Fronteiras: Journal of Social, Technological and Environmental Science
http://periodicos.unievangelica.edu.br/fronteiras/
ISSN 2238-8869

Article

Demonstration of a Governamental Initiative Through the Installation of Photovoltaic Modules in Social Projects

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ABSTRACT

In 2022, solar energy generation through photovoltaic modules saw a remarkable 26% increase, reaching nearly 1300 TWh, solidifying its status as the renewable energy source with the highest annual growth rate. This trend has sparked substantial investments from major European powers, the United States, and China (International Energy Agency - IEA 2022). This article aims to assess the feasibility of the Brazilian government implementing photovoltaic modules in low-income and peripheral households to align with global trends and mitigate energy costs during dry periods. Data from photovoltaic energy companies in Brazil and abroad were compiled for analysis, considering various module types and efficiencies. The study, conducted using Python for data interpretation through tables and graphs, concluded that solar irradiation is uniformly distributed across the country, making the project viable nationwide. Calculations showed profitability for a single household, with an estimated implementation cost of R$21,000.00, achievable after 24 years, yielding an approximate profit of R$5,640.00 over the module's 30-year lifespan. This underscores the viability of a profitable government initiative aligned with UN Sustainable Development Goal 7, reducing CO2 emissions from thermal power plants and cutting electrical energy costs.
Keywords: My House My Life Program; governmental feasibility; python; solar energy generation.

RESUMO

Em 2022, a geração de energia solar por meio de módulos fotovoltaicos registrou um notável aumento de 26%, atingindo quase 1300 TWh, consolidando seu status como a fonte de energia renovável com a maior taxa de crescimento anual. Essa tendência motivou investimentos significativos de grandes potências europeias, dos Estados Unidos e da China (International Energy Agency - IEA 2022). Este artigo tem como objetivo avaliar a viabilidade de o governo brasileiro implementar módulos fotovoltaicos em residências de baixa renda e periféricas, alinhando-se às tendências globais e mitigando os custos de energia durante períodos de seca. Dados de empresas de energia fotovoltaica no Brasil e no exterior foram compilados para análise, considerando diversos tipos e eficiências de módulos. O estudo, conduzido utilizando Python para interpretação de dados por meio de tabelas e gráficos, concluiu que a irradiação solar está uniformemente distribuída pelo país, tornando o projeto viável em âmbito nacional. Os cálculos mostraram lucratividade para uma única residência, com um custo de implementação estimado em R$21.000,00, alcançável após 24 anos, resultando em um lucro aproximado de R$5.640,00 ao longo da vida útil de 30 anos do módulo. Isso destaca a viabilidade de uma iniciativa governamental lucrativa alinhada ao Objetivo de Desenvolvimento Sustentável 7 da ONU, reduzindo as emissões de CO2 provenientes de usinas térmicas e diminuindo os custos de energia elétrica.
Palavras-Chave: Programa Minha Casa Minha Vida; viabilidade governamental; python; geração de energia solar.

Submissão: 07/10/2024 Aceite: 15/01/2025 Publicação: 05/06/2025

v.14, n.2, 2025 • p. 45-57. • DOI http://dx.doi.org/10.21664/2238-8869.2025v14i2p.45-57

Introduction

Since the second industrial revolution, the use of fossil fuels such as oil, coal, and natural gas for electricity generation has increased due to their abundance and cost-effectiveness. However, the use of these fuels has serious environmental consequences. Burning fossil fuels releases various pollutants, including carbon dioxide (CO2), the primary driver of global warming. This issue has been a recurring topic in the most important environmental meetings of recent decades, with negative impacts such as glacier melting, rising sea levels, and climate-related events like floods, hurricanes, droughts, and other problems witnessed globally in 2021 (Fey A 2017).

Another pollutant is sulfur dioxide, the main contributor to acid rain, which can corrode monuments and, more importantly, damage agricultural crops, directly affecting the economy of the region. The problems caused by coal-fired power plants are directly linked to people's health, as pollution from these plants can lead to asthma, chronic lung diseases, and lung cancer. For example, in 2019, China, the largest producer of coal-based energy with approximately 22,171 TWh that year, experienced numerous cases of lung diseases among workers, with reports of Chinese laborers threatening suicide unless the government provided financial compensation for illnesses acquired during the construction of a mega-city (Shih G 2017).

Furthermore, the transportation of fossil fuels also tends to create problems, as they are often transported by ships, which can lead to leaks that harm marine life in the area. Depending on how close to the coast these incidents occur, they can also negatively impact the local economy. A recent example was the oil spill on the Brazilian coast in the second half of 2019, where over 900 tons of oil were removed from the beaches of the northeast region, with more than 200 affected areas identified by the end of October. The negative economic impact was significant, with residents, lacking proper equipment, assisting in the cleanup efforts to restore the area for fishing and trade. However, according to experts, the damage to marine life is expected to take decades to recover (G1 2019).

In a global scenario of increasing concern for sustainability and climate change, California, known for its progressive mindset, has once again set an example. By making a bold and pioneering decision, the state of California now requires the installation of solar modules on all new residences, further reinforcing its commitment to clean and renewable energy sources (Portal Solar 2023).

This new legislation, which recently came into effect, marks a significant milestone in the journey toward energy independence and greenhouse gas emissions reduction. By making solar modules a mandatory requirement in new residential constructions, California aims to harness the abundant solar energy available throughout the year in its sunny region (Portal Solar 2023).

There are several clear and tangible advantages to this measure. Firstly, the installation of solar modules on all new homes will significantly increase the state's capacity for clean energy generation, reducing reliance on non-renewable sources. Additionally, this advanced approach will bring financial benefits to residents, who will reap the rewards of energy savings over time.

Another noteworthy aspect is the multiplier effect of this initiative. By stimulating demand for solar technologies, it is expected that the solar energy market will experience a significant boost, attracting investments, fostering technological innovation, and creating jobs in the sustainable energy industry (Climate Policy Initiative 2023).

Therefore, it is evident that the Brazilian government, one of the world's largest producers of renewable energy, should also consider promoting the installation of photovoltaic modules in Brazilian homes.

In Brazil, when there is not enough rainfall to supply hydropower plants throughout the year, during the dry season, there is an increase in electricity bills, often resulting in the well-known "red flag" surcharge. This is because Brazil relies on the importation of coal for use in thermal power plants during dry periods, which generates non-renewable energy and a significant amount of CO2 emissions, leading to higher taxes on electricity consumption.

Hence, with the aim of avoiding an increase in CO2 emissions, a global issue and one of the major contributors to climate change on Earth, this study seeks to demonstrate analytically and quantitatively the feasibility of a government initiative and partnership with a private company to implement photovoltaic energy in homes in various neighborhoods. This initiative aims to reduce tax rates during dry periods in the country.

Objective

The central objective of this study is to analyze and discuss, through research, proprietary calculations, and literature, the potential profitability for the government through a governmental initiative to install photovoltaic modules in the homes of middle-class individuals and participants of the "Minha Casa, Minha Vida" program.

Methodology

Data Collection:

Initially, data was collected from Brazilian and foreign companies based in Brazil, whether they had offices or were suppliers. The collected data includes, in summary, all information that impacts the evaluation of the company, i.e., data that demonstrates its strengths and weaknesses. This includes: location; awards; number of employees; partners; whether they manufacture or solely sell modules, kits, and other components; the types of modules provided; module prices and applications; past projects; current customer base; the amount of globally supplied energy, among other data that aids in assessing the quality of the company.

Computing and Companies and Modules

Following the data collection process, all the gathered information was transferred to a computer for tabulation and graph generation using the Python programming language to facilitate the analysis. The tabulation includes the data collected from the companies, providing an overview of the advantages and disadvantages of each company, along with information about module efficiency and cost. In the graphs, the information about the modules is presented, allowing for a more effective comparison among them.

Analyzing and Selecting a Company + Panel

With the data organized in tables and graphs, it became possible to choose the best companies and panels for the government's profit-oriented initiative.

Selecting a Neighborhood and Region

To demonstrate the potential profitability, a neighborhood with significant solar incidence was chosen using the "Global Solar Atlas" website.

Cost Calculation

Based on the area of the selected region, the cost for the installation of modules in the neighborhoods was estimated. This calculation considered the monthly energy gain, and after calculating the gain in Brazilian Reais, it was analyzed over a 30-year period, which is the expected lifespan of the chosen photovoltaic module. The governmental profit for a single household was estimated as a result of these calculations.

Final Conclusions

Using the results obtained from calculations and existing literature data, a comparison was made to assess the potential governmental profitability

Results And Discussion

As a result of the methodology, several outcomes were obtained using the Python programming language, data analysis, and feasibility calculations. These data were then transferred to tables generated in Python, such as Table 1, which displays all the analyzed companies and some of their important characteristics. Note: In subsequent tables "SI" means no information.

Company Selection:

Table 1: Characteristics of Selected Companies in the Solar Energy Sector

Company	Year	Location	Partnerships	Awards	Energy per year (GW)	Powered Houses	CO2 Avoided (ton)	N°Modules
Canadian solar	2001	São Paulo	NI	n°1 (BNEF 2020 + 3 awards	150	172,000	900,000	3
First Solar	1999	São Paulo	3	Tier 1	30	NI	NI	9
GLC-Si Longi Solar	1996	Out of Brazil	NI	NI	NI	NI	NI	12
Ja Solar	2005	São Paulo	NI	NI	103	33,000	NI	11
Jinko Solar	2005	São Paulo	NI	n°1 2016-2019 (global modulo shipment)	130	NI	NI	4
Renesola	2005	São Paulo	NI	Tier 1 (bloomberg)	25	NI	NI	10
Risen Energy	1986	São Paulo	NI	5 awards 2017-2020	30	10,000	NI	11
Trina Solar	1997	São Paulo	NI	NI	80	NI	NI	13

Authorship - Own Author

Based on the presented Table 1, it is observable that the company Canadian Solar provides nearly all the required information for analysis, whereas other companies that will be discussed in Table 2, while offering more efficient modules, do not disclose all the necessary information.

Table 2: Characteristics of Selected Photovoltaic Modules

Company	Module	Power (W)	Efficiency (%)	Circular ribbon	Area (m²)	PERC	Twin Cells
Canadian solar	BiHiku7	635~655	21.6	no	3	yes	yes
First Solar	Series 6 Plus	455~488	19.0	no	2.52	no	no
GLC-Si Longi Solar	GCL-M8/60H	365~400	22.0	no	1.8	no	no
Ja Solar	DeepBlue 3.0 Series	600	23.7	no	NI	no	no
Jinko Solar	Tiger Neo	635	23.23	yes	NI	no	no
Renesola	RS6-NBG-E3	560~580	22.45	no	2.58	no	no
Risen Energy	TITAN 40	395~420	21.8	no	1.92	yes	no
Trina Solar	VERTEX N	565~585	22.0	no	NI	no	no

Authorship - Own Author

Before proceeding, two observations are necessary:

1°) Some companies are not included in the table because they do not disclose their photovoltaic module portfolio.

2°) In this table, only the modules with the highest efficiency from each company are included. These companies offer other modules in addition to those presented in the table.

Subsequently, Figure 1 provides a more detailed visualization of the efficiency of the best modules from each company.

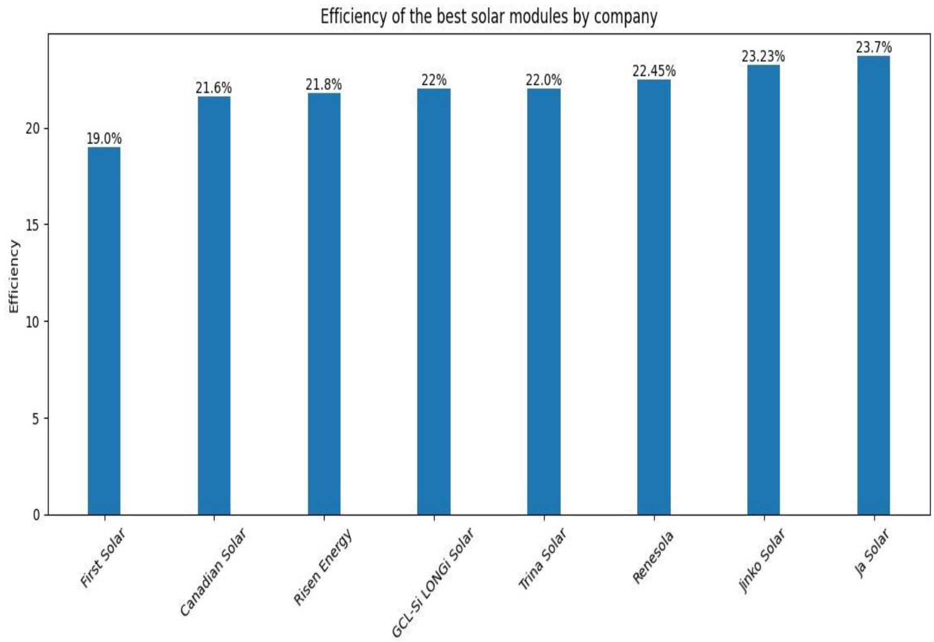

Figure 1. Efficiency of the Best Modules from Each Company. Authorship - Own Author

In Table 2 and Graph 1, it can be observed that Canadian Solar does not have the panel with the highest efficiency. In their case, the highest efficiency among the modules they offer is 21.6%, whereas JA Solar has the highest efficiency panel at 23.7%, ranking first in the list. However, when considering specific technologies that make the photovoltaic panel the most profitable and balanced, Canadian Solar continues to meet the most specifications, with the only exception being the circular ribbon. Additionally, they provide all the necessary information. Therefore, the experiment will revolve around Canadian Solar, although JA Solar would not be a bad choice either.

Region Selection

To choose the region, Figure 2, which displays the solar incidence in the country, was used.

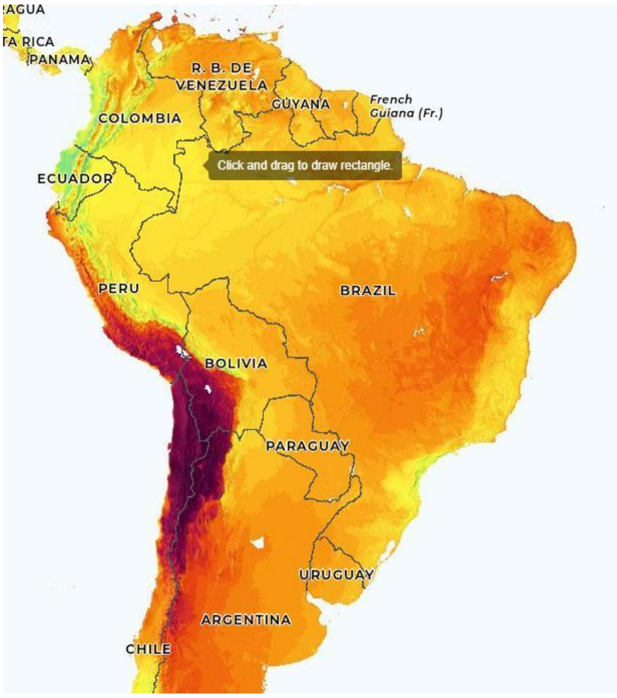

Figure 2. Solar Incidence for Photovoltaic Modules in the Country. Authorship - Global Solar Atlas, 2023

Graph 2 reveals that in Brazil, solar incidence is predominantly consistent throughout the country, with slightly higher levels in some regions. However, these differences are not significant enough to create substantial variations. Therefore, the project could potentially be implemented across the entire country, primarily considering solar incidence as a factor.

Estimates

Now, regarding the project's feasibility, an estimate was made for the purchase and installation cost of photovoltaic modules for a standard and medium-sized house in typical middle-class neighborhoods. Assuming a medium-sized house with a living room, kitchen, bathroom, and 1 or 2 bedrooms, it may have a total area ranging from 40 to 70 square meters (average 55 square meters). The most commonly used roof type in Brazil is ceramic, also known as clay tiles, with a gable roof style typically ranging from 60 to 90 square meters (average 75 square meters). Please note that these values are general estimates, and actual sizes may vary.

With these considerations, the estimated cost for a single house would range from R$12,000 to R$30,000, with an average cost of R$21,000. For experimental purposes, for 30 houses, the average cost for 30 houses would be R$630,000. Therefore, with this monetary value, it is possible to analyze whether there would be a profit within the expected lifespan of the installed photovoltaic modules, which in this case is 30 years.

Additionally, it is important to consider that the orientation of the roof surfaces in relation to solar incidence strongly affects the performance of solar energy capture. Roofs that are oriented in a way that maximizes exposure to the sun, typically facing north in the Southern Hemisphere, tend to generate higher efficiency in capturing solar energy (Huawei Solar 2024). On the other hand, roofs with inadequate orientation, such as those facing south or shaded by other structures, may result in significantly lower efficiency (Solarchitecture 2023).

Therefore, for this analysis, we will assume that all the houses have roofs with the best possible orientation, that is, facing north, maximizing the efficiency of the photovoltaic system and ensuring optimal performance in solar energy capture.

To further analyze the economic aspects related to tariff flagging, Table 3 was primarily used.

Tariff Flags, Consumption, and Electricity Costs

Table 3: Tariff Flags

	January	February	March	April	May	June	July	August	September	October	November	December
2015	1	1	1	1	1	1	1	1	1	1	1	1
2016	1	1										
2017				1	1			1		2	2	
2018						2	2	2	2	2		
2019								1	1		1	
2020												2
2021					1	2	2	2				
2022				2								
2023												

Authorship - Nova Palma Energia, 2023

According to Table 3, it can be seen that in 2021, from June to August, there was the "red flag 2," and from September to December, there was the "black flag" or "water scarcity flag." In contrast, from June to December in 2022, there was the "green flag." By comparing these flags and obtaining an average cost for each one, it is possible to analyze the differential cost between them.

Next, in Tables 4 and 5, and the continuation of Figure 3, there is the date, active kWh consumption value, and the total cost in Brazilian Reais for the expenses for a household with three residents in São Paulo, with a family income of approximately R$5,000.00.

Table 4: Electricity Consumption in kWh under Red and Black Tariffs Throughout 2021:

Month	Active consumption kWh	Total Price
11/21	353	R$397,7
10/21	311	R$318,47
09/21	369	R$353,68
08/21	543	R$509,45
08/21	428	R$389,59
06/21	458	R$396,47

Authorship - Own Author

Table 5: Electricity Consumption in kWh under Red and Black Tariffs Throughout 2022:

Month	Active consumption kWh	Total Price
12/22	301	R$234,88
11/22	377	R$293,26
10/22	466	R$380,44
09/22	490	R$391,93
08/22	416	R$327,74
07/22	341	R$259,09

Authorship - Own Author

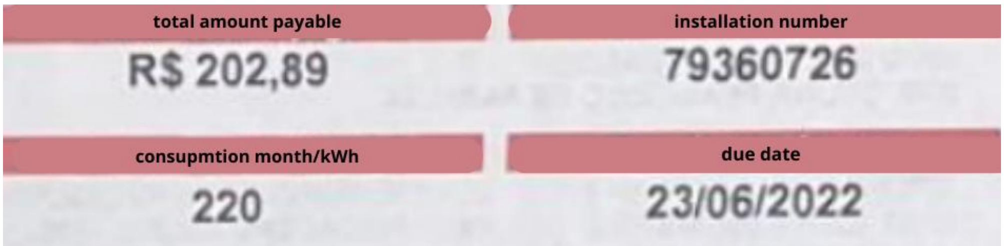

Figure 3. Energy Expenditure in June 2022:. Authorship - Own Author

Analyzing Tables 4 and 5 and Figure 1, it is evident that there is a need to analyze based on consumption rather than the date. To facilitate this, Table 6 has been created to enhance visualization.

Table 6: Consumpiton in kWh Plus Cost for 2021 and 2022

Consumption kWh + spent 2021 (R$)	Consumption kWh + spent 2022 (R$)	Difference in spent (R$)
311 - 318,47	301 - 234,88	93,59
369 - 353,68	377 - 293,26	60,42
428 - 389,59	416 - 327,74	61,85
458 - 396,47	466 - 380,44	16,03

Authorship - Own Author

Analyzing Table 6, it is evident that, with the exception of the consumption of 458 kWh (2021) and 466 kWh (2022), all other costs were significantly higher, with a difference of over R$50.00 between the tariff flags (column 3), despite the consumption being very close. In the case of 458 kWh, one might think it is due to the "red 2" flag rather than the "black" flag when compared to the "green" flag. However, the same pattern occurs with 428 kWh (2021) and 416 kWh (2022). The 428 kWh occurred during the "red 2" flag, and the 416 kWh during the "green" flag, yet the difference in cost (column 3) was much greater, even though consumption was only slightly higher by less than 10 kWh.

Calculations of simulation

To simulate how much a house with the installation of the photovoltaic module saves on energy and reduces costs, it is necessary to calculate the average energy expenditure. Therefore, for 2021, the average expenditure would be R$364.55, and for 2022, it would be R$309.08. To estimate profit, it is necessary to calculate the monthly energy generated by the installation of the chosen photovoltaic module (Equation 1).

Data Used:

· Efficiency of the chosen module: 21.6%;

· Roof Area: 75m²;

· Solar Irradiation: 5.153 kWh/m²/day.

$$E_{monthly} = RA \times MI \times E \times days \qquad (1)$$

$$E_{monthly} = 75 \times 5.153 \times 21.6\% \times 30 = 2434.8\ kWh/month$$

The tariff during this period was R$9.795 for every 100 kWh, which means R$0.098 for every 1 kWh. Therefore, using the equation for monthly savings (Equation 2), it is possible to calculate how much the electricity bill would be reduced.

$$\text{Economy} = E_{monthly} \times fare \qquad (2)$$

$$\text{Economy} = 2434.8 \times 0.098 = \text{R\$238.610/month}$$

In dollars it would look like this:

$$\text{Economy} = 2434.80 \times 0.02 = \text{US\$48.696/month}$$

With the value of how much the electricity bill would be reduced (Equation 2), it's possible calculate the final average monthly cost (Equation 3).

$$\text{FV} = \text{AS} - \text{Economy} \qquad (3)$$

$$\text{FV} = \text{R\$364,55} - \text{R\$238,61} = \text{R\$125,94}$$

In dollars it would look like this:

$$\text{FV} = \text{US\$75.09} - \text{US\$49.15} = \text{US\$25.94}$$

As the objective is governmental profit through this initiative, the amount that the family would pay would be reasonably higher than this savings, allowing the government to make a profit. Consequently, it is possible to make some estimates. Initially estimating that the bill would then be fixed at R$200.00, i.e., lower than in all months, both in "red 2" flag, water scarcity flag, and "green" flag, and with the data below, it is possible to calculate how much the government would profit per month using the following equation (Equation 4):

· Fixed bill: R$200.00;

· Calculated average final cost: R$200.00;

· Module lifespan: 30 years;

· Estimated total installation cost for an average house: R$21,000.00;

$$Earning_{monthly} = AC - FV \qquad (4)$$

$$Earning_{monthly} = R\$200{,}00 - R\$125{,}94 = R\$74.05/month$$

In dollars it would look like this:

$$Earning_{monthly} = US\$41.21 - US\$25.94 = US\$15.27/month$$

With the monthly gain value, it is possible to calculate the gain in Brazilian Reais after the maximum time (Equation 5), which is determined by the lifespan of the chosen module, in this case, 30 years.

$$TG = Gain_{monthly} \times months \times years \quad (5)$$

$$TG = R\$74{,}05 \times 12 \times 30 = R\$26.658{,}00$$

In dollars it would look like this:

$$TG = US\$15.27 \times 12 \times 30 = US\$5{,}497.20$$

Profit calculation (Equation 6):

$$Total\ profit = TG - IC \quad (6)$$

$$Total\ profit = R\$26.658{,}00 - R\$21.000{,}00 = R\$5.658{,}00$$

In dollars it would look like this:

$$Total\ profit = US\$5{,}491.06 - US\$4325.62 = US\$1165.44$$

Taking into account inflation of 5% per year:

When we apply a 5% inflation rate, both the energy costs and the savings increase over time. For example, the energy consumption in 2022 of R$309.08 would rise to R$324.53 in 2023. Similarly, the monthly savings would increase from R$238.61 to R$250.54. After factoring in this inflation, the adjusted total gain over 30 years becomes R$28,014.00 (US$5,602.80), while the total profit for the government would increase to R$7,014.00 (US$1,277.18) over the lifespan of the module. This demonstrates how inflation impacts the overall savings and profits generated, with inflation significantly increasing the total profit compared to the initial non-adjusted calculations, which showed R$5,658.00 (US$1,165.44).

In detail:

Initial monthly savings in USD:
Savings in BRL: R$238.61
Savings in USD: R$238.61 × 0.02 = US$4.77

Adjusted monthly savings with 5% inflation:
Adjusted savings in BRL: R$250.54
Adjusted savings in USD: R$250.54 × 0.02 = US$5.01

Adjusted average monthly cost after savings in USD:
Energy cost without the system in 2023: R$324.53
New monthly savings: R$250.54
New cost: R$324.53 - R$250.54 = R$73.99
In USD: R$73.99 × 0.02 = US$1.48

Government profit in USD after inflation:
Fixed energy bill by the government: R$200.00
Adjusted profit for the government after inflation: R$200.00 - R$73.99 = R$126.01
In USD: R$126.01 × 0.02 = US$2.52

Total government profit after 30 years, adjusted for inflation:
Monthly profit for the government adjusted for inflation: R$126.01
In USD: R$126.01 × 0.02 = US$2.52
Total profit after 30 years: US$2.52 × 12 × 30 = US$907.20

Adjusted Total Gain (TG) Calculation with Inflation:

Adjusted monthly gain after inflation:
Adjusted monthly savings after inflation: R$77.75
In USD: R$77.75 × 0.02 = US$5.60

Total Gain (TG) with inflation over 30 years:
Total gain over 30 years:
TG = R$77.75 × 12 × 30 = R$28,014.00
In USD: US$5.60 × 12 × 30 = US$5,602.80

Total Profit Calculation (with inflation):

Now, we calculate the total profit, considering the Initial Cost (IC) of R$21,000.00.

Total profit in BRL (with inflation):
Total Profit = TG - IC
Total Profit = R$28,014.00 - R$21,000.00 = R$7,014.00

Total profit in USD (with inflation):
Total Profit = US$5,602.80 - US$4,325.62 = US$1,277.18

Conclusions

Initially, it is worth noting that many of the values are averages and assumptions because the calculations involve the size of houses, roofs, electricity expenses, which vary from family to family. With that said, after the analysis of companies and photovoltaic modules, Canadian Solar was chosen due to its achievements, age, provided information, and photovoltaic module with an efficiency above 20% and not too far from the highest efficiency of 23.7%. To choose the region, Graph 2 was analyzed, where it was noticed that the variation in solar irradiation in Brazil is very similar across the entire country. Therefore, the average is already established at 5 Wh/m² according to the Atlas Brasil, so the choice of region is indifferent.

Next, values for installation, house and roof size, and other relevant factors were estimated for the calculation of the possibility of governmental profit. From these estimates, for one house, profit would start after 24 years, and for the first 23 years, only the installation cost would be covered. Since the module lasts 30 years, for one house, the government would have approximately R$5,640.00 in profit. For 30 houses, the value would not be simply 30 times the profit of one house due to the differences in houses. However, if this installation project were carried out for 30 identical houses within a condominium or a governmental initiative like the My House, My Life housing program, the profit for the 30 houses would be approximately 30 times

R$5,640.00. This proves to be an excellent investment and an addition to the affordable housing program, as well as very feasible for both profit and environmental purposes outside of it.

Furthermore, when considering the impact of inflation, it becomes evident that the total profit for the government would significantly increase over time. Applying a 5% annual inflation rate to the savings and profits from the photovoltaic module leads to higher profits as the years go by. For example, the government's total profit over 30 years, adjusted for inflation, would rise to approximately R$7,014.00 per house. This increase in profit due to inflation highlights the long-term financial benefits of such investments, making the initiative even more attractive for governmental housing programs and reinforcing the feasibility of sustainable, profitable investments in renewable energy.

However, an important consideration is that, since houses in neighborhoods have many variables, such as roof area, orientation of roof surfaces, and the characteristics of each residence, the project becomes more efficient when implemented in governmental programs. This allows for the consideration of these variables and enables the houses to be designed in the best possible way to optimize solar energy capture. In this way, the investment can be more effective, creating ideal conditions for solar energy use, which would be more challenging to achieve in individual homes without specific planning.

As an alternative, if the government did not want to spend as much, it would also be viable to assist with installation costs and profit with a lower percentage over 30 years. However, the initiative to cover the entire installation cost and receive it through the bill in full would be of great value, both for existing projects and for neighborhoods in various cities. Finally, another option would be to increase the cost; instead of R$200.00/month, the expense could be raised to match the cost of the "green" flag. In Table 6, the lowest cost for the "green" flag was R$234.88, a value lower than that of the "red" flag and an acceptable monthly expense.

Therefore, with this investment, there would be no need for the "red" flag or the purchase of coal for thermal power plants if applied in every house in Brazil. However, it is not possible to do this overnight, but it would definitely be worth implementing gradually. This would reduce CO_2 emissions as an environmental commitment and generate annual profit.

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