CIEEMAT | 2024
VIII Ibero-American Congress on Entrepreneurship, Energy, Environment, and Technology

Proceedings of the

CIEEMAT 2024

VIII Ibero-American Congress on Entrepreneurship, Energy, Environment, and Technology

Rio de Janeiro, Brazil
October, 14-16, 2024

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CIEEMAT 2024 | VIII Ibero-American Congress on Entrepreneurship, Energy, Environment, and Technology

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Book Cover
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Publisher
Instituto Politécnico de Bragança (IPB)
Campus de Santa Apolónia
5300-253 Bragança - Portugal

December, 2024

ISBN: 978-972-745-349-8
Handle: http://hdl.handle.net/10198/30674
DOI: 10.34620/978-972-745-349-8
URL: https://dippg.cefet-rj.br/ppges/index.php/pt/cieemat-principal
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Economic Viability Analysis of Photovoltaic Systems in the Residential Sector in Brazil and Portugal

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Abstract

The search for renewable energy, driven by high living costs and the attempt to reduce dependence on fossil sources, has led to an increase in photovoltaic solar microgeneration for self-consumption systems. This study compares the economic viability of these systems in Brazil and Portugal, considering legislation, energy compensation, and solar metric conditions. The analysis includes sizing installations, projections in PV*SOL software, and financial comparison. The results obtained show that, although Portugal has a more advantageous initial investment, the financial balance is superior in Brazil, due to legislative differences and surplus energy selling prices.

1. Introduction

To mitigate problems related to the excess injection of photovoltaic solar energy into the electrical grid, both in Brazil and Portugal, the laws governing electricity compensation are continuously being adjusted by the responsible authorities. From the recent changes in the legislation regarding the sale of surplus energy in both countries, the impacts are mainly evaluated in terms of the accumulated financial balance. In Brazil, Law 14.300/2022 (DIÁRIO OFICIAL DA UNIÃO, 2022) aims to tax the compensation of surplus energy. In Portugal, Decree-Law No. 15/2022 (Diário da República, 2022) favors self-consumption with a low tariff for the sale of surpluses. In this regard, two equivalent photovoltaic systems were designed, one in each mentioned country, with the objective of comparing economic viability in each scenario. The methodology used to obtain the results stems from simulations conducted in the PV*SOL software, whose returned graphs allow for a more accurate analysis.

2. Legislation

In the Brazilian scenario, for self-consumption systems, the purchase and sale of energy are provided by the same energy supplier company, since within the captive market there are no other options besides the one predetermined by the installation location. In the country, Normative Resolution (REN) 482 (ANEEL, 2012) was revoked with the enforcement of Law 14.300/2022: The Legal Framework for Distributed Generation (DG), associated with Normative Resolution 1059 (AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA – ANEEL, 2023).

Under REN 482, the sale of surplus energy was more advantageous for the consumer, as the kWh selling price was identical to the consumption price, according to the utility's tariff. However, Law 14,300 DG proposes a progressive tariff system on part of the energy injected into the grid, related to Fio B (which are the costs linked to the use of the local utility's distribution network infrastructure to homes, businesses, industries, and rural properties) of the Tariff for the Use of Distribution System Services (TUSD). This taxation only applies to the amount of energy injected into the electrical grid, encouraging the optimization of systems for self-consumption, since the financial return is tied to the generation of system surplus (Marques, 2022).

Portugal's legislation differs due to the availability of energy having a more decentralized character, as a large part of consumers have their tariffs linked to the free energy market, rather than the regulated captive market. As a free market, the kWh price varies according to each available supplier, both for consumption and for sale, not being predetermined by the installation location. Moreover, the consumption and sale companies are considered distinct entities, with consumption present in the distribution sphere and sale in the energy generation sphere.

The EU Directive 2019/944 and the EU Directive 2018/2001 were transposed by the current legislation of Decree-Law (DL) No. 15/2022, effective since January 14, 2022. This DL establishes the organization and functioning of the National Electric System (SEN), including microgeneration and self-consumption systems. The DL determines how to interact with the energy supplier and connect to the grid. Previously, the produced energy was for consumption and the surplus was sent to the grid without compensation. Now, if desirable, the Self-Consumption Production Unit (UPAC) must request a Producer Delivery Point Code (CPE) from the energy distributor. This makes it possible to choose to sell surplus energy. (Diário da República, 2022).

3. Methodology

The methodology was divided into four main stages, the first being the study of the current legislation in each country, focusing on the surplus sale tariffs, as presented in section 2 of this article. Subsequently, the pre-project as the second stage, in which the necessary power to meet the energy demands of a residence is stipulated. Based on this, real consumption values of a residence located in the mountainous region of Rio de Janeiro, Brazil, were acquired, resulting in a need for 4000 kWh of annual self-consumption. This resulted in a stipulated power of 3,300 Wp, which will be a baseline value for the choice of system equipment to be installed, depending on the availability in each country.

To obtain this value, through market research in both scenarios, the equipment with the best cost-benefit was selected. In Brazil, for the mentioned residence, eight 445 Wp photovoltaic modules from Canadian Solar were used, associated with two 1.6 kW micro-inverters from DEYE, resulting in an installed power of 3560 Wp. In Portugal, 550 Wp modules from Axitec were used, with a 3.0 kW inverter from GoodWe, the most viable materials at the moment, resulting in an installed power of 3300 Wp. These technical data are reflected in Table 1.

Characteristics	Brazil	Portugal
DC Peak Power (Wp)	3560	3300
Number of Photovoltaic Modules	8	6
Power per Photovoltaic Module (Wp)	445	550
Inclination Angle of Photovoltaic Modules (º)	23	35
Azimuth Angle of Photovoltaic Modules (º)	0	180
Power per Inverter (W)	1600	3000
Number of Micro-Inverters/Inverters	2	1
AC Nominal Power (W)	3200	3000
Estimated Annual Production (kWh)	4672	4818
Self-consumption (kWh)	4000	4000
Injection of Surplus into the Grid (kWh)	672	818
Estimated Losses due to Cabling (%)	0.98	0.98

Table 4: Technical Data Summary

For the third stage, aiming at the appropriation of the material, it is necessary to investigate the economic scenario of each country, with the respective difficulties linked to purchasing power, minimum wage, disparity between local currencies, and the price of the photovoltaic kit. The Real, the currency used in Brazil, according to The Economist, was devalued by 17.3% (The Economist, 2024) in relation to the Euro (currency used in Portugal) in June 2023. The exchange rate used was from that time, where the value of the euro was 5.20 reais, in July 2023 (The Economist, 2024) In this way, the values were converted to allow comparison in euros.

The price of the photovoltaic kit for the stipulated power, converting the values to euros, is 1698.00 € and 1268.00 € for Brazil and Portugal, respectively (values from June 2023). It is noteworthy that the minimum wage in Portugal is approximately 820.00 € (value corresponding to 14 annual salaries) (Portugal.GOV.PT, 2023), while in Brazil the approximate value is 260.00 € (value corresponding to 13 annual salaries) (Máximo, 2024).

The average inflation rate presented at the date of this study is 4.3% in Portugal 3% (Instituto Nacional de Estatistica - INE, 2024) and 4.7% in Brazil (Portal Solar, 2024) in 2023. Injection and energy tariffs also show inflation, with the inflation value for electricity being 7.7% in the state of Rio de Janeiro (Brazil) in 2023 (Portal Solar, 2024). In Portugal, the general inflation rate of 4.3% was used for both tariffs (Instituto Nacional de Estatistica - INE, 2024).

It should be noted that, evaluating the inflation rates of previous years, the inflation rate for 2023 is atypical, being a value higher than the average Portuguese standard. This is due to particularities, such as the war in Ukraine.

Still in this stage, the purchase and sale values of kWh in the two countries stand out. The purchase values are 0.200 euros (edp, 2024) and 0.250 euros (ENEL 2024, 2024) for kWh consumed in Bragança (Portugal) and Rio de Janeiro (Brazil), respectively. These values are from January 2024. In Brazil, the sale value of the surplus varies according to progressive taxation (Table 3), with the value being 0.231 euros in 2024 (ENEL 2024, 2024), based on the utility company Enel. In Portugal, the sale value was based on the contract proposed by EZU, one of the companies buying surplus kWh in the Portuguese scenario, presenting the value of 0.06 € for the sale of 1 kWh (EZU Energia, 2024). These economic viability data can be reflected in Table 2.

Attribute	Brazil	Portugal
Cost of Photovoltaic Kit (€)	1698.00	1268.00
Minimum Wage (€)	880.00	260.00
Average Inflation (%)	4.7%	4.3%
Electricity Inflation (%)	7.7%	4.3%
Energy Purchase Price (€)	0.250	0.200
Energy Selling Price (€)	0.231	0.060

Table 2: Economic Data Summary

Year	Rate	Selling Price kWh (€)
2023	15%	0.241
2024	30%	0.231
2025	45%	0.221
2026	60%	0.210
2027	75%	0.200
2028-2030	90%	0.190
2031-2050	100%	0.184

Table 3: Resumo da taxação progressiva

Table 3 reflects the update of Brazilian legislation, depicting the progressive taxation system on part of the energy injected into the grid, related to Fio B (which are the costs linked to the use of the local utility's distribution network infrastructure to homes, businesses, industries, and rural properties) of the Tariff for the Use of Distribution System Services (TUSD).

This taxation only applies to the amount of energy injected into the electrical grid, encouraging the optimization of systems for self-consumption. The rates are fixed and defined by Law 14,300 DG for each year of operation of the photovoltaic system. The selling price values are the result of applying these rates to the updated TUSD Fio B values, reflecting the decrease in the selling price over the years due to inflation rate adjustments.

For the fourth stage, the previously determined technical and financial values were entered into the PV*SOL software to generate results for the energy produced over the years of operation of the photovoltaic system. In this stage, it is indicated whether the system will be grid-connected or not, and the consumption is evaluated, among other options. In both scenarios, the systems are On-Grid, connected to the public electrical grid. This is to assess the financial return with the surplus injected into the electrical grid.

Regarding the climatic data of irradiation, when choosing the installation location, PV*SOL itself acquires the values through its meteorological database, Meteonorm 8.1. Then, the data related to the type of supply by the utility company responsible for the location in question are entered. In this way, mainly the voltage levels and the number of phases of the input standard are indicated.

If the system is for consumption (self-consumption), it is necessary to provide the values in kWh present in the historical energy consumption of the installation in question. By entering them, the software generates a load diagram corresponding to the energy consumption values for each month throughout the year, in kWh. These values will be used for the calculation of surplus sales and can be observed in Figure 1.

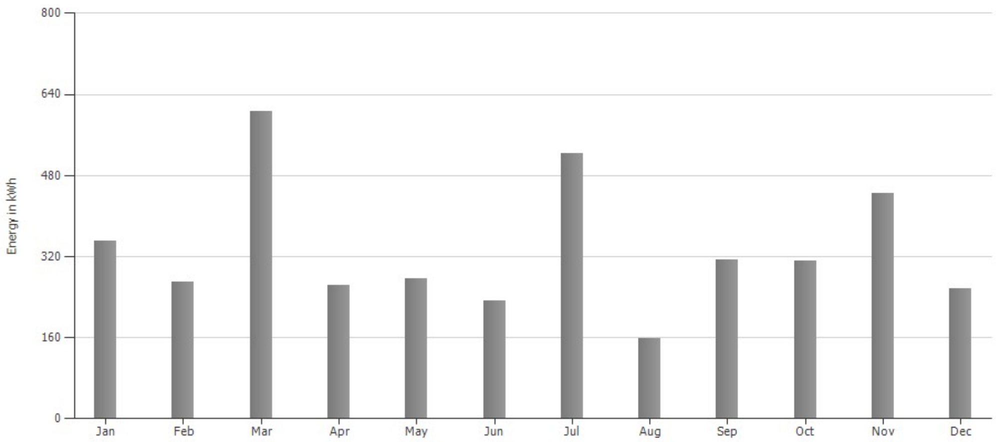

Figure 1: Annual Load Diagram Chart, by Month, Generated by PV*SOL

Following the use of the software, the second step consists of 3D modeling. In this stage, the residences were designed by prioritizing only the roof inclination consistent with the optimal inclination angles of the photovoltaic modules in each scenario. After creating the 3D model of the roof, the photovoltaic modules are allocated and connected to the inverters.

From this step, the respective inverters are inserted. In this stage, there is also the cabling between the modules and inverters, which can be done automatically by the software or manually by the designer. Next, there are the cable and wiring losses. However, for this analysis, a fixed value of 0.98% losses is used, which is a theoretical standard value.

The final stage of the software consists of the rates and tariffs of the energy supply companies. PV*SOL provides some data from a few utility companies, but if the installation location has another utility not registered in the system, there is the option to add a new utility, providing the kWh sale values, associated with the annual inflation values. Thus, the necessary values were inserted for both projects, according to the values previously presented in this work.

Finally, the data generated in both simulations is analyzed, comparing the obtained graphs of energy and financial data for the systems designed in Brazil and Portugal.

4. Results

According to the presented data, through the respective graphs generated by the PV*SOL software, relevant results such as the financial balance and the forecast of financial return are obtained. Thus, based on this information generated by the reports, comparisons can be made to identify in which country it is more economically viable to install photovoltaic systems in residences.

The energy balance (Figure 2 and 3) indicates an increase, as generation exceeded consumption during 9 out of the 12 months of the year in both cases, indicating that the system is correctly sized. As shown, the line represents the accumulated surplus over 1 year. It is noted that there is a surplus in production of more than 1500 kWh/year for both, which will highlight the differences between the financial compensation laws.

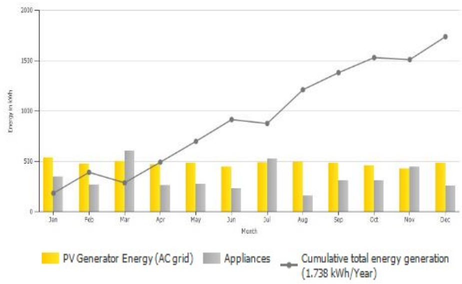

Figure 2: Brazilian energy balance

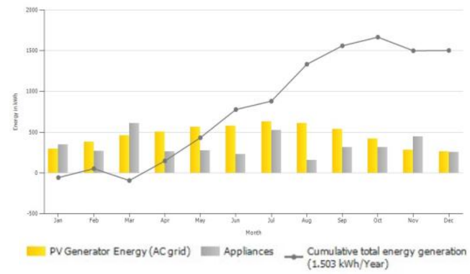

Figure 3: Portuguese energy balance

Related to this, there is the graph of the accumulated financial balance (Figure 4 and 5). At the beginning of the sizing, there is naturally a cost due to the initial investment for the project. However, with the reduction in the amount charged on the energy bill, combined with the eventual sale of the surplus, the project tends to show a financial return gradually over the years.

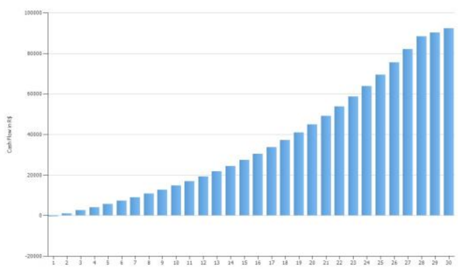

Figure 4: Accumulated financial balance in Brazil

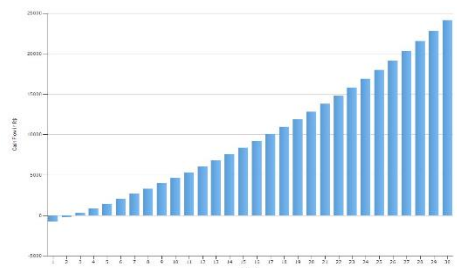

Figure 5: Accumulated financial balance in Portugal

In the first case, the financial return starts from the 3rd year after installation. As the tariff for selling the surplus is low, the flow at the end of 30 years approaches 25,000 euros. In the second case, the return already happens in the second year after installation, with an accumulation of around 90,000 euros over 30 years, clearly showing how, despite the change in the new compensation law, it is still extremely advantageous to sell the surplus in the Brazilian scenario compared to the Portuguese scenario.

It is noted that, in the Portuguese scenario, the graph follows almost a linear growth, using the premise of a fixed surplus sale rate and relatively low inflation. However, in Brazil, the flow tends to stagnate at the end of the years when taxation is higher and at a constant value. It is worth mentioning that, when simulating various scenarios in the software, varying the year of installation of residential microgeneration, the financial balance value is significantly lower the later the installation, as the stagnation of sale values occurs more quickly. However, within this scenario, financially, the Brazilian legislation is still more advantageous than the Portuguese one in terms of financial compensation related to the sale of surplus electricity.

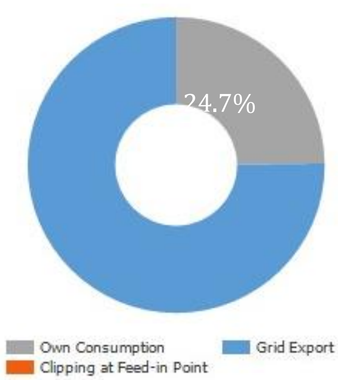

Figure 6: Brazilian utilization factor

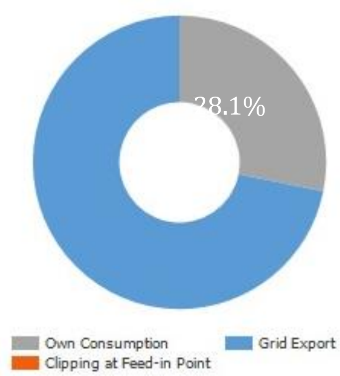

Figure 7: Portuguese utilization factor

Another analysis is the utilization of the generated energy to evaluate how much of the photovoltaic generation is used directly and how much is injected into the electrical grid. Since these are two residences, the period of highest generation usually does not coincide with the period when the residents are using the electricity. Thus, a significant portion of the generation is injected into the grid.

The utilization factor is directly linked to the load curve of each case. In the Bragança simulation, the software does not have a specific load curve for the city. Therefore, a generic load curve with late afternoon peaks was used. This curve was chosen due to its similarity to the load curve of Rio de Janeiro and because it is typically the period when most of the population is at home and using the electrical grid.

Again, the software evaluated the system's direct self-consumption and the consumption covered by the photovoltaic system. In Bragança (Figure 7), 28.1% is direct self-consumption, a value within the expected range for this type of installation.

In the Teresópolis simulation, the residential load curve of ENEL in the state of Rio de Janeiro was used. This load curve is a specific curve based on energy use in that region. Thus, the software evaluates the system's direct self-consumption and the consumption covered by the photovoltaic system, in which, in the Teresópolis project (Figure 6), 24.7% is direct self-consumption.

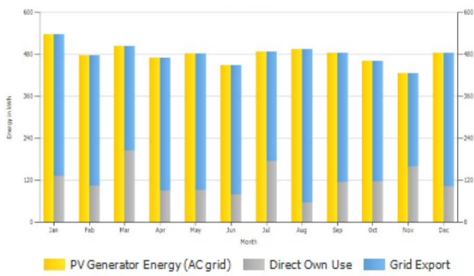

Figure 8: Utilization photovoltaic energy in Brazil

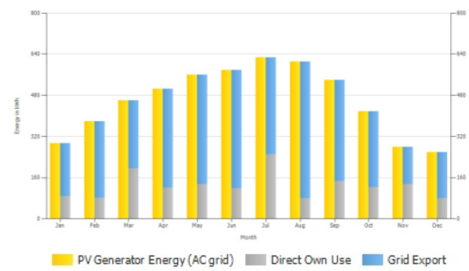

Figure 9: Utilization of Photovoltaic Energy in Portugal

Figures 8 and 9 indicate the photovoltaic generation and the destination of the generated energy. The gray bars indicate the direct self-consumption of the production, while the blue bars indicate what is injected into the electrical grid. It is noted that, as justified in the paragraph above, a significant portion is injected. Since the sale of the surplus is not very advantageous in the Portuguese scenario, it is understood that the use of zero-grid systems or the use of hybrid systems with batteries is more advantageous in this aspect. It is worth highlighting that the disadvantage is related to the sale of the surplus, as the financial return on this investment is still advantageous considering the reduction in electricity bill values.

However, in the Brazilian scenario, since the sale of the surplus is still extremely advantageous, both direct consumption and injection into the grid are beneficial, although the injection is greater than the direct self-consumption.

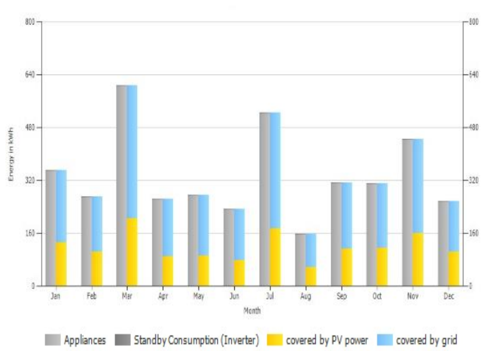

Figure 10: Brazilian consumption coverage

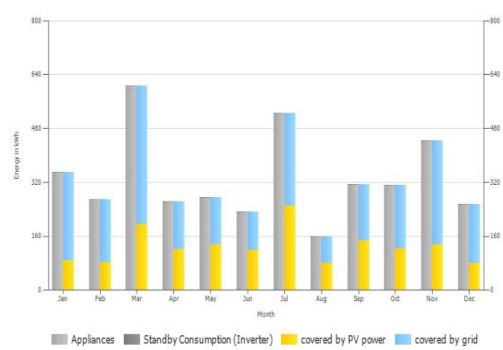

Figure 11: Portuguese consumption coverage

Still following the same line, we obtain the consumption coverage graphs, which represent, within the consumption inserted throughout the year, the proportion of how much of the consumption is covered by the photovoltaic system and how much is covered by the local electrical grid.

It is noted that, in Teresópolis (Figure 10), most of the consumption comes from the use of the electrical grid, being dominant in all months of the year. In Bragança (Figure 11), in some months of the year, most of the consumption comes from the generated photovoltaic energy, a scenario that is most suitable when sizing an On-Grid photovoltaic system. This difference between the two scenarios is due to the load curve established in each location.

It is worth mentioning that although production is higher than consumption for most of the year, this does not prevent consumption from the electrical grid, as often the use of energy in a residence is mainly during periods when there is no photovoltaic energy generation, resulting in an energy deficit.

5. Conclusions

The results highlight that the differences in financial compensation laws reflect almost immediate returns in Brazil for residential photovoltaic systems, despite the challenge of purchasing power. On the other hand, in Portugal, the main advantage lies in the initial accessibility of the systems, provided by the low cost in relation to the minimum wage, although the sale of excess energy is not as profitable due to the low selling prices per kWh. In conclusion, while the investment in self-consumption is more accessible in Portugal, the financial return is faster in Brazil, despite the initial economic challenges for both countries.

References

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA – ANEEL. (2023, 02 07). *RESOLUÇÃO NORMATIVA ANEEL Nº 1.059*. From https://www2.aneel.gov.br/cedoc/ren20231059.html

ANEEL. (2012). Resolução Normativa 482. Brasil.

Diário da República. (2022, 01 06). *Decreto-Lei n.º 15/2022*. Retrieved 07 2023, 14 from https://files.dre.pt/1s/2022/01/01000/0000300185.pdf

DIÁRIO OFICIAL DA UNIÃO. (2022, 01 07). *Lei 14.300*. From in.gov.br: https://in.gov.br/en/web/dou/-/lei-n-14.300-de-6-de-janeiro-de-2022-372467821

edp. (2024). *Tarifário de eletricidade e gás natural*. Retrieved 01, 2024 from https://www.edp.pt/particulares/energia/tarifarios/

ENEL 2024. (2024). *Taxas, Tarifas e Impostos*. Retrieved 01, 2024 from https://www.enel.com.br/pt/Tarifas_Enel.html

EZU Energia. (2024). *Venda de excedente*. (EZU) Retrieved 12 10, 2023 from https://ezu.pt/venda_de_excedente

Instituto Nacional de Estatistica - INE. (2024, 01 11). *Taxa de variação média do IPC fixou-se em 4,3% em 2023 e a taxa de variação homóloga diminuiu para 1,4% em dezembro - Dezembro de 2023*. doi:https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_pesquisa&frm_accao=PESQUISAR&frm_show_page_num=1&frm_modo_pesquisa=PESQUISA_SIMPLES&frm_texto=%C3%ADndice+de+pre%C3%A7os+no+consumidor&frm_modo_texto=MODO_TEXTO_ALL&frm_data_ini=&frm_data_fim=&frm_tema=Q

Marques, R. (2022, 01 18). *Canal Solar*. Retrieved 03 20, 2024 from https://canalsolar.com.br/tarifacao-do-fio-b-previsto-na-lei-14-300/

Máximo, W. (2024). Salário mínimo de R$ 1.412 começa a ser pago nesta quinta-feira. Brasília: Agência Brasil.

Portal Solar. (2024, 01 11). *Conta de luz acumula alta de 9,52% no Brasil em 2023*. doi:https://www.portalsolar.com.br/noticias/mercado/consumidor/conta-de-luz-acumula-alta-de-9-52-no-brasil-em-2023

Portugal.GOV.PT. (2023). Governo atualiza Salário Mínimo Nacional para 820 euros em 2024. Portugal: Portugal.GOV.PT.

The Economist. (2024, 01 25). *Our Big Mac index shows how burger prices are changing*. Retrieved 01 15, 2024 from https://www.economist.com/big-mac-index