 - energy clean and accessible, SDG 11 - sustainable cities and communities, and SDG 12 - responsible consumption and production (United Nations, 2015).

The Brazilian residential sector represents a significant portion of the country's total electricity consumption (IPEA, 2018). As highlighted by the National Institute of Energy Efficiency (INEE, 2019), traditionally, peak demand in this sector occurs during the night, and the energy needs of homes vary according to size, geographic location, climatic conditions, and conditions. consumption habits of residents.

Equipment such as air conditioning, refrigerators, and electronics - in addition to lighting systems - are mainly responsible for energy consumption in homes. However, there is a growing trend towards awareness and adoption of more sustainable practices in the residential sector, such as energy efficiency, the use of renewable energy and the installation of distributed photovoltaic microgeneration systems.

As solar energy production peaks during the day, even if it does not coincide with the period of highest residential consumption, to encourage its penetration, Brazilian legislation provides for the formation of a reserve and compensation for energy generated more than concomitant consumption. Thus, distributed photovoltaic microgeneration has grown significantly in Brazil in recent years, driven by government incentive policies, technological advances, and environmental awareness.

According to the Center for Management and Strategic Studies (CGEE, 2021), this type of energy generation allows consumers to generate part, or all the electrical energy consumed in their homes, reducing their dependence on energy concessionaires, and contributing to environmental sustainability.

The availability of energy has denoted the level of development of countries. In Brazil, in line with other developing countries, electrical energy tends to have the greatest significance due to the reduction in the share of fossil fuels in the national energy matrix (EPE, 2018). In 2022, the country consumed a total of 677.1 TWh (EPE, 2024), the projection for 2050 is a 316% growth in total electrical energy demand, with a growth of 3.2% per year (MME, 2014).

This rate, presented by the National Electric Energy Agency (ANEEL), is based on the economic growth projected by the Gross Domestic Product (GDP), the expected population growth, mostly in the urban area, of around 30 million inhabitants (in projection until 2050), due to the increase of more than 39 million households for the period, and also the decrease in the number of inhabitants per residence (EPE, 2018).

Brazil is one of the ten countries that consume the most electricity and government projections emphasize the need for strategic planning for the expansion of generation oriented to renewable sources (EPE, 2018). This increase in generation capacity must condition the decentralization of the matrix, also considering the need to guarantee energy quality and reliability, a strategic characteristic of an efficient energy sector (STEFANELLO, 2018).

But the expressiveness and consolidation of photovoltaic generation are directly linked to the opening of this market - GD - in Brazil. In this context, the problem addressed in this work consists of identifying the share of the residential sector in the load curve and verifying the supply of residential demand projected for 2050 with decentralized photovoltaic generation.

Energy demand is understood as energy consumption in each region, whose representation of temporal behavior is called load curve. Ideally, a system tends to operate best when it presents a flat behavior in its daily load curve - the fewer “peaks” the system has, the more constant (linear) the load, which tends to generate a lower maximum demand and optimize utilization. of the power generation park and transmission system.

The evolution of DG in Brazil was leveraged by ANEEL Normative Resolution No. 482/2012, when it conceptualized and characterized its use. At that time, distributed energy was incipient in the country. But this regulation – in addition to the tax incentives offered to new renewable energy installations (such as solar) – boosted this form of generation. However, with its (GD) consolidation in the Brazilian electrical system, incentives were gradually reduced, and legislation was changed to accommodate the new reality of Brazilian electrical energy generators.

In this sense, and as a problem studied, the GD legal framework was enacted in 2022, bringing about the gradual temporal reduction of the benefits that existed until that moment. Legislators still intend to present new rules to control the current incentive and dissemination of DG in the country, among them there is bill No. 4,831, of 2023, exempting the distribution concessionaire from providing a connection point to new accessors when the company itself (dealership) reaches the GD performance limit of 50% (fifty percent). This proposed law seeks to ensure the economic and financial balance of the distributors' contracts, but it is viewed with insecurity by investors in new generating systems (GD).

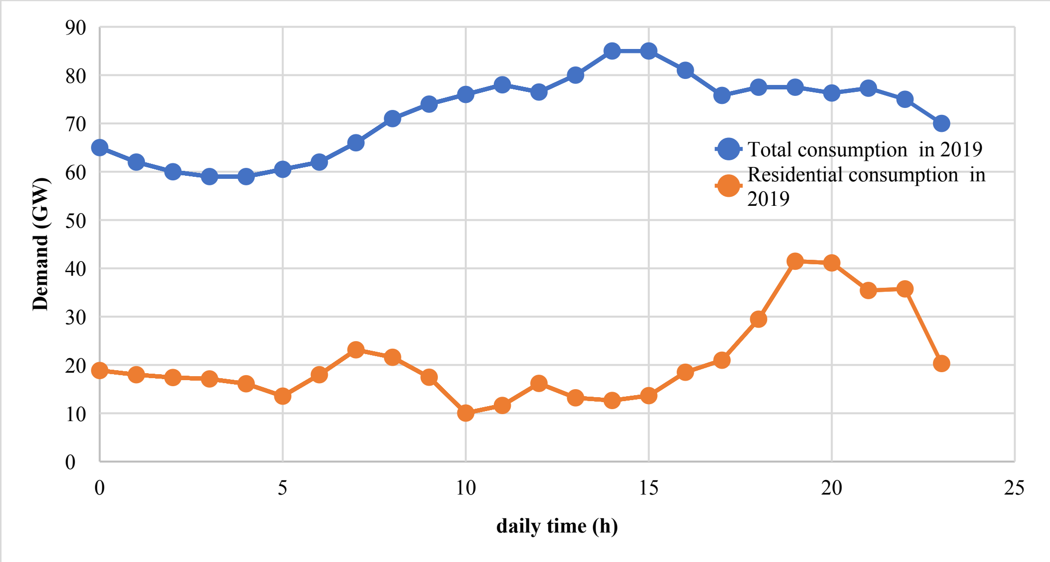
In this way, this work aims to contribute to the understanding of the phenomena of expansion and planning of electrical energy consumption in Brazil and, also, of distributed photovoltaic generation in the national planning scenario, delimited to 2050, considering for this the residential daily load curve and national demand and the growth rate of national demand. The main hypothesis of this research entails the partial supply of energy consumed in the Brazilian electrical system through the expansion of distributed photovoltaic microgeneration. The issue lies in ensuring that public policies strategically foster both public and private initiatives.

Demand curves and photovoltaic solar generation in Brazil

The daily demand curve is directly impacted by the planning and operation stages of electrical power systems. Despite technological advances and research into energy storage, the options available on a commercial scale are not yet economically viable and accessible to all consumers. Therefore, all energy generated must be consumed immediately, which implies generation capacity at least equal to the maximum peaks in demand perceived by the system (OLIVEIRA, 2013).

Like other developing countries, Brazil has shown a growing demand for energy. The national daily load curve (ONS, 2019a), observed in Figure 1, shows the daily demand on 04/04/2018 (blue dash), and 04/05/2019 (yellow dash), which are on the same day weekly. The option for the period is reinforced by behavior consistent with the sectoral pattern of consumption on a common working day, and considers the climatic factor, as it represents a mild season in temperature, in order not to influence consumption maximums and minimums, but rather an average of seasonal behavior.

Figure 1 – National real hourly demand curve (MWh/h).



Source: (ONS, 2019a).

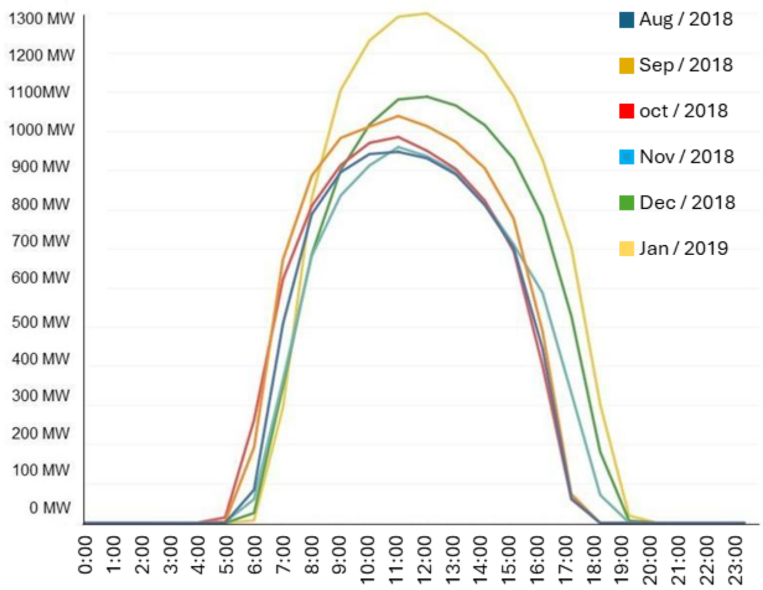
It is possible to observe - from Figure 1 - that there were no representative changes in the general characteristic of the curve, peak consumption times remained between 12pm and 6pm. In other words, there was no variation in the hourly behavior of maximum and minimum demands, maintaining the national daily demand profile.

The intermittency of photovoltaic solar generation curves can be explained by the climatological variation that exists in Brazil, due to its large territorial extension. Studies such as that by Francisco et al (2019) show that solar radiation has a direct influence on photovoltaic generation, but other climatic factors, such as temperature and rainfall, also have an influence on this generation source.

From Figure 1, it is also possible to observe that the growth of the load curve basically represents an increase in demand. According to (EPE, 2024), in 2022 distributed micro and minigeneration reached an installed power of 17,325 MW and together generated 18,423 GWh. The photovoltaic solar source participated with 17,006 MWp of installed power and 17,378 GWh of generation.

The Brazilian demand curve presents an encouraging aspect for photovoltaic solar generation, as the photovoltaic generation curve intersects with the demand curve. Figure 2 presents data on the Brazilian average generation of six days (between August 2018 and January 2019), in which daily photovoltaic generation has a characteristic curve.

Figure 2 – Average hourly photovoltaic generation graph (MWavg) for Brazil



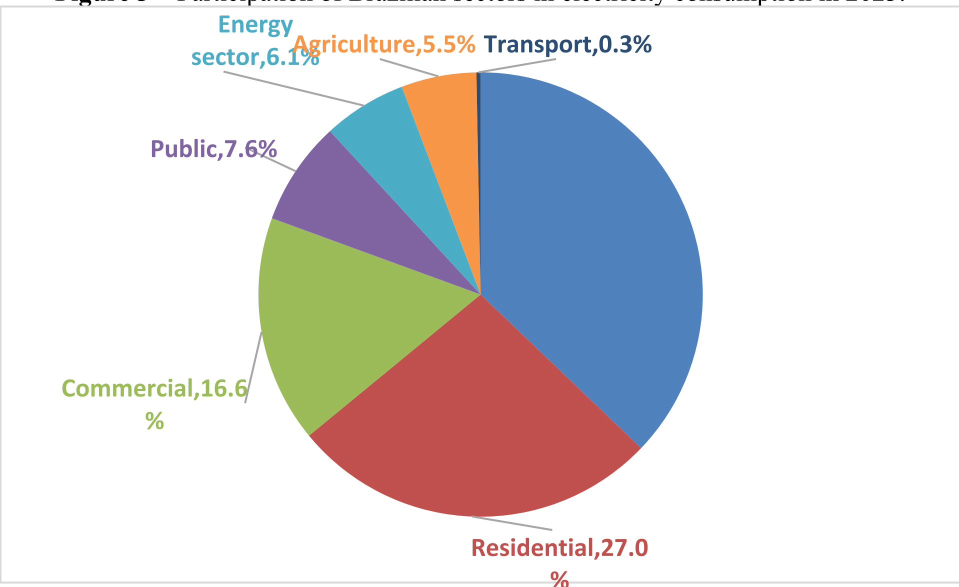
Source: Adapted from (ONS, 2019b).

It can be stated - from Figure 2 - that photovoltaic generation presents a significant daily contribution between 8am and 5pm. In this generation model, it is necessary to compensate for excess generation (if any) by dispatching this energy to the electrical distribution network (and simultaneous consumption by other consumer units).

Energy consumption in the Brazilian residential sector

A sectoral analysis of national electricity consumption data, obtained in 2023, showed that the residential sector has been the second largest consumer with 29% of the total, as shown in Figure 3.

Figure 3 – Participation of Brazilian sectors in electricity consumption in 2023.



Source: Adapted from the Brazilian Electric Energy Yearbook (EPE, 2024).

The expressiveness surrounding residential consumption is mainly due to three factors: the use of household appliances and electronics in homes; population increase; and the decrease in the number of people per household.

The Brazilian availability of renewable natural resources makes it possible to meet growing demand, maintaining the national energy matrix based on generation sources considered clean. As important as considering the prospects for the penetration of renewable sources, it is necessary to take initiatives that allow the development of technologies around them (EPE, 2007).

Diffusion of distributed photovoltaic microgeneration in Brazil

According to the Demand Scenarios for National Energy Planning 2050 (PNE 2050) by EPE (2018), the alternatives for meeting demand involve two paths: Demand Side Management (GLD or DSM).) and the expansion of supply. The first is related to the modification of the consumer demand profile, mainly with the shift of consumption in moments of peak demand, to moments with little system load (Bharlouei & Hashem, 2013). The second focuses on centralized generation through water, thermal, nuclear, wind and solar sources, and distributed and autonomous generation.

Uhlig (2019) adds that the increase in distributed generation systems to meet the supply of electricity challenges generation expansion planning, which is traditionally centralized and based on auctions. Decisions on the construction of centralized generation and transmission assets, taken based on the expansion of distributed generation, are becoming increasingly common.

In 2012, EPE published a technical note entitled "Analysis of the Insertion of Solar Generation in the Brazilian Electrical Matrix", covering the main applications of solar energy for electricity generation in Brazil. The studies showed that photovoltaic insertion would be closer to being carried out naturally via distributed generation, especially in residential and commercial self-production, given the imminent occurrence of tariff parity, that is, the equalization of the cost of energy generated by a photovoltaic system connected to the network and the tariffs charged by distributors (EPE, 2014).

At the same time and with the aim of combining financial savings, socio-environmental awareness, and self-sustainability, the first step towards market opening was taken on April 17, 2012, when ANEEL Normative Resolution nº 482/2012 came into force, which grants the consumer generate electrical energy from renewable sources or qualified cogeneration, including the injection of surplus generation into the distribution network in your location.

Through this resolution and its subsequent amendments, it was defined that electrical energy generating units with a power of less than or equal to 75 kW and that use qualified cogeneration, according to ANEEL regulations, or renewable sources will be classified as microgenerators (ANEEL, 2012).

The regulation also affects the entire compensation system, injection of surplus energy into the grid, technical and access regulation, maintenance, consumer credits and billing to the distributor, in a broad way and covering rights and duties on both sides, generators and concessionaires. (ANEEL, 2012).

In Brazil, in December 2015, the government authorized the Distributed Electricity Generation Development Program (ProGD), aiming to reach 23.5 GW of installations, mostly photovoltaic (PV MAGAZINE, 2015). Considering these benefits, solar generation has undergone increasing and greater expansion in recent years than others.

Due to the great expansion of this energy source and, within the credit system promulgated by ANEEL Normative Resolution No. 482/2012, it was observed that self-generators use the electrical grid, but do not pay tariffs and charges for the use of transmission and distribution systems. This fact generated dissatisfaction on the part of energy transmission and distribution concessionaires.

For the sustainable development of distributed generation, Law No. 14,300/2022 was sanctioned (considered as a regulatory framework for electrical energy) including 3 scenarios to start charging tariffs and charges previously disregarded in microgenerator invoices, being Brazil (2022):

a. Self-producing consumers with projects approved until 01/06/2023 would remain exempt from tariffs and charges until 12/31/2045.
b. Self-producing consumers with projects approved between 01/07/2023 and 07/06/2023 would have tariffs and charges gradually charged as per Table 1, column A.
c. Self-producing consumers with projects approved after 07/06/2023 would be gradually charged fees and charges as per Table 1, column B.

Table no 1 - Gradual collection of tariffs and charges related to wire B

Year	Percentage of tariffs and charges	
	A	B
2023	4.1%	4.1%
2024	8.1%	8.1%
2025	12.2%	12.2%
2026	16.2%	16.2%
2027	20.3%	20.3%
2028	24.3%	24.3%
2029	27%	Rule when meeting accounts
2030	27%	
2031	Rule when meeting accounts	

Notes: A) Percentage of tariffs and charges for self-producers with projects approved between 01/07/2023 and 07/06/2023. B) Percentage of tariffs and charges for self-producers with projects approved after 07/06/2023. Source: Adapted from BRASIL (2022).

With the problems presented - constant increase in electricity demand and increase in energy tariff charging within the legal framework - the objectives of this research were to simulate the energy demand of the residential sector for 2050 and verify the potential of distributed photovoltaic microgeneration for meet such demand in Brazil.

II. Material And Methods

The research design was descriptive explanatory in the sense of exposing characteristics of a given population or phenomenon, in addition to establishing correlations between variables and defining their nature, following an approach consistent with the purpose of the present research (descriptive analysis).

Study Design: collection of qualitative and quantitative data with statistical treatment.

Study Duration: real dates between 2000 to 2019. Extrapolated dates until 2050

Subjects & selection method: The approach was quantitative, characterized by the attribution of values in data collection and information processing, through statistical techniques (Richardson, 1999). Data collection was indirect, that is, from a secondary source. Regarding the technical nature, the following resources were used: bibliographic; data survey; analysis of variance; and statistical treatment.

The research began by identifying the share of the residential sector in the national load curve and was based on studies released by EPE. Once the share of the residential sector was characterized, its growth was projected considering a growth rate of 3. 2% per year (MME, 2014) and the 2050 horizon (according to PNE 2050), through point-by-point integration of the national daily load curve, made available by the National System Operator (ONS, 2019b).

Inclusion criteria: The same approach was adopted in the graphical projection of distributed photovoltaic microgeneration (MGFD), but this considered the potential service of 72.22% of the total load of the Brazilian residential sector (as stated by EPE), in a projection to 2050. The Distributed photovoltaic generation followed the current behavior presented by the ONS.

The distributed photovoltaic generating systems proposed in this work had an installed peak power of 157.9 kWh, which corresponds to the national average monthly residential electricity consumption (EPE, 2018), and the study considered these systems represent the reduction in energy consumption totality of residential units. Thus, the generating units designed in this study do not present excess energy generation, the MGFD were designed to generate sufficient credits for monthly rebates. Therefore, the opening of the market for future compensation (after 30 days) nor for the sale of energy by microgenerators, but by deducting the real monthly costs of electricity consumption.

Exclusion criteria: Such a design effectively contributes to economic engineering analyses, not only in fundamental terms, but mainly by analyzing the national dissemination of technology, not prioritizing regions with higher average residential consumption or more economically significant ones.

Procedure methodology

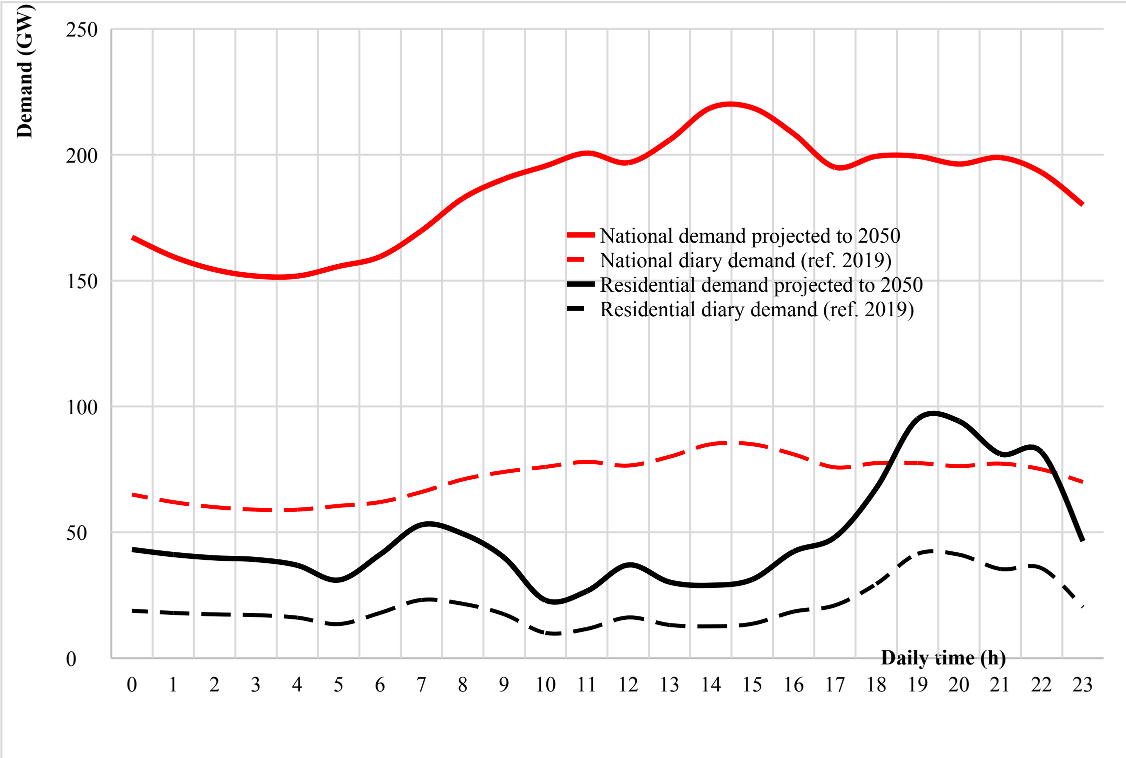
Such a design effectively contributes to economic engineering analyses, not only in fundamental terms, but mainly by analyzing the national dissemination of technology, not prioritizing regions with higher average residential consumption or more economically significant ones.

III. Result

Daily load curve and demand growth scenarios presented in PNE 2050

The annual growth rate of national demand for electrical energy, according to (EPE, 2018), is 3.2% per year in projection until 2050, and can be seen in Figure 4.

Figure no 4 – Daily load curves for 2019 and daily load projection for 2050 - Comparison.



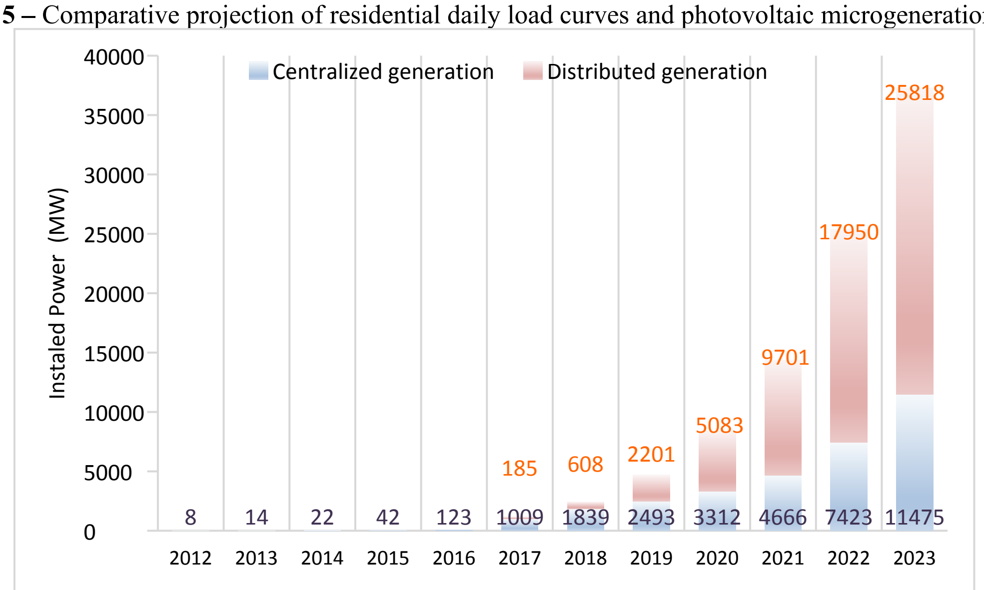
Source: Own Authorship (2023).

There is no conformity of demand over long periods, nor the guarantee that maximum hourly demands will be maintained, on the other hand, growth is factual and projected, assuming that in the absence of changes, in the period, it will agree with the current hourly profile. According to PNE 2050 (EPE, 2018), in terms of amount, national demand tends to triple at the end of the study period.

Evolution of installed solar photovoltaic generation capacity

The installed power of solar energy sources became significant from 2017 onwards and presents an exponential growth curve. Figure 5 presents data on this evolution, according to a survey carried out by ANEEL/ABSOLAR in 2023.

Figure 5 – Comparative projection of residential daily load curves and photovoltaic microgeneration curve.



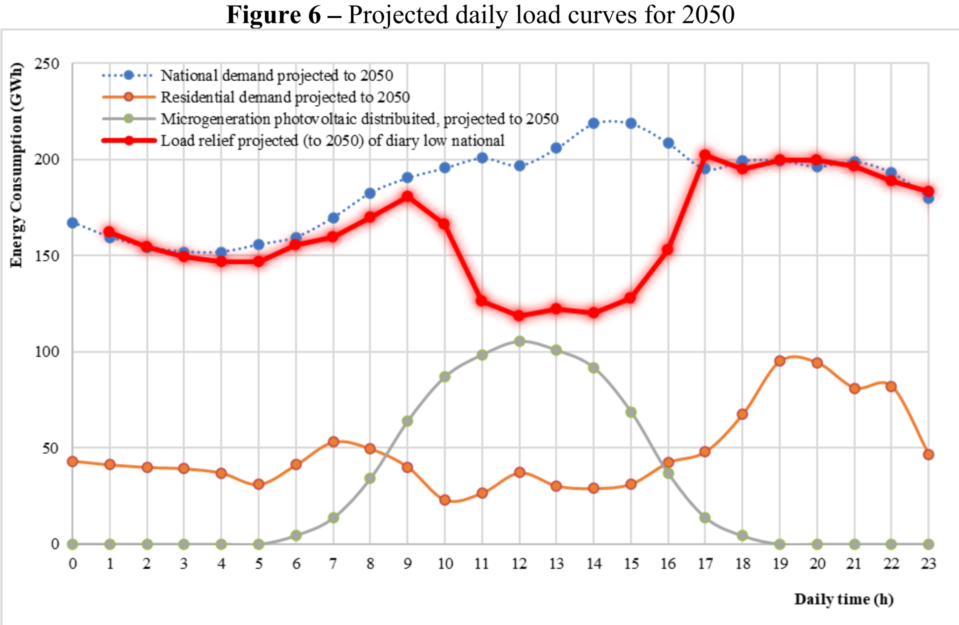
Source: Adapted from ABSOLAR (2023).

Figure 5 shows that distributed generation increased considerably in 2022 (185% over 2021) and 2023 (144% over 2022), denoting a step effect arising from the legal framework. Because these approvals of new generators still enjoyed the benefits of taxation, presented previously.

Effects of photovoltaic solar generation on the projected curve (2050) of residential and national demand

With the analysis of several aspects, including direct and indirect government incentives, which tend to influence distributed microgeneration in Brazil, to provide the necessary environment for it to meet the already estimated increase in demand for 2050, it is estimated a projection according to PNE 2050 (EPE, 2018) , Figure 6, depending on the maximum forecast for source generation in the period. Furthermore, the non-equivalence of hourly photovoltaic generation to the residential sector provides the network with a surplus with potential for collaboration in meeting demand, as can be seen in the line highlighted in red.

Figure 6 – Projected daily load curves for 2050



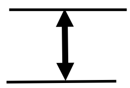
Source: Own authorship (2023).

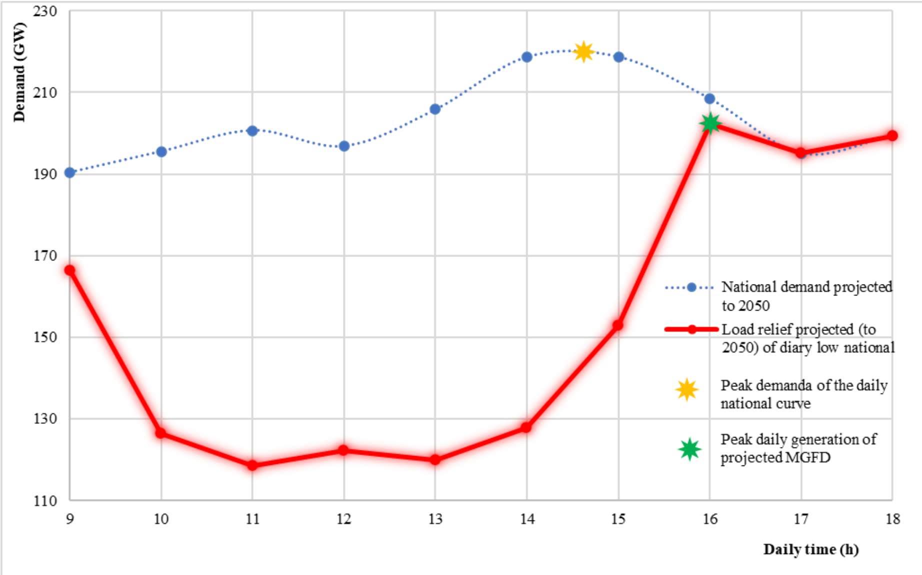
The comparative projection shows that demand growth is met in a decentralized manner through prosumers, given that photovoltaic generation has a potential reduction of 72.22% of residential demand for the period.

According to PNE 2050 projections EPE (2018), the capacity around MGFD will be 33 GWp, supplying 15 million homes, thus representing 13% of the energy demanded by the residential sector and 18% of homes. The projected implementation of MGFD.

The estimate of solar photovoltaic generation over the projected curve (2050) of national demand showed the potential of distributed photovoltaic energy and the partial state relief on investment in centralized generation, as shown in Figure 7.

Figure 7 – Projected daily load curves for 2050





Source: Own authorship (2023).

If these MME projections are confirmed, the peaks in national demand without distributed photovoltaic microgeneration and in demand relieved by MGFD projected for the year 2050 were, respectively: 218.68 and 202.39 GWp - highlighted in Figure 7 (ANEEL, 2022). It is possible to verify that the dissemination of MGFD can promote a load relief in the national generating park of 7.5%, throughout the daily cycle.

The photovoltaic generation source, despite being intermittent, provides load relief that can be strategic in conserving the hydraulic potential energy present in the plants' reservoir. Photovoltaic generation during the day allows for water savings in reservoirs, making the operation of hydroelectric plants more flexible at night and at times of peak demand.

However, the relief from direct investment in electrical infrastructure because of the growth of the specific sector, however, is partial, as granting the majority of this responsibility to MGFD opens up gaps in the incidence of events critical to the supply of demand caused by intermittency. The application and expansion of MGFD must therefore occur at a complementary level with the implementation of continuous generating sources with potential for instantaneous supply, adding robustness to the system.

Under this analysis, the correlation of sources is bidirectional, allowing weighting from both the photovoltaic generation perspective and the hydraulic generation perspective. In short-term planning, hydraulic energy helps to compensate for the intermittent and variable generation of photovoltaic energy, in this study in the distributed generation modality. In the medium and long term, when there are savings in terms of maintaining the resource in the reservoir caused by the MGFD, there is the possibility of meeting peaks in demand and the system in critical resource periods, in a more planned and effective way.

This relationship, given the inclusion of intermittent sources, becomes essential to the system, tending to be constant in favor of the quality, reliability and operability of service.

IV. Discussion

The Exponential Growth of Photovoltaic Generation: With the implementation of Federal Law No. 14,300/2022, exponential growth in photovoltaic generation in Brazil was triggered, with notable emphasis in the years 2021, 2022 and 2023.

This growth is attributed to the anticipation and momentary confirmation of the tax benefits stipulated in the law, suggesting a trend towards future stabilization in the implementation rate of distributed photovoltaic microgeneration (MGFD).

The Impact of Residential Demand on MGFD Penetration: Projections indicate a projected demand for 2050 that is three times greater than the current one. If EPE's estimates of annual growth in demand for electricity, in the order of 3.2% per year, are maintained.

This increase in residential demand serves as a significant incentive for MGFD penetration, highlighting its role in mitigating growing national demand and reducing dependence on traditional energy sources.

The Potential for Abatement of Residential Demand: The MGFD projection for 2050 demonstrates a potential to abate 72.22% of the country's residential demand, indicating a crucial role of this modality in the supply of electrical energy to homes.

This partial reduction in energy consumed by the residential sector not only reduces dependence on conventional energy sources, but also promotes sustainability and energy autonomy.

Public-Private Partnership Strategies: The establishment of public-private partnerships is essential to promote the continued growth of MGFD and ensure its efficient integration into the national electricity system.

These partnerships can facilitate investments in infrastructure, research and development, as well as promote education and awareness about the adoption of renewable energy.

Evolution of the Electrical System and New Technologies: The Brazilian electrical system is facing one of the most significant evolutions since its conception, driven not only by market flexibility, but also by the introduction of new technologies, such as MGFD.

Denying or preventing this development would delay the progress necessary for the country's energy autonomy and sustainability.

Generation Complementarity Planning: Planning at the level of generation complementarity is strategic and essential for the expansion of the national energy matrix through renewable sources.

In a context of new consumer profiles and technological advances, this planning is crucial to guarantee the stability and efficiency of the electrical system, adapting to changes in the energy market.

V. Conclusion

The development of the scenario conducive to photovoltaic microgeneration distributed nationwide, analyzed in this study, emphasizes the complementary nature of meeting national demand based on surplus photovoltaic energy injected into the electrical grid.

A well-crafted article can illuminate important aspects of energy planning and positively influence future policies and practices. This article explains the planning in Brazil to long-term energy, especially to:

a. Demand forecast: Helps predict how the population will grow and the amount of energy it will consume.
b. Sustainable Development: Promotes the rational and efficient use of natural resources, establishing action targets to improve energy efficiency and energy security, while reducing pollutant emissions.
c. Decision Support: Provides crucial information for governments and companies to make informed decisions about modernizing production systems, using new technologies and promoting innovative solutions.
d. Education and Awareness: Raises awareness about the efficient use of resources and the importance of energy education.
e. Planning the National Energy Matrix: Proper planning of the national energy matrix must be done with updated data on current energy consumption and projections of future demand.
f. In addition to understanding the various energy sources available and their contributions to the energy matrix, combined with public policies that encourage conscious, efficient and sustainable use.
g. Adaptation to Local Conditions: Allows strategies to be adapted to local conditions, considering the needs of all sectors.

The following stand out in this study:

a. The perspectives of future scenarios (technology foresight) indicate a promising scenario for MGFD in Brazil, with a central role in diversifying the energy matrix and reducing dependence on non-renewable sources.
b. The continued development of this modality requires a joint commitment from the public and private sector, in addition to investments in infrastructure and research, to guarantee a sustainable and resilient electrical system by 2050.

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