Solar Photovoltaic Generation in Mané Dendê: Democratization of Solar Energy in Popular Areas

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Abstract

The installation of 13 photovoltaic solar power plants, totaling 178 kWp, on the rooftops of the buildings in the Mané Dendê low-income residential complex, located in the suburbs of Salvador/BA, represents a strategic initiative of Neoenergia Coelba's Energy Efficiency Program, regulated by ANEEL (Brazilian Electricity Regulatory Agency). The project aims to promote social inclusion and mitigate energy poverty, directly benefiting 260 low-income families by supplying energy to both common areas and individual housing units. The observed impacts span three main dimensions: democratic access to clean and renewable energy, previously unattainable due to economic constraints; a significant reduction in electricity bills, allowing the reallocation of saved resources to essential expenses such as food; and increased use of electricity, enabling the operation of previously underutilized appliances. The partnership with the Municipality of Salvador, responsible for the operation and maintenance of the plants, was crucial in overcoming infrastructure challenges and ensuring the project's sustainability without additional costs to the beneficiary families. Beyond immediate benefits, the initiative seeks to establish a replicable model for other low-income communities, contributing to reduce inequalities in energy access and accelerating the transition to renewable sources, in alignment with the principles of energy justice and sustainable development.

Keywords: energy efficiency, energy poverty, low-income population, photovoltaic solar power, renewable sources, social inclusion, sustainable development.

1. Introduction

The International Energy Agency (OECD/IEA, 2017) defines energy poverty as the inability to use modern energy sources. This definition encompasses both the financial difficulties families face in affording energy expenses and the lack of infrastructure to meet these needs. Thus, energy poverty is a broad concept that goes beyond the mere absence of electrical infrastructure. It includes both restricted access to modern energy sources — such as reliable electricity and clean fuels — and the challenge families face in covering the costs associated with energy consumption.

This means that even in areas where energy is available, many people live in vulnerable conditions due to their inability to maintain adequate levels of heating, cooling, lighting, or the use of essential household appliances, compromising their quality of life, health, and well-being.

On the other hand, although the regulation of distributed generation (DG) from photovoltaic solar energy in Brazil began in 2012, official data from the Brazilian Electricity Regulatory Agency (Distributed Generation Dashboard, 2025) indicate that by 2024, the country had surpassed 13 GW of installed capacity in photovoltaic solar power plants under the micro and mini distributed generation (MMDG) model in the residential sector, with over 2 million consumer units connected to the grid. However, access to this technology remains concentrated within certain social classes. According to the Electric Sector Study Group at UFRJ (GESEL, 2025), only about 3% of residential solar systems in the country are found in the poorest households, due to the initial investment required and the prerequisites for accessing potential financing sources.

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In light of this scenario and to help reduce this disparity, Neoenergia Coelba's[1] Energy Efficiency Program invested over BRL 1 million (one million Brazilian reais) in the implementation of 13 photovoltaic solar power plants ranging from 13 to 19 kWp in a Minha Casa Minha Vida housing complex. This initiative directly benefits residential customers living in the development who would not have the financial means to implement a photovoltaic solar plant with their own resources to participate in the Electric Energy Compensation System (SCEE).

Figure 1 below illustrates the solar plants installed on the rooftops of the buildings and connected to the meters of the common areas, enabling classification as a Development with Multiple Consumer Units (MUCE). As defined in Article 2, item XIV-A of ANEEL Normative Resolution No. 1,059 (ANEEL, 2023), an MUCE is a set of consumer units characterized by:

a) location of the consumer units on the same property or on contiguous properties, without separation by public roads, aerial or underground passageways, or by third-party properties not part of the development;

b) connection of the micro or mini distributed generation system to the consumer unit serving the common areas, distinct from the others, with independent use of electricity; and

c) responsibility of the condominium, management, or property owner for the consumer unit to which the micro or mini distributed generation system is connected.

Figure 1: Plants installed in the Mané Dendê Condominium

Thus, with the installation of the solar power plants, the project not only provides a reduction in monthly energy expenses for resident families but also promotes social inclusion by integrating low-income customers into access to renewable and sustainable energy. This tangible impact translates into more resources available for other essential needs, contributing to an improved standard of living for the community.

Furthermore, the initiative aligns with the Sustainable Development Goals (SDGs), particularly goals 7 (affordable and clean energy), 10 (reduced inequalities), 11 (sustainable cities and communities), 12 (responsible consumption and production), and 13 (climate action).

In this context, the partnership with the city government to overcome infrastructure challenges, as well as to operate and maintain the solar plants, highlights an effective collaboration model that can be replicated in other low-income communities, accelerating the adoption of solar energy to benefit families with limited financial resources.

[1] Neoenergia Coelba is the third-largest electricity distributor in Brazil in terms of number of customers and the sixth in volume of energy supplied, being the largest in the North and Northeast regions. Operating in 415 out of the 417 municipalities in the state of Bahia, Neoenergia Coelba has a concession area of 563,000 square kilometers, serving over 6 million customers (more than 15 million inhabitants).

2. Project Implementation Steps

2.1. Signing of Cooperation Agreement with Salvador City Hall

To enable the implementation of the project at no cost to consumers, establishing a partnership with the Municipality of Salvador was essential. Upon completion of the energy efficiency project, the solar power plants will be officially transferred to the Municipality, which will assume responsibility for the custody, operation, maintenance, and preservation of the equipment throughout its estimated 25-year lifespan.

The formalization of the partnership took place during a ceremony held at the residential complex itself, attended by the Mayor of Salvador, Bruno Reis, and Neoenergia Coelba's CEO, Thiago Guth (Figure 2), lending legitimacy and credibility to the initiative among the beneficiary community.

Figure 2: Cooperation Agreement signing event

It is also important to highlight the institutional support provided by the Salvador City Hall through its Social Office, which played a key role in the formation of the housing complex and in mobilizing the community. This support was essential to ensure active participation of residents in informational meetings and to facilitate their engagement with the project, strengthening the connection between beneficiaries and the energy efficiency initiative.

It is noteworthy that the collaborative approach with the Salvador City Hall to overcome infrastructure barriers demonstrates an innovative public-private partnership strategy, which is essential to ensure the project's long-term viability and sustainability. This interinstitutional coordination not only enabled the implementation of the solar power plants at no cost to consumers but also reinforced the commitment to social inclusion and sustainable development.

In this way, the initiative goes beyond energy and financial gains, promoting equality in access to clean and renewable energy sources and contributing to the construction of a replicable model of energy justice.

2.2. Actions with the community

To accelerate engagement with the community and ensure residents' participation, several actions were carried out within the housing complex:

- Lectures and informational meetings: held with the aim of presenting the project, clarifying doubts, and communicating its benefits. These meetings were essential to promote transparency and strengthen residents' trust in the initiative. To facilitate ongoing communication with beneficiaries, direct channels via WhatsApp and email were made available. Figure 3 illustrates one of these meetings, highlighting the active involvement of the community in the project's implementation process.


Figures 3 and 4: Presentations made to the residents of Mané Dendê

- Possession and Habits Survey (PHS): this phase was conducted with families interested in participating in the project, aiming to gather detailed information about the appliances present in the households and the residents' energy consumption habits. Through this approach, it was possible to understand how electricity is used in the families' daily lives, identify usage patterns that could be optimized, and propose customized solutions to promote more rational consumption. Additionally, the data collected served as a foundation for developing educational and technical strategies aligned with the actual needs of the beneficiaries and the energy profile of the housing units;

- Debt Regularization: to enable residents' participation in the project, at least two debt regularization campaigns were carried out in the housing complex. The first action, conducted at the beginning of the project, allowed consumers to settle their debts and become eligible to receive the benefits of solar generation. Later, during the results monitoring period, a second campaign was held focusing on maintaining payment compliance. On that occasion, service disconnections were also carried out for consumer units that remained delinquent, reinforcing the importance of financial commitment for the continuity and sustainability of the project.

2.3. Installation of Solar Power Plants

Between August 2023 and April 2024, technical and operational actions were carried out to enable the connection of 13 photovoltaic solar power plants. The main activities included:

- Technical inspections of the installation areas;
- Issuance of technical reports, covering structural aspects and the Lightning Protection System (LPS);
- Development of basic and executive designs;
- Submission of the projects to the electricity distribution company for formal grid access requests;
- Procurement and installation of equipment required for the operation of the solar plants.

It is worth noting that, due to the installed capacity, it was necessary to upgrade the electrical service standard, changing the connection of the condominium common areas from single-phase to two-phase, in compliance with the distributor's technical requirements and ensuring compatibility with the new infrastructure.

2.4. Consumption Study and Definition of Energy Allocation per Apartment

To determine the amount of energy to be allocated to each family, a study of the historical consumption of the consumer units was conducted and compared with the data from the Ownership and Habits Survey (PHS). After processing and consolidating the data, a mathematical model was developed to correlate average consumption with the respective number of residents, as illustrated in Figure 5 below.

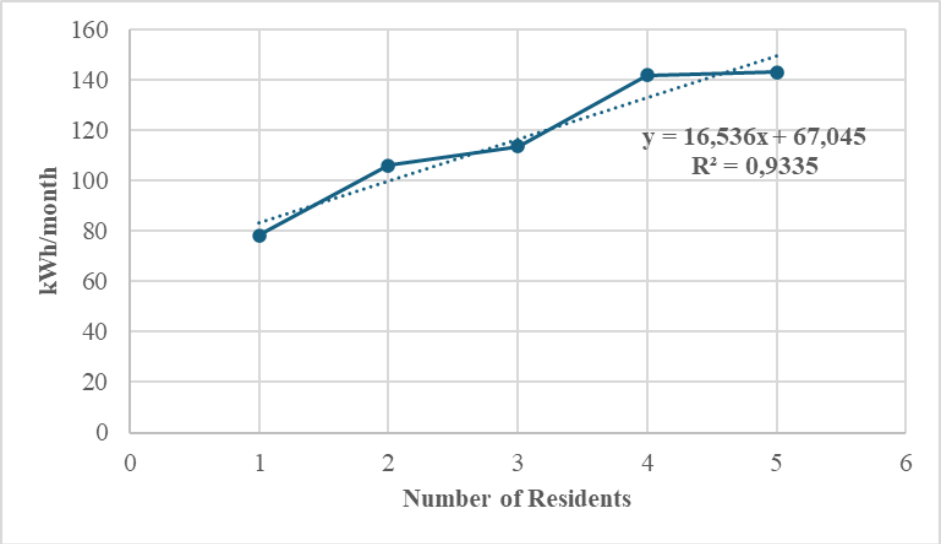

Figure 5: Correlation between average consumption and number of residents

Thus, as shown in Equation 1 below, it was defined that for residential units, the amount of energy distributed monthly would consider a fixed value per residence (70 kWh) and an additional value per resident (17 kWh). Information on the number of residents in each apartment was extracted from the Tenure and Habits Survey.

$$Distributed\ energy\ (kWh/apt.month) = 17 \times Number\ of\ residents + 70 \quad \text{(eq. 1)}$$

Figure 6 below illustrates the relationship between the monthly consumption of each apartment and the discount obtained on the respective month's bill in the first 9 months of operation.

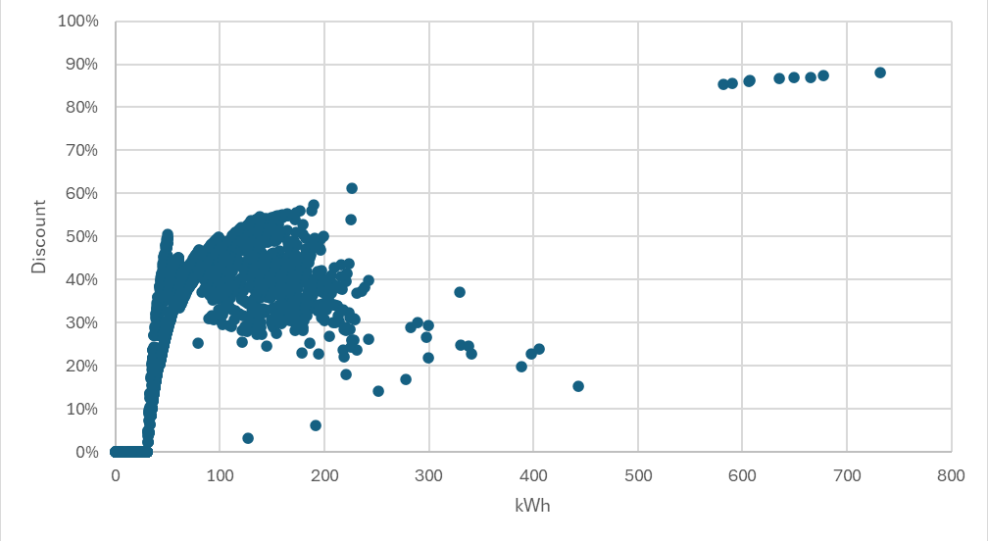

Figure 6: Correlation between the discount (%) and the consumption measured in the month (1st Methodology)

It is possible to observe that:

- 9% of the records showed consumption of up to 30 kWh, a range in which no discount is applied to the bill, as the customer must pay the availability cost established by regulation, commonly referred to as the “minimum charge”;
- The majority of the data (53%) corresponded to monthly consumption between 30 kWh and 100 kWh. In these cases, the applied mathematical model (Eq.1) was able, in most instances, to match the amount of energy requested by the residents, establishing a linear relationship between measured consumption and the applied discount;
- For monthly consumption above 100 kWh (38% of the records), data dispersion was observed, indicating that energy use is not solely correlated with the number of residents. Records exceeding 500 kWh refer to condominium units responsible for water distribution to the apartments, the kiosk,

and the water tower, which receive discounts of up to 90% on their electricity bills.

Based on the monitoring of these results, the need to update the applied model was identified. The revised methodology began to use the measured consumption from the previous month as a reference, excluding values related to the availability cost or any exemptions established by Resolution No. 1,000 (ANEEL, 2021a), as shown in the following equation:

$$Distributed\ energy\ (kWh/apt.month) = kWh_{Measured} - kWh_{Not\ compensable} \quad \text{(eq. 2)}$$

The variable $kWh_{Measured}$ refers to the measured consumption of the apartment in the previous month, while $kWh_{Not\ compensable}$ represents the amount of energy that cannot be offset, as established by regulation and defined as:

- Availability cost (30 kWh) for single-phase residential consumer units (ANEEL, 2021a);
- 100% discount on 80 kWh for customers under the Social Electricity Tariff, as established by Provisional Measure No. 1,300/2025 (Brazil, 2025).

The new methodology was applied starting in February 2025, and after seven months of monitoring, the results—illustrated in Figure 7 below—showed a significant reduction in consumption dispersion at higher usage levels.

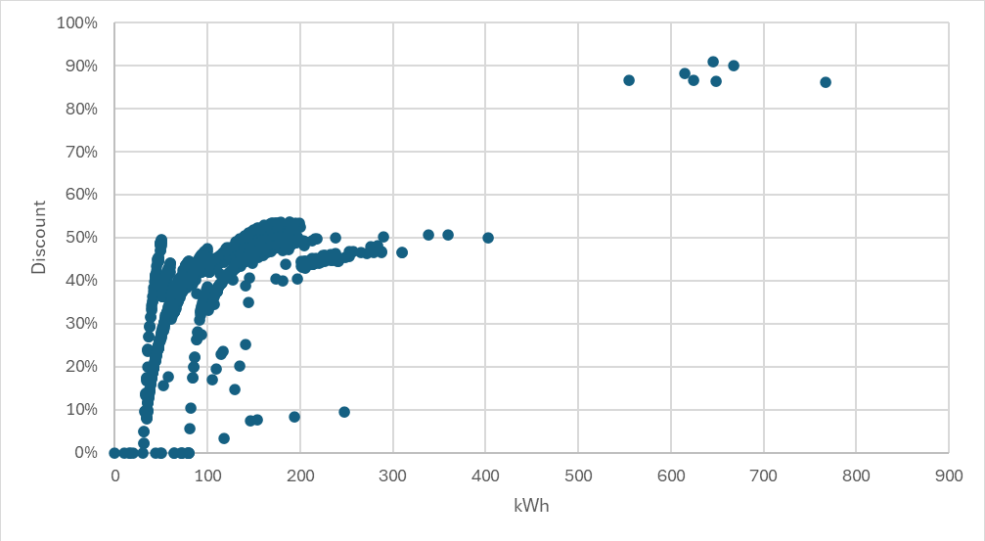

Figure 7: Correlation between the discount (%) and the consumption measured in the month (2nd Methodology)

The data distribution reveals three distinct behavioral ranges:

- Consumption up to 30 kWh: in this range, discounts are virtually nonexistent due to the minimum charge, meaning that even if the consumer unit receives energy, it does not result in a reduction on the bill;
- Consumption between 30 and 200 kWh: once the minimum charge threshold (30 kWh) is exceeded, there is a significant increase in discounts up to around 200 kWh. This indicates that compensation leads to reductions more proportional to consumption, having a stronger impact on the bill amount;
- Consumption between 200 and 400 kWh: in this range, discounts stabilize between 40% and 50%. Compensation remains advantageous, but the relative gain tends to remain constant.

It is important to note that in July 2025, new regulations came into effect exempting customers under the Social Electricity Tariff from payment up to 80 kWh. This explains the presence of zero discounts up to this energy amount in some records.

2.5. Project Enrollment

To participate in the project and benefit from the energy generated by the solar plants, the following criteria had to be met:

- Be an active Neoenergia Coelba customer, classified as residential and residing in the Mané Dendê Residential Condominium;

- Be connected, in good standing, and with regular consumption according to the distributor;
- Be an individual and the holder of the electricity bill to be registered for system acquisition (or have a power of attorney);
- Allow access to the consumer unit by a technician for interviews before the installation of the modules and afterward, if necessary and at the distributor's discretion;
- Sign the Enrollment Agreement.

Enrollments began at the end of March 2024 and reached 214 beneficiary families, representing 82% of the total (260). Currently, most customers who did not enroll have outstanding debts with the distributor and have had their service disconnected. It is also worth noting that some apartments are vacant or unoccupied.

2.6. Replacement of Refrigerators and Light Bulbs

Based on the PHS, it was identified that several apartments had the potential to improve energy efficiency through the replacement of inefficient refrigerators and light bulbs. As a result, 137 residents agreed to replace their refrigerators, which were substituted with energy-efficient models bearing the Procel Energy Efficiency Seal. Additionally, 34 customers replaced inefficient light bulbs (fluorescent, incandescent, halogen) with LED models, totaling 157 bulbs replaced.

The equipment replacement events were accompanied by educational lectures on efficient energy use, along with the distribution of manuals containing guidelines for conscious consumption. Figures 8 and 9 illustrate one of the refrigerator replacement events.

Figures 8 and 9: Refrigerator exchange event

Monitoring the consumption of customers who benefited from refrigerator replacements indicated an average reduction of 22% compared to families who did not replace their appliances, as illustrated in Figure 10.

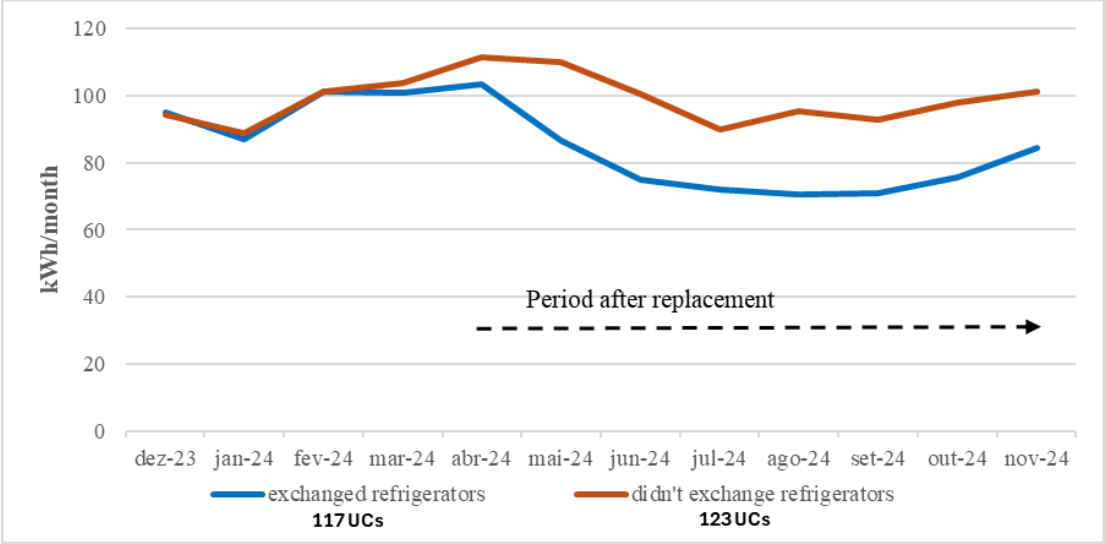

Figure 10: Average consumption comparison

2.7. Monitoring of Results

In addition to the routine monitoring of the operation of the 13 solar power plants, the results tracking includes monthly activities, as detailed below.

2.7.1. Monitoring of Customer Payment Compliance

This activity includes:

- Periodic updates of the list of overdue and unpaid electricity bills, with assessment of the total uncollected amount within the condominium;
- Identification of beneficiary consumer units with outstanding debts to the electricity distributor;
- Immediate contact with delinquent residents, aiming to regularize debts and maintain their participation in the project..

2.7.2. Monitoring of Commercial Loss Reduction

Since payment compliance is a requirement for participation, a reduction in the distributor's commercial losses was expected. To monitor this benefit, the Accumulated Collection Index (ACI) was used, as defined in Equation 3.

$$ACI_{month} = \frac{\sum_1^n Collection}{\sum_1^n Billing} \quad \text{(eq. 3)}$$

Being:

- "ACI_{month}": the collection index for the given month, considering the accumulated data from the past 12 months;
- $\sum_1^n Collection$: bills issued and compensated (paid and recognized by the system) up to the assessment date;
- $\sum_1^n Billing$: bills issued, due, and not compensated up to the assessment date;
- n: number of customers. The database is cumulative, meaning that in the case of a change in account holder, previous contract accounts remain in the dataset.

2.7.3. Update of Beneficiary Customer List and Redistribution of Energy Allocation

After validating payment compliance criteria, an initial screening is conducted to identify customers eligible to receive project benefits. Then, the measured consumption of each unit is analyzed in comparison to the non-compensable energy portion, as defined in Equation 2. The result of this process is an updated list of customers, along with the respective amount of energy to be compensated.

2.7.4. Complementary Social Surveys

In addition to regular monitoring activities, complementary surveys are occasionally conducted to expand the project's reach by identifying additional benefits perceived by residents through their participation. One example is the survey conducted in February 2025 — after 10 months of solar plant operation — with a sample of residents, aiming to determine whether they perceived a reduction in electricity expenses and, if so, how the saved amount was used.

Out of 155 units visited:

- 106 apartments, about 70% of the total surveyed, reported a reduction in their electricity bills. Respondents indicated that the saved amount was primarily redirected to food, payment of other bills, education, and the purchase of household appliances, in that order (Figure 11). Although appliance purchases were not the top priority, 24 families reported acquiring new electrical equipment for their homes;
- 49 families did not notice a reduction in their electricity bills. However, 80% of this group acquired new appliances during the period, such as freezers, electric showers, washing machines, computers, and fans. This behavior suggests that the project contributed to the increased use of electricity without compromising the family budget.

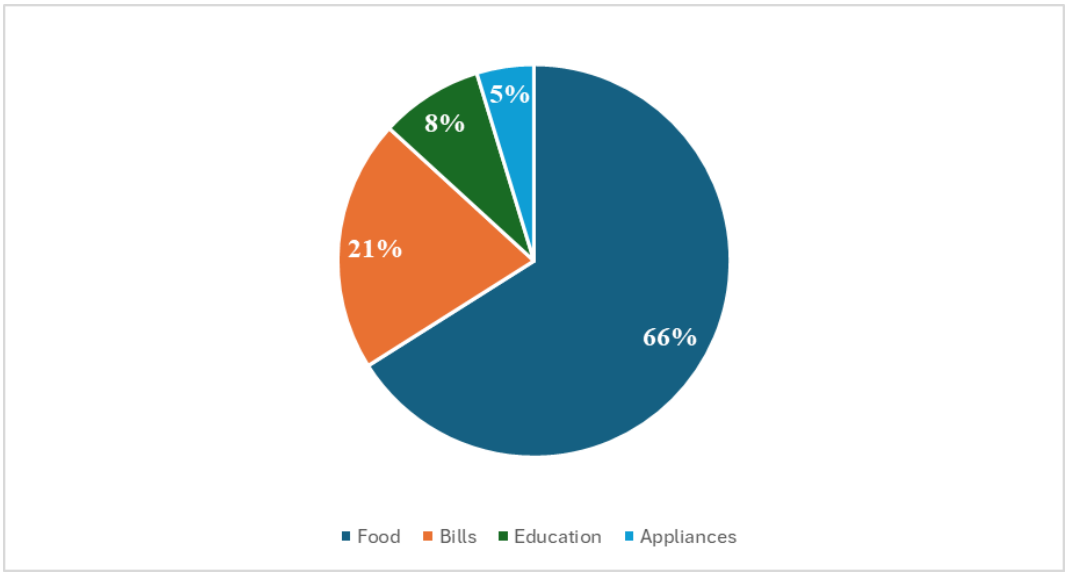

Figure 11: Allocation of Resources saved on the energy bill

The survey results show that the project has generated diverse and positive impacts on the lives of residents, going beyond the simple reduction in electricity bills. The perception of savings by most families and the redirection of these resources to essential areas such as food, education, and bill payments highlight the transformative potential of the initiative. Moreover, even among those who did not notice a direct reduction in their bills, there was an increase in access to durable goods and domestic comfort, indicating that the project contributed to expanding the safe and sustainable use of electricity without compromising the family budget.

These findings reinforce the importance of continuous monitoring and active listening to beneficiaries as key tools for improving and expanding the project's benefits.

3. Results

The power plants began operating in April 2024, and after 16 months of operation, energy generation exceeded 310 MWh. Of this amount, more than 231 MWh were immediately offset, while 79 MWh were accumulated as credits, available for use by the respective consumer unit (CU) over a period of up to 60 months. Figure 12 below illustrates the monthly values of generation and compensation, based on the billing month (from May 2024 to August 2025).

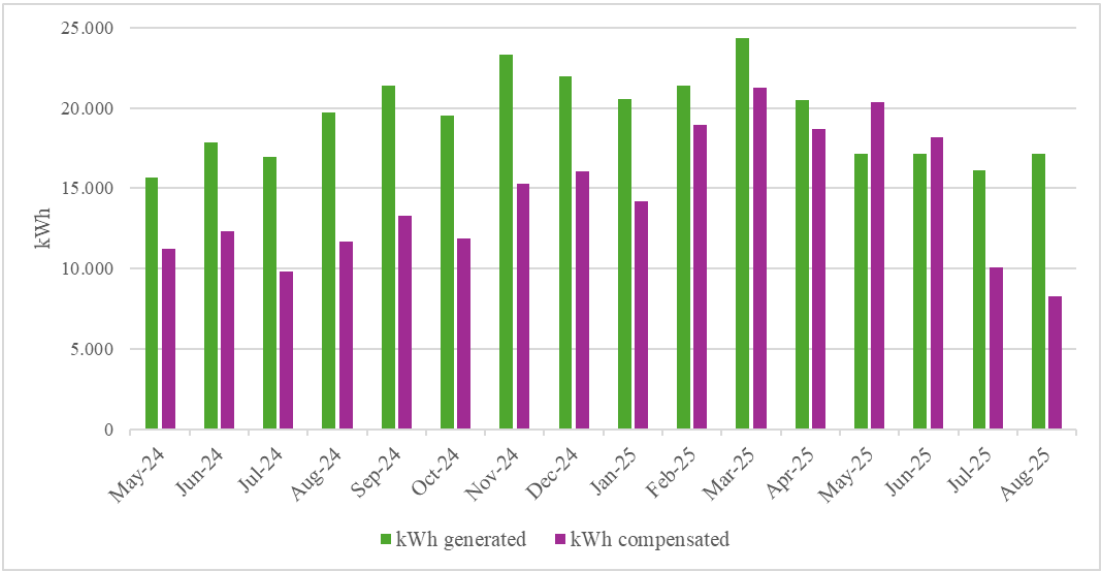

Figure 12: Generated vs. compensated energy

Compensation closely followed generation in a proportional manner, with the exception of two months — May

and June 2025 — during which the compensated energy exceeded the generated energy, indicating the use of credits accumulated in previous months. This dynamic demonstrates not only the efficiency of the solar plants but also the effective management of energy credits, ensuring continuous benefits for residents.

Between May 2024 and August 2025, more than BRL121,000 (one hundred and twenty-one thousand Brazilian reais) in discounts were granted, representing an average reduction of BRL39 (thirty-nine Brazilian reais) per family. Over the 16-month period, in addition to the two condominium units that achieved discounts above 90%, families experienced an average 37% reduction in their electricity bills.

Another benefit observed after the project's implementation was the improvement in the Accumulated Collection Index (ACI) of the electricity distributor. As shown in Figure 13, the ratio between the amount collected (BRL) and the total billed (BRL) before the project (Dec 2022 to Feb 2024) averaged 82%, while the indicator observed after the installation of the solar plants fluctuated around 91%.

It is important to note that electricity bill payment compliance is expected to fluctuate throughout the year due to seasonal expenses that impact family budgets. During periods such as the beginning of the year (with taxes and school supplies), popular festivities (Carnival, Christmas, and New Year) or vacation, expenses increase significantly, leading consumers to prioritize certain payments.

In these moments, the electricity bill may be postponed due to limited available resources, resulting in a temporary drop in payment compliance. This dynamic is directly linked to families' payment capacity and financial management in response to seasonal demands

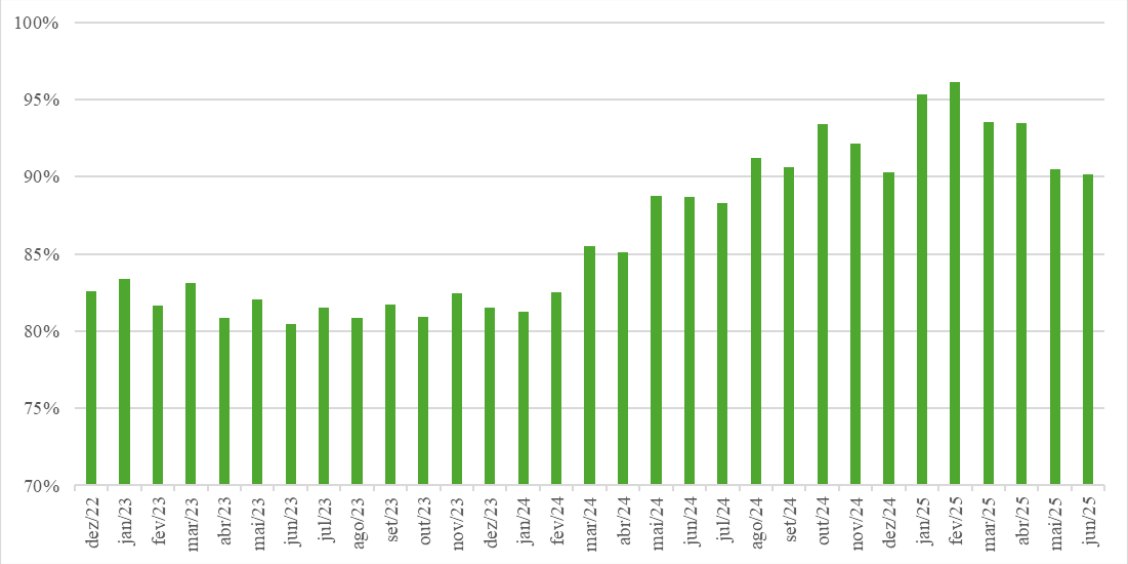

Figure 13: Evolution of ACI

4. Observed challengs

Given the pioneering nature of the project, the emergence of adverse situations during its execution was expected. These challenges required the adoption of specific mitigation actions to ensure the continuity of activities and the effectiveness of the expected results. Below are examples of these situations and the respective measures taken.

4.1. Incomplete Coverage of Families

Despite the team's ongoing efforts to mobilize all residents of the condominium to join the project, the number of participating families initially reached 214, representing 82% of the total. It is noted that some residents' delinquency, as well as turnover in the housing units — which remain vacant for significant periods — are factors that hinder full participation.

Nevertheless, strategic actions continue to be carried out to increase the number of beneficiaries, including the distribution of informational cards, door-to-door visits, service campaigns, and phone calls, with the aim of registering new apartments and extending the bill discount benefit to more families.

4.2. Impact of Common Area Delinquency on Generator Plant Availability

The condominium administration faced difficulties in paying the electricity bills for the common areas, where the solar panels were installed, due to some residents' failure to pay the condominium fee. It is believed that this is due to a lack of payment culture regarding the fee, with possible prioritization of other expenses. As a result, the administration struggled significantly to collect the amounts due.

This delinquency led to the disconnection of one of the generator consumer units for a period exceeding 40 days. It is estimated that this interruption caused a generation loss of approximately 2,300 kWh, directly impacting the project's performance and reducing the expected savings benefit.

As a mitigation measure, awareness campaigns were conducted with residents, focusing on the importance of regular payment of the condominium fee. The goal of these actions is to prevent further service interruptions and ensure the continued distribution of generated energy, allowing residents to fully enjoy the benefits of the solar panels installed in the condominium.

4.3. Outdated Records and Difficulty Contacting Residents

Some customers change the ownership of the consumer unit without promptly notifying the team responsible for project management. This lack of record updates compromises the review of the energy compensation list and may cause delays in monthly billing due to the need for individual case verification.

In situations where the family structure changes, it becomes necessary to conduct a new Ownership and Habits Survey (PHS), which requires additional time and operational resources.

As a corrective measure, communication with customers was intensified, including the distribution of informational materials in card format via WhatsApp, aiming to raise awareness about the importance of updating records and mitigating impacts on energy compensation (as shown in Figure 14).

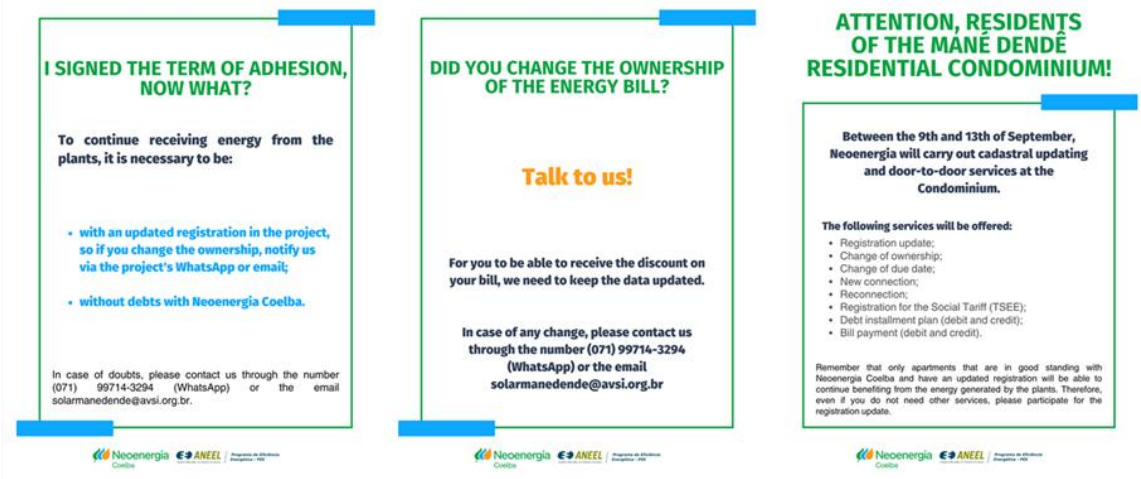

Figure 14: Promotional *Cards*

During the execution of the project, it was observed that a large portion of the condominium residents had outdated contact information in the project's contact list. Additionally, some customers did not own cell phones or had older models that did not support WhatsApp, and many were not accustomed to answering phone calls, making direct and agile communication with beneficiaries difficult—especially in situations requiring record updates or clarification regarding energy compensation.

In response to this challenge, field actions were intensified, with in-person visits conducted during non-business hours to expand communication reach and ensure resident engagement. These activities were carried out by field agents, reinforcing the commitment to inclusion and operational effectiveness.

5. Conclusions

The installation of 13 photovoltaic solar power plants, totaling 178 kWp, on the rooftops of buildings in a low-income housing complex demonstrated significant results from energy, financial, and social perspectives. With

over 310 MWh generated in 16 months of operation—231 MWh directly compensated, and 79 MWh accumulated as credits—the project promoted democratic access to clean and renewable energy for low-income families.

The financial impact was equally relevant, with more than BRL 121,000 (one hundred and twenty-one thousand Brazilian reais) in discounts granted, representing an average savings of BRL 39 (thirty-nine Brazilian reais) per family, which was redirected to essential needs such as food, education, and the purchase of household appliances. From a social standpoint, there was an increase in electricity usage, enabling the operation of previously underutilized appliances due to economic constraints, contributing to greater comfort and quality of life for residents.

Additionally, the project positively influenced the Utility Collection Index (IAR) of the electricity distributor, which rose from an average of 82% to up to 91% after implementation, indicating greater regularity in bill payments.

The essential role of the Salvador City Hall is also highlighted, as it became responsible for the operation and maintenance of the solar plants after the first year of operation. Its involvement was crucial in overcoming infrastructure challenges and ensuring the project's sustainability without generating additional costs for the beneficiary families. This institutional partnership reinforces the importance of coordination between public authorities and energy efficiency initiatives as a driver of social inclusion and sustainable development.

The project remains in progress, with ongoing actions aimed at expanding results and improving the residents' quality of life

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