The impact of the COVID-19 pandemic on the economic viability of distributed photovoltaic systems in Brazil

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Abstract
Electricity consumption in Brazil increases significantly, making feasibility studies to diversify the Brazilian electricity mix with other renewable sources become essential. However, the electricity market continues to be primarily driven by government or regulatory incentives and economic status. With the coronavirus pandemic since the beginning of 2020, the market has been undergoing significant changes that cause uncertainty in consumer investments in grid-connected photovoltaic systems. This article presents an economic feasibility analysis of photovoltaic system installation for the Brazilian residential sector, estimating a cash and term investment and comparing the viability of the investment before the global pandemic (December 2019) with the pandemic scenario (April 2021) for each of the 27 Brazilian capitals. The baseline scenario for economic feasibility analysis calculations considered a power system of 4 kW. The results show that the effects of the pandemic in the electricity market were positive in the feasibility of investing in grid-connected photovoltaic systems. Also, financing the system increases the chances of profitability. The current scenario is possibly the most attractive ever experienced by potential investors. However, this favorable scenario could decline in the coming years due to climatic and governmental factors.

KEYWORDS
coronavirus, economic feasibility, electricity tariff, PV system, solar energy

1 | INTRODUCTION

The electricity demand has increased over the years due to demographic evolution and the growth of economic activity. With the significant increase in electricity consumption, public policies to expand energy generation have intensified globally. The production of electrical energy through photovoltaic (PV) technology is a particularly efficient initiative with low environmental impact, as PV systems do not emit pollutants in their operation, do not produce noise, and can be installed on residential roofs.

Renewable energy production has considerably competed with traditional energy sources, and its notorious growth is due to the incentives through public policies. The Brazilian government launched different incentives to boost the development of renewable sources. In 2012, the Electric Energy Regulatory Agency (ANEEL), through resolution No. 482/2012, introduced a net metering system to promote distributed microgeneration from renewable energy sources. This compensation system allows the active energy injected into the grid to be transferred to the distributor and subsequently compensated with energy consumption. At the end of the month, if generation is more significant than consumption, the remaining balance reduces consumption in some subsequent months. The consumer only pays the basic tariff (30 kWh for single-phase installations, 50 kWh for two-phase, and 100 kWh for three-phase). In addition, in
June 2021, the Brazilian President published Decree No. 10387 (incentives to finance infrastructure projects with environmental and social benefits), which encourages environmentally sustainable infrastructure projects and allows for more flexible financing conditions for the electricity sector. Solar energy equipment has its taxes zeroed by the end of 2021 to reduce the amount paid by the consumer and stimulate the solar energy market.

PV systems correspond to approximately 95% of all distributed generation (DG) in Brazil. One reason is that Brazil is privileged concerning daily insolation levels. In most country regions, the average daily insolation reaches 6–7 h, with some places reaching 8 h, and radiation levels in the country reach between 2.22 and 6.11 kWh/m² per day. Using this potential to supply electricity to residential stretches can be an attractive solution to meet annual energy demand and reduce dependence on fossil fuels. Investments in PV energy generate economic benefits for consumers and the country’s economy.

In March 2020, the World Health Organization (WHO) declared that the world was affected by a global pandemic by Coronavirus. The primary guideline to reduce the spread of the virus was to avoid crowds of people. That year, many countries adopted the so-called “lockdown,” the most stringent pandemic measure, which requires social distancing by the population. With the global economy almost completely shut down after the declaration of the pandemic, electricity systems around the world faced severe shocks on both the supply and demand sides. As in many countries, Brazil faced a general reduction in electricity consumption, a change in consumption profile, an increase in tariffs, and a decrease in interest rates for financing. A little over a year after the outbreak of the new coronavirus pandemic (COVID-19), which profoundly reversed the national and world scenario, uncertainties related to the future of the pandemic and the economy are still high. Consumers do not feel safe to make a long-term investment, and decision-making in a global crisis scenario becomes difficult.

For the distributed PV sector, the effects of the COVID-19 lockdown cause some scenarios. The installation companies are experiencing a shortage of labor, an increase in the cost of logistical time, and even the stagnation of logistics, which generate difficulties in transporting raw materials and semi-finished and finished products. In addition, the subsequent outbreak and steady spread of COVID-2019 abroad could trigger new export demand after the recovery of production in the PV industry, which would increase uncertainty in this industry. Besides, the PV systems investor is dealing with a moment of insecurity in the market and the increase in tariffs, government tax incentives, and falling interest rates. In an economic crisis, banks need to encourage money movement by offering lower rates, such as the Interbank Certificate of Deposit (CDI) index, which was reduced during the pandemic in Brazil.

The solar energy development in Brazil is economically viable, but the financial aspect is the investors’ primary concern. Understanding the economics of PV systems is one of the most important considerations when deciding on solar energy, especially in times of crisis, as the world is going through with COVID-19. So, this study aims to compare the economic feasibility of installing PV systems for the residential sector before and during the COVID-19 pandemic, considering the electricity costs and local radiation in each of the 27 Brazilian capitals. The analysis comprises a 4 kW power system which represents, on average, the monthly expenditure of households in the range of 480–710 kW. Residential consumers, belonging to group B1 (residential class and voltage less than 2.3 kV), represent around 29.61% of the country’s electricity consumption (EPE, 2019). Given the current economic situation in Brazil, some consumers do not have the monetary amount to invest. Therefore, it was decided to calculate the value of the equipment through financing. The economic viability aims to characterize the enterprise, assess the applicability of the business in the regions studied, make it a determining factor for companies in this field of activity, and serve as a decision tool for homeowners.

2 | METHODOLOGY

This section presents the approach followed in this study to assess the economic viability of grid-connected solar PV systems in the 27 Brazilian capitals. The economic evaluation of this study has four scenarios: (1) Before the pandemic with payment in cash; (2) before the pandemic with financed payment; (3) during the pandemic with cash payment; and (4) during the pandemic with financed payment. For pre-pandemic calculations, December 2019 is as the base month and year, and for calculations during the pandemic, April 2021 was set. This section has four subsections: general data for cash flows, calculation of electricity tariffs for each capital, calculation of electricity generation for each capital, and economic feasibility calculations. Supplemental information about Brazil’s electricity billing system can be found in the Appendix S1.

2.1 | General data for projecting cash flows

The total cost of the 4 kWp PV system was obtained in the Strategic Study of DG carried out by Greener. Greener publishes biannual studies carried out with installers companies throughout Brazil, and these studies include final prices charged by them to their customers. From January 2019 to April 2021, prices for small systems varied little. The high dollar raised the purchase prices of imported equipment. However, installers absorbed this cost and reduced their profit margin, keeping prices competitive. Therefore, the cost for the scenario before the pandemic and during it is the same, 4.70 R$/Wp, resulting in a total investment of R$ 18,800.00. This value served as the basis for the calculations of the 27 Brazilian capitals. The intention is to scale PV systems to partially, totally, and excessively supply the average residential electricity demand.

PV systems are known for their long service life, reaching over 25 years of full operation. Among the parameters to be analyzed is the annual system efficiency loss, also called the performance degradation rate, defined as the annual reduction rate of the maximum expected power of a PV module or a complete PV system. The degradation rate is associated with the specific PV technology and various
factors, such as the system's temperature, humidity, precipitation, dust, and solar irradiation. Manufacturers guarantee that PV modules will provide a performance degradation rate of less than 1% per year during the first 10 years of operation and a maximum of 20% until the end of the modules' useful life. With a performance guarantee of up to 25 years, solar panels guarantee high power, which will decrease at a rate of about 0.7% per year. It means that, even after 25 years of installation, the panels will still work with at least 80% of their initial power. However, the inverters have a shorter useful life, estimating their replacement in approximately 13 years of operation for low-power residential inverters. The costs related to operation and maintenance refer to hiring teams for cleaning and checking cables, electrical safety systems, and checking the fixing structures on the roofs. For this, according to the prices practiced by the installers, a constant annual value was fixed, which represents 0.5% of the initial investment portion.

The average residential tariff has increased by 73.77% in the last 10 years, according to ANEEL data, mainly due to the increase in energy chain costs. The objective of the annual tariff adjustment is to restore the utility's purchasing power. In other words, this constant increase in electricity tariffs will continue to increase, so to calculate the feasibility of a PV system, an increase of 7.37% per year was considered, which reflects the annual historical average.

For the financed investment scenario, the option of most Brazilian investors, the calculation considers the system acquisition through financing, according to the budget provided by a credit union. For this purpose, the Interbank Deposit Certificate (CDI) + 0.45% per month for 2021 is applied as an interest rate, with the CDI at an average of 0.22% per month. The CDI in Brazil is used as a reference index for the price of money in the economy, used as a benchmark in many investments. In the system acquisition calculation using the scenario before the Brazilians faced the pandemic, the same system acquisition values were considered, but the 2019 tariffs had low values, the state taxes also had minor changes, as well as higher values in the rates of financing that in 2019 the researched credit union applied the CDI + 0.72% per month, in addition to the rate added to the CDI being higher, the CDI was also higher at 0.48% per month.

Finally, for economically viable techniques, it is necessary to use a Minimum Attractive Rate of Return (MARR). The MARR used by the electricity sector in Brazil is the Weighted Average Cost of Capital (WACC), the remuneration rate of regulatory capital used to review the tariff or revenue of electricity distributors, transmission, and generators companies. The method for estimating the WACC is based on national parameters and uses public data sources. The WACC treats the nature of the capital sources used by energy distributors differently, considering that equity is less flexible than third-party capital. Table 1 presents a summary of the data used in the cash flows.

### Table 1 Data used in cash flows

| Parameters | Values |
|------------|--------|
| Investment cost (B1 – residential 4 kW) in 2019 and 2021 | R$ 4.7/Wp |
| System lifetime | 25 years |
| Annual electricity tariff increase | 7.37% per year |
| Minimum attractiveness rate of return | 7.00% |
| Annual operating and maintenance cost | 0.5% |
| Annual system efficiency loss | 0.7% per year |
| Inverter replacement costs (inverter replaced in year 13) | R$ 8000.00 |
| 2019 Financing fee | CDI of 0.48% p.m. + 0.72% p.m. |
| 2021 Financing fee | CDI of 0.218% p.m. + 0.45% p.m. |
| PIS/COFINS 2019 and 2021 | 5.05% |
| ICMS 2019 and 2021 | Between 15.4% and 27.7% |

2.2 Calculation of electricity tariffs in capital cities

The base scenario for the economic feasibility analysis uses the electricity tariffs of the 27 Brazilian capitals for December 2019 and April 2021. The regulatory agency ANEEL determines the tariff amount. The reference tariff was consulted on the ANEEL database to calculate the tariff of each capital, considering the green tariff, where conditions are favorable for energy generation, and which makes the viability of PV systems less optimistic. State tax rates, ICMS (Tax on Circulation of Goods and Services), and federal taxes that are the PIS (Social Integration Program) and COFINS (Contribution for Social Security Financing), which are defined in specific laws. To calculate the tariff charged to final consumers, as of the amendment to Laws 10.637/2002, 10.833/2003, and 10.865/2004, PIS and COFINS had their rates changed to 1.65% and 7.6%, respectively, and calculated on a “non-cumulative” basis, that is, the new rates are based on a net calculation basis, with the total gross revenue deducting the costs allowed by law.

The changes introduced by these new laws resulted in the removal of PIS and COFINS from the electricity tariff, and both are now reported individually in electricity bills and may vary monthly. Due to monthly variations, a historical average of the rates charged on the electric energy bills of five states was carried out, which resulted in a rate of 5.5%. Thus, for calculating economic feasibility, 5.05% of the rate was standardized for PIS and COFINs since the effective post-tax tariffs are defined by Equation (1).

$$\text{Fee} = \frac{\text{ANEEL Fee}}{1 - \left(\%\text{PIS} + \%\text{COFINS} + \%\text{ICMS}\right)}$$

2.3 Calculation of generated energy

A search was carried out for the average local irradiance values of the 27 capitals in the SunData–CRESESB database. By obtaining the daily local irradiance of each city, it was possible to calculate the
energy generated by the system, considering a residential PV system with 4 kWp, thus applying Equation (2) for the calculation. The value of 98% of inverter efficiency was considered, with annual degradation of 0.7% and total power losses of 18.5%. The actual energy generated by the system is obtained through the application of the percentages in Equation (3).

\[ En = \text{Annual solar irradiace (kWh/m}^2\text{ year)} \times \text{Power (kW)} \] (2)

\[ E = [En \times (1 - \text{Loss})] \times \text{Efficiency} \] (3)

2.4 | Survey of financial fees and economic feasibility calculations

To project the value of electricity tariffs in capitals, besides adding the percentages of state and federal taxes, 7.37% per year was applied, referring to the annual tariff adjustment, based on the historical average increase in the last 10 years of the residential tariff. As the MARR, the WACC rate explained in Section 2.1 was used. The project installation cost, the estimated annual electricity produced, the electricity price per kilowatt-hour, and its inflation rate are the main factors that play a role in the payback period of a PV solar system, as well as the MARR and possible government incentives. However, the payback period is not enough to provide insight from the investor's point of view because the payback period does not consider maintenance costs, inflation, depreciation, and the project lifetime. Therefore, to increase the cost-effectiveness and measure the project’s profitability, the net present value (NPV) and the internal rate of return (IRR) were calculated. Developers can compare their discount rate with the IRR to determine whether a system would be a financially attractive investment.

The IRR is the discount rate at which the NPV of all cash flows is zero. It can be calculated from Equation (4):

\[ \text{NPV} = \sum_{y=1}^{25} \frac{R_y - M_y}{(1 + \text{MARR})^{y-1}} - I = 0 \] (4)

where, \( I \) is the initial investment, the total price of a system connected to the grid, \( R_y \) and \( M_y \) are the revenue and maintenance costs in year \( y \), respectively. Annual maintenance costs are deducted from the revenue stream, and the resulting net annual revenue is discounted over the 25-year life of the project. Annual revenues are equal to the sum of the energy yield, measured in kWh, multiplied by the price of the electricity tariff plus taxes.

The NPV, presented in Equation (5), is the indicator that calculates the present value of a series of future financial movements, discounted at the MARR, considering the investment and revenues and costs over time.

\[ \text{NPV} = \sum_{y=1}^{25} \frac{R_y - M_y}{(1 + \text{MARR})^{y-1}} - I \] (5)

PV indicates the potential to generate value. Therefore, if NPV is positive, the investment will bring a positive result. The payback period or discounted payback (DP) is the period in which the return on investment occurs, considering the value of money over time, being calculated in the cash flow of the useful life of the investment. In calculating the financing of the PV system, the budget provided by Cooperativa Sicredi’s financial institution was sought by applying the interest rate, CDI of 0.48% + 0.72% per month for 2019 and CDI of 0.218% + 0.45% per month for 2021.

3 | RESULTS

The base scenario for the economic feasibility analysis uses values of average electricity tariffs (residential) and average daily irradiance for each of the capitals. The results were found to depend on the relationship with the rate and the level of local irradiation. It is noticed that obtaining only one of these favorable conditions may not be enough for a positive viability result. The adoption of solar energy involves high initial costs, considered an irreversible investment, or too expensive to revert.

Therefore, consumers tend to wait for a more optimistic scenario, waiting to see how electricity prices, government incentives, and solar technology will evolve before deciding to invest. It implies that, compared to investments whose returns are subject to less uncertainty, consumers may demand a higher rate of return on their PV energy investments. The following variables were changed that affect the result to calculate the IRR and NPV in Brazilian capitals: electricity tariff, generated energy, annual radiation, ICMS. Each of these variables is directly related to the result, and all depend on the location.

3.1 | Economic viability before COVID-19

Before Brazilians faced the pandemic, the feasibility calculation used data from December 2019, when the country had not yet had any confirmed case of the coronavirus, and the government had not taken regulatory preventive measures. The calculation for the acquisition of the PV system considered the financing of the value of the equipment, applying the interest rate at that time, CDI of 0.48% + 0.72% per month, with a credit union that is currently the second source of financing for PV systems in Brazil. Likewise, the MARR of 7% per annum is based on the WACC.

Among the financial engineering techniques used for the analysis, DP is the value of most significant interest to investors for decision making. That said, Figure 1 shows the DP values, in years, for each Brazilian capital and the spot scenario (on the left) and the split scenario (on the right). The DP is faster in the cash system investment for all capitals except Rio de Janeiro. On average, the DP for the cash system is 4.71 years, and for the financed system, it is 5.59 years. Curitiba (PR), São Paulo (SP) and Macapá (AP) had the highest DP times for both scenarios. The first two are due to the irradiance levels...
in these capitals. SP is known for the “land of the drizzle” and has a lower solar potential. Macapá, on the other hand, is due to its electricity tariff being the lowest in the country. The DP means of the cash values for the financed values are statistically different (paired t-test, \( p \)-value = 0.009).

The capital of Rio de Janeiro has the lowest DP as its electricity tariff is the highest in the country. The tariff is raised mainly by the share of “commercial losses,” where fraud and electricity theft raise the tariff for all consumer units in the capital. Therefore, the consumer who installs a PV system under the distributed modality does not pay for electricity, fraud, or theft. As the monthly return on investment in the PV system is greater than the interest payment of the financed system, the financed investment was more attractive.

The feasibility analysis was favorable in both investment models (spot and financed). Regardless of the investor’s choice, it is possible to affirm that the decision to invest in a PV system in 2019 guaranteed a positive financial return in a few years. The decision to finance or pay in cash probably considers other factors, such as the financial moment in which the investor was, the amount of cash the investor had available at the time of acquisition, and other concomitant investments present more attractive financing rates.

### 3.2 Economic viability during COVID-19

Feasibility calculations during COVID-19 used data from April 2021, a critical moment of the pandemic in Brazil. The country faces its impacts for 1 year and seeks to maintain economic balance by reducing financing rates mobilizing the population to turn the money in the market. The pandemic brought several financial and investment problems, such as high inflation, high electricity tariffs, and several bankrupt companies. Periods of economic instability are marked by a retracted market, mass layoffs, financial difficulties, and instability among investors.

However, this scenario that affects most sectors may be an opportunity for others, where some investors may benefit from the situation, as can be seen in this feasibility study, in which DG investors may be experiencing the moment of greater economic viability for purchase of a PV system and installation in the form of DG. Higher electricity tariffs and taxes, coupled with no increase in PV system prices and lower financing rates, make the economic viability of this investment even more attractive than in the period before COVID-19. Figure 2 shows the DP values in years for each Brazilian capital and the cash scenario (on the left), and the financed scenario (on the right). The DP means of the cash values for the financed values are statistically different (paired t-test, \( p \)-value = 0.00006).

As the financing rate proposed by the credit cooperative has reduced, the investment viability is more attractive in the system financed in 21 of the 27 Brazilian capitals. The present scenario is the best seen by Brazilians. In the capitals of Rio de Janeiro, Belém, and Sergipe, the financed system presents a financial return in the first year, and Cuiabá and Palmas, which present a return in less than a half year. Of the 27 capitals, only six had the sight scenario more attractive than the financed scenario. These six capitals are among the 12 capitals with the lowest electricity tariff, and all had DP over 5.2 years. All capitals show returns in less than 6 years, which makes the investment highly attractive.
The main difference between the investment period before COVID-19 and during COVID-19 is in financing rates. The equivalent annual rate of CDI + Sicredi Cooperative Fee is 15.44% per year for financing in December 2019 and 8.32% for financing in April 2021. The second main difference is the increase in electricity tariffs used in 2021. This increase in electricity tariffs in 2020 is mainly due to the non-charging of tariff flags from May to December 2020, which generated a billionaire loss. Not charging the yellow flag (the period using thermoelectric plants) had been a policy to support consumers during the pandemic crisis.

Table 2 presents the maximum, minimum, and average values for the 27 Brazilian capitals in the analyzed scenarios under the DP, NPV, and IRR techniques. It is noteworthy that the IRR was not evaluated for the financed scenarios because non-uniform cash flows, with inversions of signs and exits after period zero, generate multiple IRR rates that do not reflect reality. Like the DP, the NPV indicates greater viability for the systems during COVID-19. Even though the cash NPV presents higher values than the finance, the cash, and financed values are not statistically and significantly different (paired t-test, p-value = 0.96). It proves that DP is the best technique for comparative analysis of these scenarios, as the values are statistically different (paired t-test, p-value <0.01). For spot systems, IRRs are observed well.
above the MARR of 7% p.a. Which means that even if investors have higher minimum attractiveness rates, the investment is still viable, up to 23.68% return in the worst-case scenario.

4 | FUTURE PERSPECTIVES

Forecasts indicate that Brazil’s electricity system will continue to be pressured by higher costs until 2022 due to the impacts of the worst rainy season in two decades on the production of hydroelectric plants, the primary source of energy generation in the country. The lack of rain leads to a sharp drop in the volume of water stored in the reservoirs of these hydroelectric plants, causing the government to create ways to save water from these reservoirs and reduce energy production by the hydroelectric plants.28 It is necessary to activate the thermo-electric plants to compensate and meet the energy demand.26

Brazil experienced an electricity crisis in 2013–2015, with some blackouts, a high risk of not having enough supply to meet demand, and skyrocketing electricity prices. As hydroelectric power generation accounts for more than 80% of generation, the lack of water in reservoirs can lead to an intense crisis in the sector.27 The energy generation by hydroelectric plants in the Brazilian electricity mix implies that, in regular years, water reservoirs are capable of supplying seasonal variations in demand. Consequently, thermoelectric dispatch remains only for exceptional circumstances. However, when weather conditions are adverse, such as prolonged droughts, such as that which occurred in 2013–2015, the risk of supply shortages increases, which makes it necessary to plan how to plan the supply and which energy to develop in order to avoid rationing and meeting the increase in demand.28

Thermoelectric plants, mainly natural gas, present themselves as an alternative to diversify the electric energy mix in Brazil due to their reliability and ease of dispatch. They can provide sufficient capacity to meet growing demand, aiming to reduce the risk arising from water scarcity.28 As Brazilians are already going through difficult times with the fight against the pandemic, and the history of water scarcity in reservoirs reminds us of moments of crisis in the electricity sector that contaminate the entire financial market of a country, the National Electric System Operator (Operador Nacional do Sistema Elétrico – ONS) decided to guarantee the energy supply by activating the thermoelectric ones. Energy generation by thermoelectric plants, which depend on fuels such as oil and natural gas to produce, becomes more expensive than hydroelectric plants, an additional cost that directly reflects an increase in electricity bills. With the use of thermoelectric plants after the light rains, experts project that electricity bills in the country should remain more expensive until the end of the year, with the activation of yellow and red tariff flags, which generate extra costs for consumers.

The scenario is promising in terms of investment in the PV system because two reasons. At first, due to the financial return, that becomes more attractive than investing in the PV system due to the increase in the electricity bill resulting from the change in tariff flags that tend to stay between yellow and red due to the thermoelectric plants’ activation. In the second stage, the increase in energy generation by the final consumer will alleviate the need for the generation coming from large plants when analyzed on a large scale. The scenario motivates consumer investment to achieve a balance between generation and consumption of electricity in the country.

However, the fast growth of PV solar energy through DG has led ANEEL to revise the Electricity Offset System to balance grid costs for DG participants and non-participants. In addition, the insertion of DG in the Brazilian electricity grid worried electricity concessionaires and their monopoly. They faced the prospect that customers will reduce their electricity purchases as they adopt solar PV generation and enter a positive feedback loop (death spiral).29 In this sense, through public consultations in 2019 and 2020, ANEEL developed a new compensation rule for the DG that adds costs of the Tariff for the Use of the Distribution System (TUSD) to the energy concessionaires of DG users.30 This pricing policy can occur through five alternatives and, if approved, concessionaires can implement it from 2022.

The entry of the TUSD charge for DG systems shows a tendency to reduce the benefits that Brazil has given to renewable energies. Because with the regulatory review, the payback time for investors increases. One study points to a 50% increase in turnaround time for applying ANEEL’s alternative 5, the worst-case scenario.31 This fact can lead the market to a cycle of expansion and contraction, requiring a high installation volume before the end of the incentive and a high contraction after the end of the incentive. Therefore, Brazil may be going through a moment of high expansion for the future high contraction. Even with the continuity of economic viability, the increase in the return on investment may force some investors to decide not to install a PV system of the DG modality.

5 | CONCLUSION

PV energy in Brazil is still at an early stage of development. However, the country has shown its interest in disseminating this technology, constantly changing its regulations in search of better conditions and aiming to diversify the Brazilian electricity mix. This study helps potential residential investors identify the economic feasibility of installing a PV system in each Brazilian capital in a moment of economic uncertainty due to the coronavirus pandemic.

This study presented a satisfactory economic evaluation for four scenarios, and in all the configurations presented, the results were viable. A constant observed is that, due to the effects of the pandemic, the financing rates present decreases, making the financeable system more attractive than the cash system in most capitals. It would be advisable to buy a financed PV system in these capitals and use the cash value in other possible investments. This attractiveness is also reinforced by the low risk involved in this type of investment, as there is legal certainty guaranteed by a regulation considered consolidated and in constant evolution, which makes it even more vital. It is noteworthy that the variables used in the calculations may be different for other regions of the country and, therefore, the results are specific for the systems studied in the capitals.
This study confirms to policymakers that the incentives proposed by the government are being of great value and, currently, all Brazilian capitals are already economically viable in the implementation of PV systems in residential sectors. A difficulty to be overcome in DG is the attitude of energy distributors, who manage the entire process of grid-connection, a bureaucratic and time-consuming administrative process. While it is bureaucratic, it is also essential to maintain the security and quality of the network. ANEEL needs to create mechanisms to evaluate both the fulfillment of deadlines by electricity distributors and the quality of service provided by the installers.

Policymakers need to know that if the amendment proposed by ANEEL is approved, the attractiveness of the DG for residential purposes will be reduced. Brazil was affected by the economic crisis of the coronavirus and, at the same time, by a historic drought, impacting the real case must be carefully analyzed and calculated. Every real case must be carefully analyzed and calculated.

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CONFLICT OF INTEREST
The authors declare no potential conflict of interest.

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Graciele Rediske: Methodology (equal). Lauren Peres Lorenzoni: Conceptualization (equal). Tiago Bandeira Marchesan: Supervision (equal).

DATA AVAILABILITY STATEMENT
Data available on request from the authors.

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REFERENCES
1. Vaziri Rad MA, Toopshekan A, Rahdan P, Kasaeian A, Mahian O. A comprehensive study of techno-economic and environmental features of different solar tracking systems for residential photovoltaic installations. Renew Sustain Energy Rev. 2020;129:109923. doi:10.1016/j.rser.2020.109923
2. Cristea C, Cristea M, Birou I, Timovan R-A. Economic assessment of grid-connected residential solar photovoltaic systems introduced under Romania’s new regulation. Renew Energy. 2020;162:13-29. doi:10.1016/j.renene.2020.07.130
3. Silva TC, Pinto GM, de Souza TAZ et al. Technical and economical evaluation of the photovoltaic system in Brazilian public buildings: a case study for peak and off-peak hours. Energy. 2020;190:116282. doi:10.1016/j.energy.2019.116282
4. Shahbaz M, Raghutla C, Chittedi KR, Jiao Z, Vo XV. The effect of renewable energy consumption on economic growth: evidence from the renewable energy country attractive index. Energy. 2020;207:118162. doi:10.1016/j.energy.2020.118162
5. Rocha LCS, Aquila G, de Oliveira Pampolina E, de Paiva AP, Chieregatti BG, de Sá Brasil Lima J. Photovoltaic electricity production in Brazil: a stochastic economic viability analysis for small systems in the face of net metering and tax incentives. J Clean Prod. 2017;168:1446-1462. doi:10.1016/j.jclepro.2017.09.018
6. Rosas Luna MA, Fontes Cunha FB, de Miranda Mousinho MCA, Torres EA. Solar photovoltaic distributed generation in Brazil: the case of resolution 482/2012. Energy Proc. 2019;159:484-490. doi:10.1016/j.egypro.2018.12.036
7. ABSOLAR. Governo quer impulsionar desenvolvimento das fontes renováveis em linha com demanda da sociedade. Assoc Bras Energ Sol Fotovoltaica; 2020.
8. Governo do Brasil. Governo zera imposto de importação de equipamentos de energia solar; 2020.
9. ANEEL AN de EE. Geração Distribuída; 2021.
10. ABSOLAR. Energia solar gera aos brasileiros 3 vezes mais benefícios do que custos; 2020.
11. Heffron R, Körner M-F, Schön M, Wagner J, Weibelzahl M. The role of flexibility in the light of the COVID-19 pandemic and beyond: contributing to a sustainable and resilient energy future in Europe. Renew Sustain Energy Rev. 2021;140:110743. doi:10.1016/j.rser.2021.110743
12. EPE E de PE. Previsões de carga para a 1ª Revisão Quadrimestral da Carga 2021–2025; 2021.
13. Sun X, Chavali RVK, Alam MA. Real-time monitoring and diagnosis of photovoltaic system degradation only using maximum power point—the Suns-Vmp method. Prog Photovolt Res Appl. 2019;27:55-66. doi:10.1002/pip.3043
14. Greener. Estudo Estratégico Geração Distribuída; 2020:105.
15. Martin-Martinez S, Cañas-Carretón M, Honrubia-Escribano A, Gómez-Lázaro E. Performance evaluation of large solar photovoltaic power plants in Spain. Energy Conver Manage. 2019;183:515-528. doi:10.1016/j.enconman.2018.12.116
16. Sun X, Chavali RK, Alam MA. Real-time monitoring and diagnosis of photovoltaic system degradation only using maximum power point—the Suns-Vmp method. Prog Photovolt Res Appl. 2019;27:55-66. doi:10.1002/pip.3043
17. ANEEL AN de EE. Tarifas Residenciais: Efeitos dos Reajustes Tarifários; 2020.
18. ANEEL AN de EE. Tarifas Residenciais: Efeitos dos Reajustes Tarifários; 2020.
19. Brito CC de R para ES e ES. Potencial Solar Renováveis em linha com demanda da sociedade; 2020.
20. Hamisu Umar N, Bora B, Banerjee C, Gupta P, Anjum N. Performance and economic viability of the PV system in different climatic zones of Nigeria. Renew Sustain Energy Technol Assess. 2021;43:100987. doi:10.1016/j.rseta.2020.100987
21. Drank G, de Lima J, Bonotto R, Machado R. Economic and risk analysis of small-scale PV systems in Brazil. IEEE Lat Am Trans. 2018;16:2530-2538. doi:10.1109/TLA.2018.8795132
22. Tao JY, Finenko A. Moving beyond LCOE: impact of various financing methods on PV profitability for SIDS. Energy Policy. 2016;98:749-758. doi:10.1016/j.enpol.2016.03.021
23. Tomosk S, Haysom J, Hinzer K, Schriemer H, Wright D. Mapping the geographic distribution of the economic viability of photovoltaic load management in Brazil.
displacement projects in SW USA. Renew Energy. 2017;107:101-112. doi:10.1016/j.renene.2017.01.049
24. Faria VR, Magalhães ML, Neto DP, Domingues EG. Economic viability of business models for photovoltaic solar generation in Brazil: studies of cases. Renew Energy Power Qual J. 2020;18:292-297.
25. ANEEL AN de EE. Acionada bandeira amarela para o mês de Abril 26/03/2021; 2021. https://www.aneel.gov.br/sala-de-imprensa-exibicao-2/-/asset_publisher/zXQREz8EVI26/content/acionada-bandeira-amarela-para-o-mes-de-abril/656877?inheritRedirect=false&redirect=https%3A%2F%2Fwww.aneel.gov.br%2Fsala-de-imprensa-exibicao-2%3Fp_p_id%3D3D101_INS
26. Carpio LGT. Model for the flexible commercialization of thermoelectric plants in Brazil. Energy Sour, Part B Econ Plann Policy. 2016;11:229-236. doi:10.1080/15567249.2011.606556
27. Rego EE, de Oliveira Ribeiro C, do Valle Costa OL, Ho LL. Thermoelectric dispatch: from utopian planning to reality. Energy Policy. 2017;106:266-277. doi:10.1016/j.enpol.2017.03.065
28. Leal FI, Rego EE, de Oliveira RC. Levelized cost analysis of thermoelectric generation in Brazil: a comparative economic and policy study with environmental implications. J Nat Gas Sci Eng. 2017;44:191-201. doi:10.1016/j.jngse.2017.04.017
29. do Nascimento FM, Mairesse Siluk JC, de Souza Savian F, Bisognin Garlet T, Renes Pinheiro J, Ramos C. Factors for measuring photovoltaic adoption from the perspective of operators. Sustainability. 2020;12:3184. doi:10.3390/su12083184
30. ANEEL. Revisão das regras aplicáveis à micro e minigeração distribuída - Resolução Normativa nº 482/2012; 2019:60.
31. Rigo PD, dos Santos JRG, de Freitas CV, Rabenschlag DR, Siluk JCM. Impacto da TUSD na viabilidade econômica de sistemas fotovoltaicos no Brasil. ENEGEP 2019, Santos; 2019.

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