

COB-2023-0315 PUBLIC POLICY FOR ROOFTOP PV GENERATION

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Abstract. *This work proposes an incentive program for rooftop photovoltaic distributed generation in Rio de Janeiro city, as an alternative to the traditional centralized generation. The study case was performed in the neighborhood of Campo Grande, using the web applicative Solar Map from the Rio de Janeiro city hall for prospecting the roof area available and the photovoltaic generation potential. The study followed the family composition of four people per household. After inserting a list of frequent devices, the annual average electric energy consumption and expenses were obtained through a simulation performed on the local utility website. Complete installation options of 700 kWh/month and 2,100 kWh/month mounted with the same commercial photovoltaic module were considered. Their retail values came from a market search. The total energy losses were fixed at 18.0%. The total distributed power generation was approximately the same as the Mauá 3 thermopower plant and Foz do Chapecó hydropower plant, located in the Amazonas and Santa Catarina States, respectively. The first has an installed capacity of 583 MW and has produced 377,784 MWh as a monthly average through an enterprise of R\$ 1.1 billion. The last has an installed capacity of 855 MW, and have produced 379,550 MWh as a monthly average, with a construction expense of R\$ 4 billion. In scenario 1, the government will subsidize fifty percent of the purchasing and installation costs of the photovoltaic systems in 543,000 homes, adopting the double the photovoltaic generation needed to meet the families' demand, to inject the surplus into the network. The feasibility appraisal considered official data of construction and O&M costs of the traditional above-mentioned power plants over a 25-year horizon, and the terms of the energy purchase auction. On the other hand, the surveyed installation costs and the estimated energy generation of the distributed photovoltaic power plant were taken into account. The results obtained by the performed analyses show that applying programs that encourage the generation of photovoltaic energy in residences, is cheaper for the government than the construction of a new thermopower plant. Additionally, this proposal brings social benefits as income generation for low-income people, besides the well-known environmental ones.*

Keywords: *photovoltaic, solar energy, feasibility study, distributed generation.*

1. INTRODUCTION

The Brazilian Electric Matrix is 87.9% renewable, and 61.9% comes from hydropower plants (EPE, 2023). The low cost of hydroelectric generation has delayed photovoltaic (PV) penetration in Brazil. Wind and solar energy currently gain space in the Brazilian electric matrix because hydropower is complemented by thermopower, and the untapped hydroelectric potential in Brazil is concentrated in the Amazonian Region, which is characterized by unfavorable terrain, distance from the consumption centers, and significant environmental and social impacts. Solar energy has prevailed in distributed generation (DG). The last term refers to generation close to the consumption, which reduces transmission and distribution losses and postpones investments in constructing new transmission lines.

When PV systems became financially attractive, there was no regulation to connect distributed PV systems to the electric grid. Only in 2012, with the approval of normative resolution RN 482/2012 (ANEEL, 2012), was the regulation for the net metering system established in Brazil. This regulation allows consumers to have their own electricity generation system and to accumulate and exchange credits with the utility. According to (ABSOLAR, 2022), solar energy has already brought approximately R\$ 103 billion in new investments to Brazil, generated over R\$ 27.2 billion in tax

revenues, and created more than 600,000 jobs since 2012. In addition, it avoided the emission of 28.4 million tons of CO₂ during electricity generation.

In 2022, a new Brazilian energy policy for distributed generation was introduced through Federal Law 14,300 (Planalto.gov.br, 2022) which significantly changed the existing Brazilian net-metering policy outlined by RN 482. New distributed generation systems must pay TUSD Fio B for the energy they consume and feed back into the grid. The costs related to strengthening the distribution grid to accommodate low-voltage distributed generation fall under the utility's responsibility. However, these reinforcement costs will be factored into tariff reviews, affecting all consumers. The new Brazilian policy is to reduce the loss of revenue in distributed energy (Almeida et al., 2023). (Iglesias and Gomes, 2022) found an increase in the average payback time for distributed PV systems from 6.69 years to 8.67 years with the new energy compensation system, although it is still considered attractive for consumers to adopt PV systems under Law 14,300 policy.

The rooftops of buildings offer significant potential for implementing PV systems and allow for a better geographical correlation between supply and demand. The installation of photovoltaic modules has a low impact from an urban planning perspective because the panels are mounted on existing roofs (Pinna and Massidda, 2022). The energy generated by PV systems can play a pivotal role in reducing greenhouse gas emissions. The contribution of rooftop PV systems is essential in smart cities, and estimating their production potential is a prerequisite for transforming cities and energy communities into zero-net energy districts (Pinna and Massidda, 2022).

The literature presents some Brazilian studies on PV rooftop potential and correlated public policies. (Miranda et al., 2015) conducted a spatial analysis of the technical and socio-economic potential for PV installation in the Brazilian residential sector using the Geographic Information System (GIS) tool. In 2014, approximately 1,500 households were available to install photovoltaic panels. The authors found that even areas with lower solar incidence can have economic potential if the local residential tariff is high and the opportunity cost is low. The technical PV potential surveyed in that study corresponded to 43.4% of the electricity consumption in the residential sector in 2013, and the majority of these PVs were located mainly in urban areas. (Ferreira et al., 2018) presented the key aspects of the evolution of regulatory incentives for using photovoltaic solar energy in Brazil.

(Antoniolli et al., 2022) reported an 8% increase in annual electricity consumption and a 54% reduction in the energy bill of 1,250 participating households in a rooftop photovoltaic installation program in Florianópolis, SC. These systems produced an average of 1,379 kWh/kWp yearly, avoiding the emission of approximately 1 kg of CO₂ for every 13.3 kWh generated. The authors found economic viability even in a scenario without subsidies, considering a 25-year timeframe.

(Da Silveira and Fernandes, 2022) measured the impacts of integrating distributed generation systems in the concession area of CELESC Distribuição. The study started in 2021 with 16,968 systems connected to the distribution network, totaling an installed capacity of 199 MW, which generated 215 GWh in 2020. They reported an accumulated increase of only 5% in consumers' energy tariffs during the analysis period. As a result, there will be a reduction in the distributor's revenue and investment capacity, leading to negative impacts on the quality of services provided by CELESC Distribuição.

(Komeno et al., 2022) presented an economic viability analysis method for net metering policies using risk analysis and a cost-benefit approach. The study focused on 54 Brazilian utilities and found that continuing the current net metering policy would decrease payback periods for micro- and mini-PV systems and increase costs for utilities and non-distributed-generation consumers. Across all scenarios, the cost of net metering outweighed its benefits, leading to negative cash flow for utilities and consumers. Benefits outweighed costs only in scenarios with high self-consumption rates, and increasing self-consumption rates reduced losses.

The State of Rio de Janeiro has an annual solar irradiation ranging from 1,460 to 2,010 kWh/m² according to Solar Atlas of the State of Rio de Janeiro. Rio de Janeiro has become the 4th state in Brazil in terms of the number of installed PV systems, overcoming 36,054 units, which produces 324,221.93 kWh (Portal Solar, 2023). The Metropolitan Region of Rio de Janeiro is one of the hottest in Brazil and has 10,153,398 inhabitants (IBGE, 2021). Air conditioning usage is the top trend in increasing the world's energy consumption. The electric energy demand peak for air conditioning coincides with the PV generation peak.

This study proposes an incentive program for rooftop photovoltaic distributed generation in Rio de Janeiro as an alternative to traditional centralized generation. The study case was performed in the neighborhood of Campo Grande, using the web applicative Solar Map of the Rio de Janeiro city hall (EPE, 2016) for prospecting the roof area available and the photovoltaic generation potential.

2. METHODOLOGY

The methodology comprises nine main stages (dos Santos, 2021): (1) selecting the rooftop PV DG power plant capacity after choosing hydro and thermal power plants with similar capacities; (2) surveying technical and economic data from the centralized power plants selected in stage one; (3) surveying the number of residences and the available roof area; (4) calculating the PV generation potential; (5) surveying the average energy consumption of the households; (6) determining the individual PV system capacities; (7) defining the economic scenarios; (8) conducting the economic

viability analysis; and (9) comparing the results with the two traditional centralized generation options chosen in stage one.

A technical and economic feasibility analysis (TEFA) was conducted for distributed photovoltaic generation on rooftops in Rio de Janeiro. This assessment involved a comparison with traditional centralized hydropower and thermal power plants. A survey of the construction and operation costs over a 25-year horizon was conducted for two power plants with approximately the same generation capacity: The Foz do Chapecó hydroelectric plant and the Mauá 3 thermal power plant, located in Santa Catarina and Amazonas, respectively.

The Foz do Chapecó Hydroelectric Plant is situated in the Uruguay River, between the municipalities of Águas de Chapecó, SC, and Alpestre, RS. With a capacity equivalent to 28% of the energy consumption of Santa Catarina, or approximately five million households, the construction of this plant commenced on March 1, 2007, lasting 42 months. The first generating unit became operational on October 14, 2010. Notably, the construction of this plant has brought about socio-environmental changes and health impacts on the local population. The Foz do Chapecó plant boasts an installed capacity of 855 MW, maintaining an average monthly generation of approximately 379,550 MWh. The construction project's estimated value is R\$ 4 billion, according to (Furnas, 2021). When considering operational expenses and the projected cost of constructing transmission lines, the total cost is R\$ 5,154,372,453.24.

The Mauá 3 thermal power plant was the pioneering facility in the country's northern region to operate in a combined cycle using gas and steam turbines. It generates an average monthly output of approximately 377,784 MWh from an installed capacity of 583 MW. The project represented an investment of R\$ 1.1 billion, with additional operational costs factored into the company's overall cost allocation. Moreover, the results were forecasted over a 25-year period, aligning with the operating period stipulated in the energy purchase auction. The calculation considered a correction factor of 7.06%, derived from the current National Consumer Price Index (IPCA), along with an additional 3.79% factor for a 25-year projection, following Direct Treasury 2021. The total projection amounted to R\$ 10,961,597,894.17.

This study focused on residential consumers in the Campo Grande neighborhood. A family composition of four people per household was adopted, and its monthly average electric energy consumption was determined through a simulation conducted on the local utility website in December 2020, considering the list of devices presented in "Table 1".

Table 1. Energy consumption of a household in the Campo Grande neighborhood, simulated in (Light Museum, 2020).

Quantity	Description	Daily use	Unit	kWh / month	cost / month	Total Consumption
2	Water Pump	2	hours/day	24.60	20.82	6.48%
1	Electric Shower	20	minutes/day	45.00	38.08	11.85%
2	Air conditioner	5	hours/day	150.00	126.96	39.50%
1	Iron	9	minutes/day	2.70	2.28	0.71%
1	Electric stove	5	minutes/day	5.71	4.83	1.50%
1	Electric furnace	5	minutes/day	1.25	1.06	0.32%
1	Freezer	4	hours/day	9.00	7.62	2.37%
1	Refrigerator	24	hours/day	39.60	33.52	10.43%
10	Illumination	43	hours/day	11.42	9.67	3.00%
1	Washing machine	1	hours/day	15.00	12.67	3.95%
1	Modem	24	hours/day	5.76	4.88	1.52%
2	Notebook	6	hours/day	3.60	3.05	0.95%
2	Television	6	hours/day	32.40	27.42	8.53%
1	Cable TV	4	hours /day	2.40	2.03	0.63%
2	Ventilador	12	hours/day	25.92	21.94	6.82%
1	Video Game	1	hours/day	5.43	4.59	1.43%
Full				379.79	321.45	100%

The initial step in assessing the feasibility of large-scale urban solar panel installations as an alternative to traditional centralized power generation is to conduct a cost survey of photovoltaic installations. The price survey involved kits with production capacities of 700 and 2,100 kWh/month, comprising 20 and 60 panels, respectively, taking retail prices and requiring that all components have registration at the National Institute of Metrology, Quality, and Technology

(INMETRO). The photovoltaic installation kit covers labor costs, project approval, panels, and auxiliary equipment. The quotation was obtained on January 7, 2021, considering an exchange rate of \$1.00 = R\$5.39 for the commercial dollar to the Brazilian real. "Table 2" provides a breakdown of costs for the first kit. The quantities are three times for the 2,100 kWh/month kit, except for the last two items, totaling R\$ 90,622.64.

Table 2. Mini Solar Power Plant Kit - 700 kWh/month

Quant.	Components	Company	Kit cost	Installation Cost
1	Hoymiles MI-1200 Micro Inverter 220v Bi-phase / Single-phase	A	R\$24,325.26	R\$3,450.00
20	Talesun 330 W Polycrystalline panels	B	R\$26,648.46	R\$3,050.00
6	AC Cables with 15 meters	C	R\$25,676.66	R\$4,395.00
2	String Box Ac 20A (With Walthimeter 2 Dps and 2 Circuit Breakers)			
2	AC Female			
1	End Cap			
1	Installation structure according to roof	Average	R\$25,550.13	R\$3,631.67
Total purchase and installation cost to set up a mini Solar Plant				R\$29,181.80
Quoted on 07/01/2022. Dollar value = commercial this day \$1.00 = R\$5.39				

In this study, two scenarios were considered. In Scenario 1, the government subsidizes 50% of the purchase and installation of 20 PV panels in 543,000 homes. This capacity is double the photovoltaic generation required to meet the families' energy demands. The surplus energy can be sold back to the grid, allowing households to recover their investments. In Scenario 2, the government subsidizes the purchase and installation of 60 photovoltaic panels in 217,000 residences, providing photovoltaic generation that is six times the demand of families. A sample set of 400 houses was selected using the Solar Map of Rio de Janeiro, allowing for the determination of the average available roof area for installing 20 or 60 panels, with the latter constrained to 75% of the roof area. The predicted energy to be injected into the electricity grid was calculated by subtracting the average consumption from the total generation with losses (GTP), as calculated by 'Eq. (1)' following (Biagio, 2016).

$$GTP = \sum_{t=0}^n I_0 \times A \times \eta \times (1 - \mathcal{P}) \quad (1)$$

Where n represents the number of days in a month, I_0 is the average daily radiation for the month in question, A is the total area of photovoltaic panels, η is the panel efficiency, and \mathcal{P} is the overall system losses. The latter was determined from the sum of all possible sources, as reported in "Table 3", resulting in 18%.

Table 3. Losses in photovoltaic generation (Miranda et al., 2015)

Losses	Considered Value	Minimum and Maximum Loss Variation
Deviation in nominal module yield (plate data) and 1000W/m ²	2.5%	-5.0 à 10.0%
Temperature in the module	3.5%	-3.0 à 6.0%
Conductor losses on the DC side	2.0%	1.0 à 3.0%
Conductor losses on the AC side	1.0%	0.7 à 2.0%
Inverter Conversion Efficiency	1.5%	1.0 à 15%
Mismatch MPPT	2.0%	1.5% à 3.0%
Shading	0.0%	0 à 100%
Diodes and connections	0.5%	0.30%
Transformers (such as the isolation transformers in the inverter)	2.0%	2.0% à 4.0%
Solar-Tracking System	0.0%	0% à 2.0%
System unavailability	0.0%	2% à 0.5%

Dirt on the modules	3.0%	2% à 25%
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The calculation considered the average photovoltaic generation potentials during the winter and summer solstices, which were obtained from the Solar Map of Rio de Janeiro. The photovoltaic potential depends on factors such as roof inclination, geographic orientation, and elevation relative to neighboring structures.

An economic feasibility study (TEFA) was conducted over a 25-year horizon to assess the net present value (NPV), payback period, and internal rate of return (IRR) for a family's investment in a photovoltaic system. The analysis assumed an attractiveness rate of 15%, and in all scenarios, the system was considered operational six months after the initial investment. An annual revenue growth rate of 5.6129% was factored in. The tariff rate from Light for surplus energy injected into the grid was R\$ 510.00 per MWh, excluding taxes. The monthly consumption was estimated to be approximately 350 kWh, including taxes.

3. COMPARING THE SOLAR MAP OF RIO DE JANEIRO WITH OWN CALCULATING METHODOLOGY

Given that the proposed methodology relies on a database of others, a validation process was conducted. Average monthly daily solar irradiation data were obtained from (SunData v.3, 2018) for an inclination equal to the latitude and 0° N azimuth in Rio de Janeiro. These data were then converted into monthly average hourly values using "Eq (2)", as described by (Duffie & Beckman, 2013).

$$rt = [(\pi \div 24) \times (a + b \times \cos\omega)] \times \{(\cos\omega - \cos\omega_s) \div \{ \sin\omega_s - [(\pi \times \omega_s) \div 180] \times \cos\omega_s \}} \quad (2)$$

The coefficients a and b are given by

$$a = 0.409 + 0.5016 \times \sin(\omega_s - 60) \quad (2.1)$$

$$b = 0.6609 - 0.4767 \times \sin(\omega_s - 60) \quad (2.2)$$

Where ω represents the solar hour angle in degrees for the given time (i.e., the midpoint of the hour for which the calculation is made), ω_s denotes the sunset hour angle, and rt represents the ratio of the hourly total to daily total solar irradiation. The sunset hour angle ω_s is given by

$$\omega_s = -(\tan \phi \times \tan \delta) \quad (2.3)$$

Where ϕ is latitude and δ is solar declination.

The declination (δ) is approximately given by "Eq. (3)"

$$\delta = 23.45 \times \sin\{360 \times [(284 + n) \div 365]\} \quad (3)$$

Specific days of each month are chosen for calculating extraterrestrial solar radiation averages using "Eq. (3)" because they closely approximate the monthly averages. These days are as follows: January 17th ($n = 17$), February, 16th ($n = 47$), March 16th ($n = 75$), April 15th ($n = 105$), May 15th ($n = 135$), June, 11th ($n = 162$), July, 17th ($n = 198$), August, 16th ($n = 228$), September, 15th ($n = 258$), October, 15th ($n = 288$), November, 14th ($n = 318$), December, 10th ($n = 344$)."(Duffie and Beckman, 2013)"

The monthly average hourly ambient temperatures were obtained from (Silva, 2019), who calculated them using hourly data from the São Cristovão weather station of the Precipitation Monitoring System from the Rio de Janeiro City Hall (ALERTA RIO, 2020) for the years 2008 to 2018. The Talesun 330 W panel, with the characteristics presented in "Table 4", was selected.

Table 4 - Panel TALESUN 330W TP672P characteristics, from the manufacturer's datasheet

Model	TALESUN 330W TP672P	Open- Circuit Voltage (Voc)	45.2V
Maximum Power	315W	Short-Circuit Current (Isc)	9.11A
Efficiency	16.2%	Operating Current (Impp)	8.56A
Cell Temperature (NOCT)	45°C	Operating Voltage (Vmpp)	36.8V
Coefficient of Maximum Power Thermal	-0.40%/C		

Temperature Coefficient Voc	-0.31%/C	Panel Area	1.94m ²
Temperature Coefficient Isc	+0.06%/C		

The monthly average hourly temperature of the photovoltaic cell was calculated using “Eq. (4)” (Kamuyu et al., 2018).

$$T_{Cell} = T_{NOCT} + (T_{amb} - T_{amb NOCT}) \times (G \div G_{NOCT}) \quad (4)$$

Where T_{Cell} represents the cell temperature and T_{NOCT} is defined as the cell temperature reached when the cells are mounted in their typical configuration under specific conditions: a solar radiation level of 800 W/m² (G_{NOCT}), wind speed of 1 m/s, ambient temperature of 20°C ($T_{amb NOCT}$), and no-load operation. The monthly average hourly efficiency (E_{η}) of the PV panel was calculated using “Eq. (5)”.

$$E_{\eta} = E_{\eta STC} + (T_{Cell} - T_{STC}) \times K_{MP} \times E_{\eta STC} \quad (5)$$

Where $E_{\eta STC}$ represents efficiency at Standard Test Conditions (STC), T_{STC} is the temperature at STC, and K_{MP} is the maximum power temperature coefficient. The monthly average hourly electricity production was determined by multiplying the hourly solar irradiation by the corresponding values of the photovoltaic panel efficiency. To determine the monthly average daily electricity production, the hourly values were summed and then multiplied by the number of days in the respective month to obtain the total monthly production. A similar approach was used to determine the annual production. Notably, the annual average monthly electricity production of 41.33 kWh is closely aligned with the average monthly production value of 39.39 kWh presented in the Brazilian Labeling Program table.

In a study of the technical and feasibility analysis of installing a PV system at Piquet Carneiro Polyclinic, a comparison between the methodology above presented and the Solar Map of Rio de Janeiro was performed. Consulting the address Marechal Rondon Avenue, 381, São Francisco Xavier neighborhood, in the Solar Map of Rio de Janeiro, an option for a 5,000 m² roof area was found. Taking a utilization factor of 0.75, the available roof space became 3,750 m² allowing for the accommodating of 1,932 panels with an average monthly production of 39.39 kWh per panel, the monthly electricity production reached 76,101.48 kWh. This value was close to the photovoltaic generation potential reported in the Solar Map of Rio de Janeiro.

4. RESULTS

Table 5 presents the results of the TEFA for the kit designed to produce 700 kWh of monthly energy without subsidies and for scenario 1. Notably, even without subsidies, rooftop PV generation is economically viable. When applying a 50% subsidy, the net present value (NPV) doubled, the payback period was shortened by one year, occurring in the fourth year, and the internal rate of return (IRR) increased from 20.67% to 35.00%.

Table 5 – TEFA for 25 years for the kit for monthly energy production of 700 kWh without subsidies and for scenario 1.

Year	Cash Flow	Cumulative balance	Cash Flow	Cumulative balance
0	-29,181.99	-29,181.99	-	-R\$14,591.00
1	2,436.73	-26,745.26	R\$2,436.76	-R\$12,154.24
2	5,146.99	-21,598.27	R\$5,146.99	-R\$7,007.25
3	5,435.89	-16,162.38	R\$5,435.89	-R\$1,571.36
4	5,741.00	-10,421.38	R\$5,741.00	R\$4,169.64
5	6,063.24	-4,358.14	R\$6,063.24	R\$10,232.88
6	6,403.57	2,045.43	R\$6,403.57	R\$16,636.45
7	6,762.99	8,808.42	R\$6,762.99	R\$23,399.44
8	7,142.60	15,951.02	R\$7,142.60	R\$30,542.04
9	7,543.50	23,494.52	R\$7,543.50	R\$38,085.54
10	7,966.92	31,461.44	R\$7,966.92	R\$46,052.46
11	8,414.09	39,875.53	R\$8,414.09	R\$54,466.55

12	8,886.37	48,761.90	R\$8,886.37	R\$63,352.92
13	9,385.15	58,147.05	R\$9,385.15	R\$72,738.07
14	9,911.94	68,058.99	R\$9,911.94	R\$82,650.01
15	10,468.29	78,527.28	R\$10,468.29	R\$93,118.30
16	11,055.86	89,583.14	R\$11,055.86	R\$104,174.16
17	11,676.42	101,259.56	R\$11,676.42	R\$115,850.58
18	12,331.81	113,591.37	R\$12,331.81	R\$128,182.39
19	13,023.98	126,615.35	R\$13,023.98	R\$141,206.37
20	13,755.01	140,370.36	R\$13,755.01	R\$154,961.38
21	14,527.07	154,897.43	R\$14,527.07	R\$169,488.45
22	15,342.46	170,239.89	R\$15,342.46	R\$184,830.91
23	16,203.62	186,443.51	R\$16,203.62	R\$201,034.53
24	17,113.12	203,556.63	R\$17,113.12	R\$218,147.65
25	18,073.67	221,630.30	R\$18,073.67	R\$236,221.32
Minimum Attractive Rate		15%	15%	
Net Present Value		R\$12,077.87	R\$25,243.13	
Internal Rate of Return		20,67%	35%	

In their TEFA (Gobbo and Silva, 2017) obtained similar results using a total cost of the complete photovoltaic installation package of R\$ 29,674.21 and an average annual monthly production of 547.4 kWh. The payback period in their study occurred in the sixth year, assuming an electricity tariff of R\$ 890.00/MW. They reported an NPV of R\$ 41,426.22 for a minimum attractiveness rate of 11.25% over a 25-year horizon. A comparison reveals a reduction in PV costs, as with the same investment, the predicted monthly energy production increased by around 28% compared to (Gobbo and Silva, 2017) findings. The difference in results can be attributed to the higher electricity tariff adopted by (Gobbo and Silva, 2017) and a lower attractiveness rate, which resulted in the better NPV found in their study.

Table 6 demonstrates the potential productive outcomes based on the number of households covered by the distributed photovoltaic energy generation program.

Table 6 - Predicted PV power production and outcomes, 2021.

Cost sizing for the rooftop PV power plant		
Scenarios	Capacity (MW)	Installation Kit Value
Complete kit for setting up a PV power plant - 700kWh/month.	280	R\$11,672,797.33
Complete kit for setting up a PV power plant - 2100kWh/month.	840	R\$36,249,057.33

Table 7 shows that adopting PV distributed generation is economically more advantageous than using thermal power generation when the government covers 50% of the implementation costs of the program, which corresponds to scenario 1.

Table 7. Direct cost comparison and scenarios, 2021.

Direct Cost Comparison of Solar Power Plant for the Same Production Capacity as Foz do Chapecó			
Households	Scenarios	MWh/month	Cost of Kit and Installation
543,000	Complete Kit to Assemble a PV Power Plant: 700kWh/month (Government covers 50%)	380,100,00	R\$7,922,911,190.00
217,500	Complete Kit to Assemble a PV Power Plant: 2100 kWh/month.	380,625,00	R\$19,710,424,925.00
Average amount		380,362,50	R\$13,816,668,057.50

Total Construction Cost of Foz do Chapecó Hydropower Plant and Operation and Implementation Cost of UTE Mauá 3		
Thermal Power Plant Mauá 3 (Mauá 3 TPP)	377,784.00	R\$10,961,597,894.17
Foz do Chapecó Hydropower Plant	379,549.11	R\$5,154,372,453.24

“Figure 1” shows that PV distributed generation was cheaper than centralized thermal generation over a 25-year operational horizon. The same production scenario was adopted for the different energy generation options, and the cost of the transmission lines directly connected to the Foz do Chapecó hydropower plant was also considered. It is highlighted that the energy production of the 2,100 kWh kit is a net value obtained after subtracting the energy consumed by households.

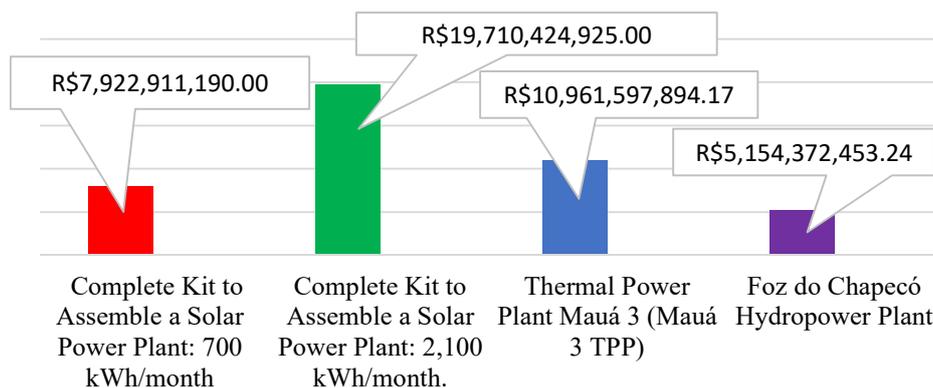


Figure 1. Direct cost comparison of a PV power plant with the same production capacity as the Foz do Chapecó hydropower plant and Mauá thermal power plant.

5. CONCLUSION

The literature supports various policy models to incentivize photovoltaic generation, with the following prevailing options: Feed-in Tariff, Net Metering, Rebate, and Renewable Energy Quota Auctions. These mechanisms offer enhanced security to clean energy producers by providing fixed rates and guaranteed energy purchases over extended periods. This, in turn, inspires greater investment confidence in renewable energy production and distribution. In addition, these policies prioritize the dispatch of energy to regions near the production center, thereby reducing the need for long-distance transmission from large hydroelectric and thermal power plants. Consequently, they lower transmission costs and maintenance.

The results obtained by the performed analyses show that applying programs that encourage the generation of photovoltaic energy in residences, is cheaper for the government than the construction of a new thermopower plant. It also highlights the lack of implementation of an incentive mechanism by the Brazilian government for regulating the sale of energy injected into the grid, which is essential to implement this alternative proposal.

Another point to highlight is the retention of the Tax on the Circulation of Goods and Services (ICMS) by the State of Rio de Janeiro, which applies to the portion of energy generated by consumers and injected into the grid. In addition, the municipality of Rio de Janeiro collects a service tax (ISS) related to the project, registration, and installation of PV systems. These factors are expected to contribute significant revenue to the state and municipality of Rio de Janeiro, ultimately leading to job creation within the photovoltaic system installation sector.

In Santa Catarina, (Antoniolli et al., 2022) examined the economic feasibility of rooftop PV installations from the consumer’s perspective. In contrast, (da Silveira and Fernandes, 2022) discussed the adverse impacts of the integration of distributed generation systems on local utility. Notably, this study did not address the technical and economic limitations of the local electric grid.

This proposal offers a pathway for low-income individuals to generate income by leasing rooftop spaces to install photovoltaic distributed generation (PV DG) power plants or becoming investors in renewable energy. Potential social and economic advantages include the following: (1) Economic Empowerment: Low-income households can access a new income source, potentially improving their financial well-being; (2) Grid Resilience: Contributing to a more decentralized and resilient energy grid can help reduce the burden on the centralized grid and enhance its resilience against disruptions; (3) Clean Energy Adoption: Encouraging investment in renewable energy sources, such as PV DG, promotes the adoption of clean energy technologies, reducing greenhouse gas emissions, and addressing climate change; (4) Lower Energy Costs: Households and communities investing in PV DG systems can reduce their energy bills by generating electricity, which may make energy more affordable for low-income households; (5) Economic Diversification: By allowing low-income households to participate in the energy market, this proposal promotes economic diversification and reduces their

dependence on a single income source; (6) Job Creation: Local installation, maintenance, and operation of PV DG systems can create job opportunities in the renewable energy sector, benefiting the local economy.

However, several challenges and considerations must be addressed during the implementation of this proposal: (1) Upfront Costs: Installing PV DG systems can be expensive, which may pose a challenge for low-income individuals. Implementing financial incentives or subsidies can help overcome this barrier; (2) Skills and Training: A comprehensive training program is required to provide the technical expertise required to install and maintain PV systems; (3) Regulatory Framework: Current government regulations and policies may not support this proposal. New regulations are essential to outline the rights and responsibilities of individuals and investors; (4) Education and Awareness: Communities need to be educated about the benefits and risks of investing in PV DG systems and their income-generating potential; (5) Financial Inclusion: Ensuring access to financing and investment opportunities is crucial. Efforts should be made to facilitate low-income individuals' access to loans or grants for these investments; (6) Equity and Inclusivity: Measures should be in place to ensure that this opportunity is accessible to all, regardless of their socioeconomic status, to promote equity and inclusivity.

In conclusion, careful planning and a supportive regulatory environment are necessary to overcome the associated challenges and maximize the benefits of such a program.

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