INSTITUTE
OF ECONOMIC STUDIES
Faculty of Social Sciences
Charles University

IMPACT OF REGULATORY CHANGES ON ECONOMIC FEASIBILITY OF DISTRIBUTED GENERATION SOLAR UNITS

Gabriel Nasser Doile de Doyle
Paulo Rotella Junior
Luiz Célio Souza Rocha
Rogério Santana Peruchi
Karel Janda
Giancarlo Aquila

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Institute of Economic Studies,
Faculty of Social Sciences,
Charles University in Prague

[UK FSV – IES]

Opletalova 26
CZ-110 00, Prague
E-mail : ies@fsv.cuni.cz
http://ies.fsv.cuni.cz

Institut ekonomických studií
Fakulta sociálních věd
Univerzita Karlova v Praze

Opletalova 26
110 00 Praha 1

E-mail : ies@fsv.cuni.cz
http://ies.fsv.cuni.cz

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Impact of Regulatory Changes on Economic Feasibility of Distributed Generation Solar Units

Gabriel Nasser Doile de Doyle [1, 2]
Paulo Rotella Junior [3,5,6]
Luiz Célio Souza Rocha [4]
Priscila França Gonzaga Carneiro [1]
Rogério Santana Peruchi [3]
Karel Janda [5, 6]
Giancarlo Aquila [7]

[1]Renewable Energy Graduate Program, Federal University of Paraiba, Brazil
[2]Electric Engineer PhD Program, Federal University of Itajubá, Brazil
[3]Department of Production Engineering, Federal University of Paraiba, Brazil
[4]Department of Management, Federal Institute of Education, Science and Technology - North of Minas Gerais, Brazil
[5]Faculty of Finance and Accounting, Prague University of Economics and Business, Czech Republic
[6]Faculty of Social Sciences, Charles University, Czech Republic
[7]IEPG, Federal University of Itajubá, Brazil
Email (corresponding author): paulo.rotella@academico.ufpb.br

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Abstract:

The Brazilian National Electrical Agency (ANEEL) proposed in 2019 that the costs for accessing the electricity grid should be shared among all consumers. This would do away with cross-subsidies where normal consumers without installed solar distributed generation (DG) units effectively cover the costs of access to the grid for consumers with DG units. We compared the viability of two scenarios, one before and the other after the proposed changes, to understand how this legislature will affect the viability of DG projects in Brazil. We did this by studying all 5 regions covering the whole Brazilian area by analyzing data on average solar radiation, demand, and energy prices. We conducted stochastic analysis by varying the investment costs, demand, and energy prices, for DG solar plants. Lastly, we conducted scholastic analysis for the national scenario by varying the Discount Rate (DR). We confirmed that there is a statically significant reduction in economic viability for DG solar units in Brazil if the proposed legislation were to be enacted, while the payback period and other financial indicators differ across regions. We confirmed that solar radiation is not the only decisive factor in determination of economic viability of DG solar production.

JEL: Q41, Q48

Keywords: Distributed Generation, Regulation Policy, Cross-subsidies, Micro-Power Plants, Economic Feasibility Analysis, Solar Photovoltaic Energy

1. INTRODUCTION

Renewable Energy (RES) has been the focus of governments worldwide, in an effort to expand its share in energy production [1]. Governments worldwide have been pushing legislation to ease integration of solar power into the energy markets [2], however recent policy proposals of Brazilian government are running against the global trend of supporting the solar power [3].

Up until the late 2000s in Brazil, solar power units were mostly comprised of small installations in rural areas that did not have access to the main power grid lines, as it was not economically viable to expand coverage to these areas [4]. This was somehow changed by the two most important solar distributed generation Brazilian policies, 2012 and 2015 regulations REN 482 and REN 687.

The Brazilian regulatory agency on National Electrical Energy (ANEEL) which is responsible for drafting and passing legislation on electrical energy in Brazil passed a resolution (REN 482) in July 2012 that set out the guidelines for micro generation and mini generation in Brazil. Micro generations is defined as up to 75kW installed power, while mini generation is defined at 75kW-1MW installed power connected to the main grid. The resolution also established the conditions for compensation [5].

In November 2015 ANEEL published another regulation, REN nº 687, outlining benefits to micro and mini generators, and defining included joint and remote distributed generation systems, stating that generated energy can be shared among several consumer units, as long as they fall within the same concession area. Furthermore, energy credits were adjusted and the validity period was increased from 36 to 60 months [6]. Also, maximum generation power per unit increased from 1 MW to 5 MW and the process of connecting the DG unit to the distribution network was simplified [7].

Public Hearings [8] were also held to help ANEEL improve existing legislation. Two examples of these were Public Hearing No. 001/2019 and Public Hearing No. 025/2019 [8,9], which conducted Regulatory Impact Analysis (RIA) and allowed the public to suggest changes to a resolution that would be published in 2021.

The price of electricity is influenced by many factors, including transmission costs, and charges for electrical losses etc. These costs are fixed costs and are divided among all consumers. However, many consumers that have installed Distributed Generation systems (DG) were not paying these costs, per the regulations set out in REN no 482. This cost was therefore effectively paid for by other non-DG consumers [10].

For DG users, ANEEL therefore proposed that only energy costs should be compensated for. All ventures that have already been installed, or that have completed their installation requests up until the publication date of the new standard, will be allowed a transition period, and will continue with the subsidy under the standard until 2030. New entries will be subject to the new rule.

A natural policy question is to ask how much the proposed removal of a subsidy will affect the financial viability of solar DG conditional on regionally specific natural and economic conditions. We answered this question by using a before and after financial analysis. We took data on energy prices, demand, and solar incidence from all different regions in Brazil: the northeastern region, the southeastern region, the central western region and the north and south of Brazil. These five regions cover the whole area of Brazil. We varied demand, installation capacity, energy prices, and initial investments using Stochastic Analysis via Monte Carlo Simulations (MCS). Lastly, we conducted stochastic analysis on a national scale (Brazil) by changing the Discount Rate (DR), also know as Minimum Attractive Rate of Return.

The existing literature shows that microgeneration technologies have been more widely adopted because they save energy and are cheaper [11]. Users end up reducing their electricity costs and have positive Returns on their Investment (ROIs) [12]. Furthermore, micro generation units help prevent transmission blockages, replace capital intensive infrastructure, and reduce transmission losses [13]

In our analysis we contribute to the development of more accurate models of renewable energy assets and their prices with a focus on importance of particular market structure and institutional settings. We use standard financial analysis tools of Net Present Value (NPV), the Payback time (PB), and the Internal Rate of Return (IRR). These are all essential metrics for analyzing the economic viability of energy projects [14], and studies conducted and presented in the literature have exemplified these types of analyses [15–18].

We will complement them with Monte Carlo Simulations (MCS) as Arnold and Yildiz [19] who analyzed RES projects using MCS for energy derived from wood residue. Similarly, Tudisca et al. [20] studied solar energy installations in Sicily added to factories, and Cucchiella et al. [21] analyzed solar energy installation with battery storage units installed at residential buildings in Italy.

The rest of this article is organized in a following way: Section 2 presents the methods used in this study. Section 3 presents the results and a discussion of the results. Section 4 concludes this study.

2. MATERIALS AND METHOD

2.1 Proposed Changes to Regulation

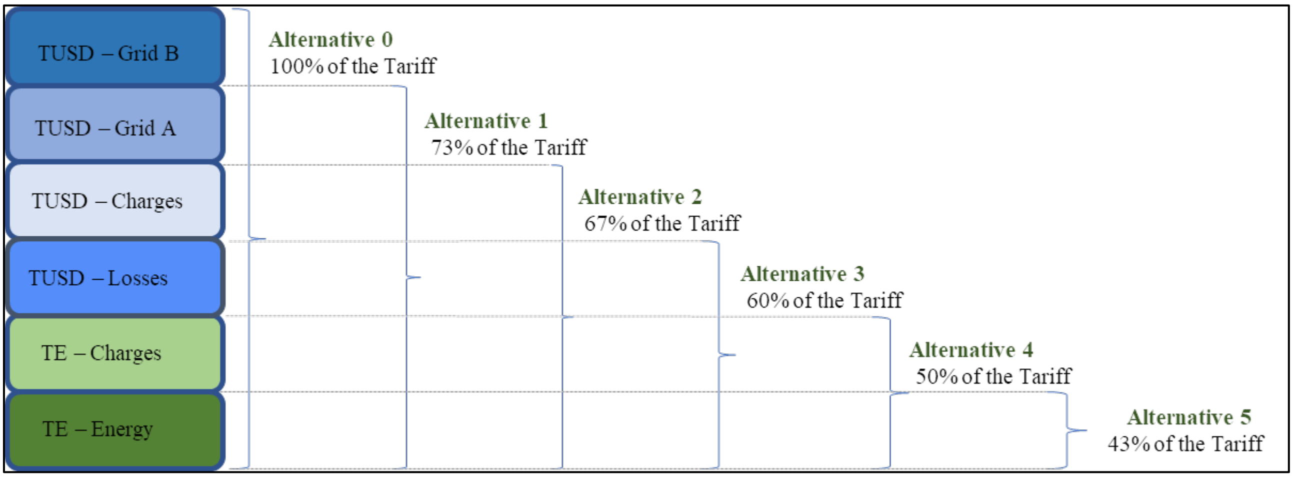
Resolution No. 482 was published in 2012, which allowed surplus energy generated by the prosumer (producer and consumer) units to be injected back into the distributor grid. Future consumption could be discounted from this surplus supply.

The current proposal for this mechanism in 2019, which was maintained in its original form after the revision of REN nº 482/2012 [5] by REN nº 687/2015 [7], stated that the excess energy will be used to reduce energy consumption considering its final retail price, which includes, in addition to generation costs, distribution costs and tariffs.

The main solar distributed generation policy discussion in Brazil is on how surplus energy should be re-injected back into the national grid. Energy concessionaires and consumers alike state that the current system for compensating for surplus energy injected back into the grid does not adequately account for the costs associated with maintaining the grid itself, and that these costs are, therefore, effectively passed on to normal consumers. In contrast, others believe that DG units help promote energy savings on a societal level and that the current model should stay in effect to help promote an introduction of even more DG units in the country. This was made clear from the proceedings contained in Public Hearing 025/2019 [9].

REN No. 482/2012 [5] sought to eliminate entry barriers for DG in Brazil and to modify the rules for connecting the DG units to the grid, in order to make these ventures more viable. However recently

ANEEL made a proposal, that can be seen in Figure 1 (Alternative 5), in which only 43% of the energy produced and surplus injected into the national grid will be compensated for.



TUSD – Grid A: distribution system usage tariff, unmanaged by the distribution company.
TUSD – Grid B: distribution system usage tariff, directly managed by the distribution company.
TUSD – Charges: it refers to electrical sector charges, not including fees and taxes.
TUSD – Losses: it refers to electric and not-electric losses.
TE: Electric energy tariff.

Figure 1. Alternatives proposed by Brazilian National Electricity Agency. Source: ANEEL [9].

2.2 Input Variables

Data on five inputs are necessary in this study – solar radiation, residential demand, installed power capacity, electricity consumption tariff and minimum acceptable return. Three of them vary by the region analyzed so they will be considered as input factors. These three are solar radiation, demand, and tariffs. The Discount Rate (DR) will be fixed, except for the stochastic analysis conducted for the whole of Brazil. Furthermore, the investment, the energy price, and the demand will be treated as stochastic variables. The DG unit's nominal power will vary according to demand and will be calculated for each simulation.

2.2.1 Solar Radiation

According to the National Brazilian Institute of Geography and Statistics (IBGE) [22], the national territory of Brazil is 8,515,767,049 Km^2 which makes it the fifth largest country in the world after Russia, Canada, US and China. With such vast land reserves, the RES will expand in Brazil into wind and solar energy [23]. Pereira et al. [24] show that daily total annual average solar radiation in Brazil makes it an excellent country for solar installations. This is shown in Figure 2.

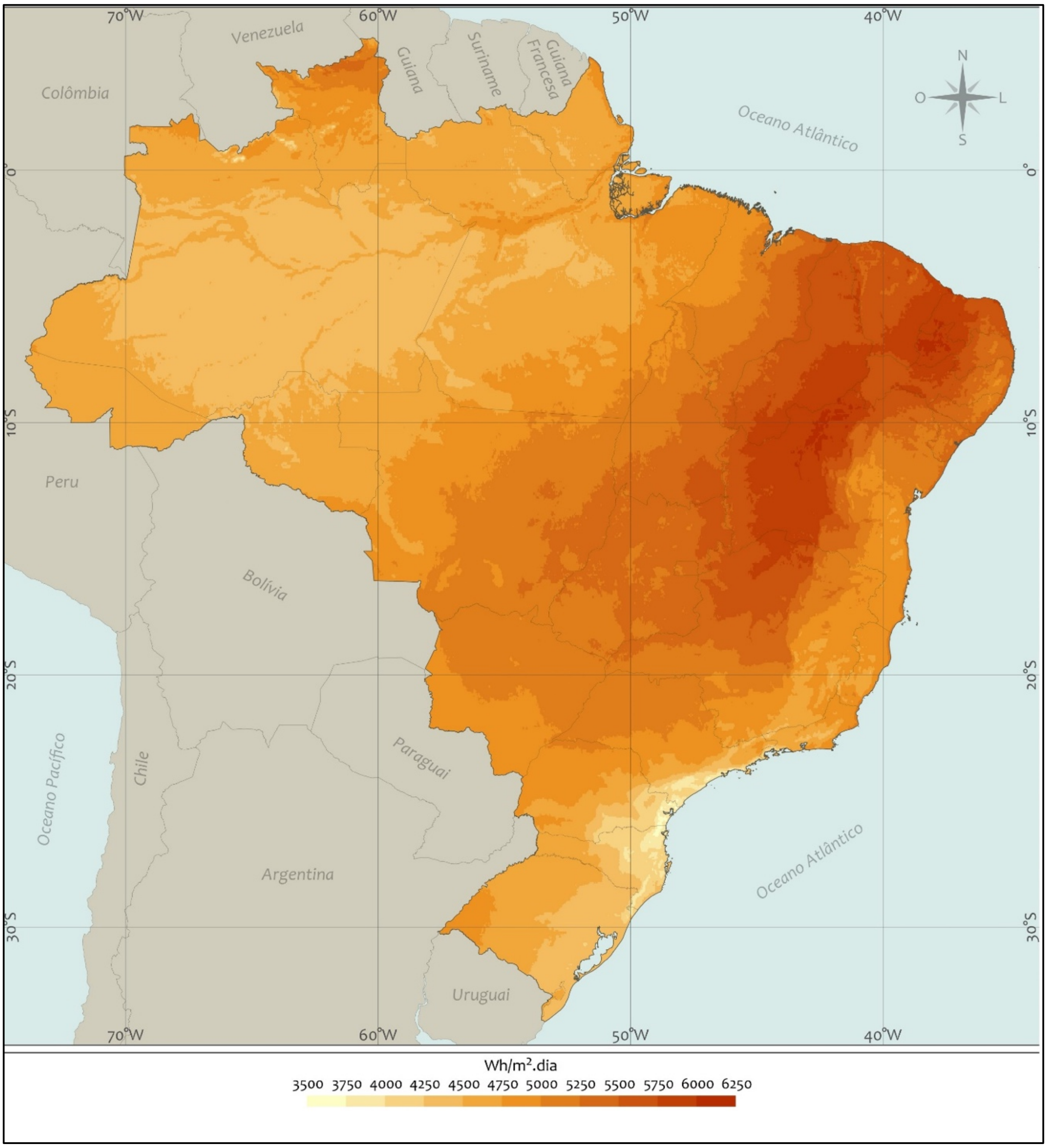


Figure 2. Annual average of daily total of global solar radiation. Source: Pereira et al. [24].

Pereira et al. [24] conclude that, even though climatic conditions vary in Brazil, solar radiation is nonetheless quite uniform. Maximum Brazilian solar radiation is 6,5 kWh/m² per day. This occurs in the northern part of Bahia state in the east of Brazil, close to the border with the Piauí state. This area has a semi-arid climate with low rainfall throughout the year (approximately 300 mm/year), and the lowest annual average cloud cover. This area belongs to North-Eastern region, according to division used in the analytical part of this article. The lowest global solar radiation is 4,25 kWh/m² per day and, occurs on the north shore of Santa Catarina state in the south of Brazil where precipitation is well distributed throughout the year. This area belongs to Southern region, in the terminology of our article. The annual mean of daily horizontal global solar radiation in any region of the Brazil (1500-2500 kWh/m2) is much greater than the most European countries, like Germany (900-1250 kWh/m2), France (900-1650kWh/m2), and Spain (1200-1850 kWh/m2) where projects to harness solar resources are already widely implemented, with many government incentives. In this study, the average radiation for each analyzed region was used, as shown in Tables 1 and 3 in the next section.

2.2.2 Residential Electricity Demand

Demand should be based on monthly electricity consumption levels for middle income families, according to Silva et al. [25], and these values can be extended to small businesses or industrial applications. According to residential demand disclosed by [26], in the following section, Tables 1 and 3 show the values that we adopted. A linear 0,5% growth rate was taken for all scenarios.

2.2.3 Installed Power Capacity

Dias et al. [27] state that mono and polycrystalline silicon solar panels perform the best. We considered the CS6P model (Canadian Solar Inc.) with 250 W of nominal power, and an area of 1.6 m², and efficiency of 15.85%. We adopted a lifetime of 30 years for the project, with 0.7% annual energy efficiency losses.

The local average solar radiation, and average consumer demand [26] must be known to accurately determine the power levels of a DG solar unit. Nominal power levels must be equal to the average energy demands. The optimal power levels for DG solar units are calculated to meet all energy demands with minimum energy residues. First the minimum required area must be determined, as shown in Equation 1.

$$A_T = \frac{D_m}{R_m \times \varepsilon} \tag{1}$$

Where: A_T represents the total area covered by the solar PV panels (in m²); R_m represents the average annual value of radiation (in kWh/m²); D_m represents the average annual demand (in kWh); ε is the efficiency value of the PV panels.

Then, the nominal power (P_n) of the DG solar unit will be calculated for each simulation. P_n (in kilowatts) is determined by Equation (2).

$$P_n = \frac{A_T}{1.6} \times 250, \tag{2}$$

where 250 W is the nominal electricity power and 1.6 m^2 is the area of each panel.

2.2.4 Electricity Consumption Tariff

In Brazil, ANEEL is responsible for setting and regulating all energy prices within the country. These costs are determined by taking the energy prices, the distribution and transmission costs, and the taxes charged for the sector in account. We adopted the values shown in Table 1 and 3, in the next section, according to data obtained from [28].

2.2.5 Discount Rate (DR)

DR is the Minimum Attractive Rate of Return or the Interest Rate that will satisfy an investor. The discount rate could varies primarily with opportunity cost, liquidity, and business risk [29]. When investors invest a sum of capital, they always expect to obtain returns on the capital greater than the DR, for the project life span [30]. In this study, we assumed that the investment was made by an individual. Therefore, the DR value recommended by EPE [31] for individual investments in energy was used, that is, 8% per year. We performed the stochastic analysis via MCS with the Crystal Ball® tool by varying the DR. These percentages correspond to the minimum obtainable returns from savings accounts in Brazil, and potential maximum returns from high-risk investments, respectively.

2.3 Initial investment costs

We consulted 5 regional retailers and we considered 51 types of DG solar units from different manufactures to determine the initial investment cost of the unit. We estimated the costs of USD$1,221.10 per kW installed for each installed solar panel. The costs of frequency inverters were estimated at USD$654.38 per kW, which is about 50% of the cost of the Solar DG unit.

The installation costs were also calculated in accordance with the ANEEL's Homologatory Resolution No. 758/2009 [32]. We consider the labor costs for installation, which correspond to approximately 25% of the investment cost.

There are maintenance and operation costs (O&M) that must also be considered. For example, the Inverters must be replaced every 15 years, and the Surge Protector Device (SPD) must be replaced every 5 years. Using NPV calculations over a 30-year project lifespan, we saw that these costs correspond to about 1% of the initial investment, per year.

2.4. Economic variables

Economic viability analysis is conducted to determine if a venture will be viable or not, and thus whether one should invest in the venture or not [33]. We used deterministic parameters to estimate the viability of the project by considering the fixed inputs, which are solar radiation, demand, energy prices, the DR, and the nominal power levels, to calculate the IRR, NPV, and Discounted Payback (DPB) values. We then conducted stochastic analysis by varying the nominal power

Of all the possible methods for determining the financial viability of a given project, Li et al. [34] state that the NPV method is the best. The NPV method calculates future cash flows by deducting expenses from revenue, which is then discounted using a fixed rate. The NPV formula is shown in Equation 3 [14,35,36].

$$NPV = -C_0 + \sum_{j=1}^{n} \frac{C_n}{(1+r)^n} \tag{3}$$

Where C_0 is the initial investment; Cn represents the cash flow in period n; n is the duration of the project in years; r is the discount rate (DR).

An NPV=0 is the minimum feasibility scenario, in which the investor will fully recover the invested capital, given a DR [19]. A negative NPV indicates that the investment is not able to offset opportunity costs, while a positive NPV indicates that the investment is viable with an IRR greater than the DR [37].

According to Rodrigues et al. [16], the IRR is found when NPV=0, as shown in Equation 4 [38], and this rate should be compared to interest rates. A high IRR indicates that the investment will likely be lucrative, while an IRR<DR indicates that an investment is not viable.

$$\sum \frac{C_n}{(1+IRR)^n} = C_0 \tag{4}$$

The payback period is another important metric when analyzing investments, according to Tao and Finenko [17]. The payback period is the time it takes to recoup the initial investment, or the time when cumulative cashflows go positive. We used the DPB in this study, i.e. cash flows as NPV compared to the initial investment. In this case the DPB will be the year when the sum of cashflows in the initial year is equal to, or greater than, the initial investment. In this criterion, the purpose is to obtain a shorter return period.

3. Results and discussion

Cash flows are determined by many factors, including investment, operational and maintenance cost, life-span, the payback period, inflation rates, the DR, the non-returnable subsidy rate, interest rates for loans, the sale price of electricity, income tax rates, and whether additional revenue generated by carbon credits is included or not [32].

We used five cases for the cash flow analysis in this study, one for each region, according to existing legislation in 2019. Legislation at the time stated that 100% of re-injected energy could be compensated for i.e., a 1:1 surplus to consumption ratio. These results are shown in Table 1.

Table 1 – Results before the propose changes

Region	**Average Demand – AD (kWh)**	**Electricity Tariff - ET (US$)**	**Average Solar Radiation – AR (kWh/m²)**	**IRR**	**NPV (US$)**	**DPB (years)**
North-Eastern (NE)	112.69	0.18	5.9	18.03%	2,189.27	9.88
South-Eastern (SE)	175.35	0.18	5.6	18.33%	3,728.38	8.83
Central-Western (CW)	171.36	0.18	5.7	23.00%	4,125.97	6.72
Northern (N)	167.15	0.21	5.5	25.75%	4,745.83	5.59
Southern (S)	176.93	0.17	5.2	16.92%	3,271.79	9.87

Brazil (BR)	158.61	0.18	5.58	20.78%	3,598.21	7.79

With changes to the system, only 43% of surplus will be compensated for in consumption. To perform this calculation, we must first determine how much energy is generated and consumed by the user before re-injecting surplus energy into the national grid.

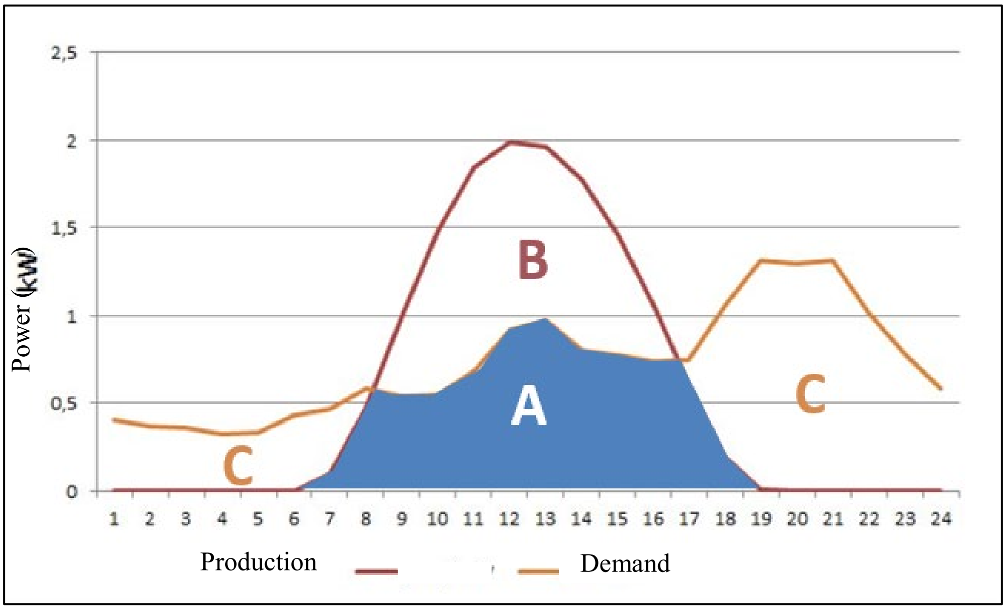


Figure 3. Brazilian average curves of generation and consumption (in days). Source: ANEEL [9].

We calculated the annual average of produced and consumed energy based on ANEEL [10] (area A in Figure 3). We conducted economic analysis using the 43% rule (area B in Figure 3). The sum of both C areas corresponds to consumption that can be offset by re-injections, according to REN 482/2012 [5]. The Cost of Availability (CA) is the minimum cost the prosumer must pay to be connected to the grid. This was 30 kWh per month. The three scenarios study the effect of then presence and absence of the 43% rule, and are shown in Table 2. In this, B and C are the areas represented in Figure 3, and CR the energy credits from previous periods (center hypothesis).

Table 2. Hypothesis without and with reduction to 43% proposed by ANEEL

Hypothese	**Without reduction**	**With reduction to 43% proposed**
$B = C - CA$	Only the Cost of Availability (CA) tariff will be paid by the prosumer;	The prosumer will pay $0.57 \times (C - CA) + CA$

$B > C - CA$	Only CA will be paid by the prosumer, which will receive credits equal to the difference of $B - (C - CA)$ for each kWh;	The prosumer will pay $0.57 \times (C - CA) + CA$ and will receive 43% credits equal to the difference of $B - (C - CA)$ for each kWh in the future.
$B < C - CA$	The prosumer will pay $CA + (C - CA - B - CR)$;	The prosumer will pay $CA + (C - CA - 0.43 \times B - 0.43 \times CR)$

The integrated area of Section A is 42.86% for the demanded energy, and 54.33% for the generated energy. Section C is 57.14% for the demanded energy, and Section B is 45.67% of total electricity generation from the DG solar unit. The results shown that 36.03% of the demanded energy is offset by the generated energy surplus and 21.11% of the energy is consumed from the national grid. The results are presented in Table 3.

Table 3 - Results after implementing the proposed changes to legislation.

Region	**AD (kWh)**	**ET (US$)**	**AR (kWh/m²)**	**IRR**	**NPV (US$)**	**DPB (years)**
North-Eastern (NE)	112.69	0.18	5.9	12.97%	1,184.27	16.95
South-Eastern (SE)	175.35	0.18	5.6	13.49%	2,136.23	13.94
Central-Western (CW)	171.36	0.18	5.7	16.67%	2,558.97	10.90
Northern (N)	167.15	0.21	5.5	18.45%	3,020.19	8.83
Southern (S)	176.93	0.17	5.2	12.48%	1,796.78	17.96
Brazil (BR)	158.61	0.18	5.58	15.20%	2,168.31	11.91

While the comparisons of before and after policy change situation in Tables 1 and 3 provides already a first indication of the considered ANEEL policies, we provide additional insights through following stochastic analysis. Our MCS was performed using the Crystal Ball® tool, considering the parameters shown in Table 4. A probabilistic model is built in this approach, where one or more parameters where one or more parameters assume values within a probability density function (PDF). The Probability Density Function (PDF) is an essential step in MCS with random variables [19,39]. This is given in Equation 5.

$$P_{NPV>0}(x_n) = \int_{-\infty}^{+\infty} pdf(NPV)dNPV \tag{5}$$

Where P_{NPV} characterizes the accumulated probability of NPVs, pdf (NPV) is the probability density function of the project NPVs, and x_n is a vector associated with random variables of the project.

Table 4 - Probability distribution and definition of parameters for input variables

Parameters	**Distributions**	**Regions**	**Minimum Value**	**Maximum Value**	**More Probable**
Investment (US$)	Triangular	All	707.72	2,416.65	1,221.65
Energy Tariff (US$/kWh)	Triangular	NE	0.185	0.253	0.185
		SE	0.173	0.221	0.196
		CW	0.167	0.202	0.185
		N	0.152	0.307	0.192
		S	0.113	0.221	0.173
		BR	0.113	0.307	0.186
Electrical Demand (kWh)	Triangular	NE	73.13	132.81	106.75
		SE	103.75	215.06	163.68
		CW	120.73	213.54	168.66
		N	119.04	298.15	194.01
		S	118.59	282.62	173.24
		BR	73.13	298.15	163.85

Table 5 presents the stochastic results of the simulations. This table presents the results for the probability of viability for each of the five regions under analysis for the before and after (proposed regulatory changes) scenarios: NE, SE, CW, N, S, and BR.

In summary, the table shows the probability values for obtaining a NPV > 0, where we can see scenarios with high probabilities for economic feasibility.

Table 5 – Probability of viability by region, before and after the proposed regulatory changes.

P (NPV) > 0	**NE**	**SE**	**CW**	**N**	**S**	**BR**
Before	99.94%	100%	100%	100%	99.80%	99.88%
After	95.48%	99.66%	99.80%	99.90%	93.20%	97.12%

To better understand the results for each region, we have presented Figures 4 to 9. These Figures show the results for each scenario, before and after the proposed changes, and the histogram and cumulative distribution function (CDF) are also presented, resulting from the simulations. The before scenario is shown in red, and the after scenario is shown in blue. For example, for the NE region in the before scenarios (Figure 4), the cumulative probability for NPV less than 0 is 0.06%, so P (NPV> 0) =

99.94%. However, for the after scenario, the cumulative probability for NPV less than 0 is 4.52%, so P (NPV> 0) = 95.48%.

The two **y** axis show the frequency and cumulative probability, respectively, while the **x** axis shows the NPV value. The same interpretation of results can be performed for the SE (Figure 5), CW (Figure 6), N (Figure 7), S (Figure 8) regions and the Brazilian case (Figure 9).

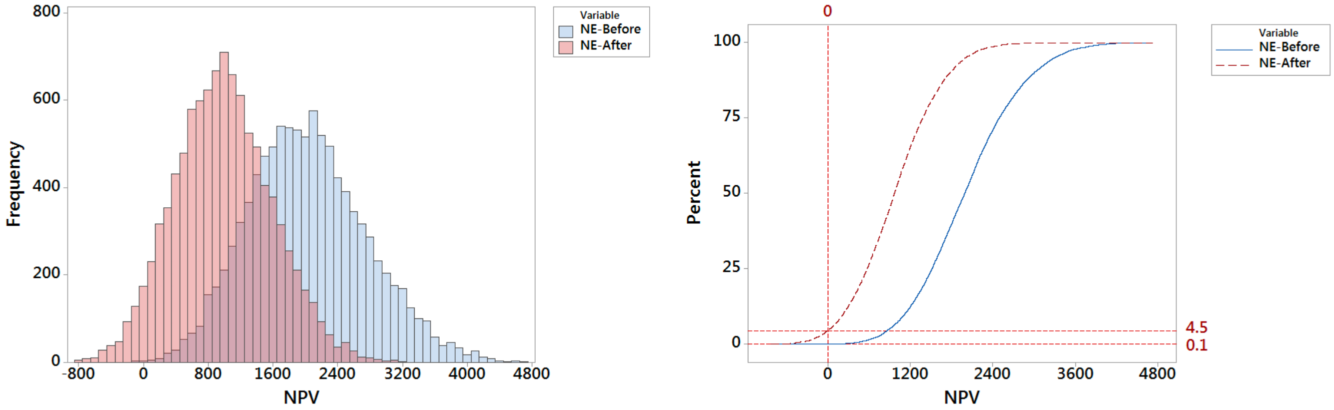


Figure 4. Probabilities of economic feasibility for the NE region.

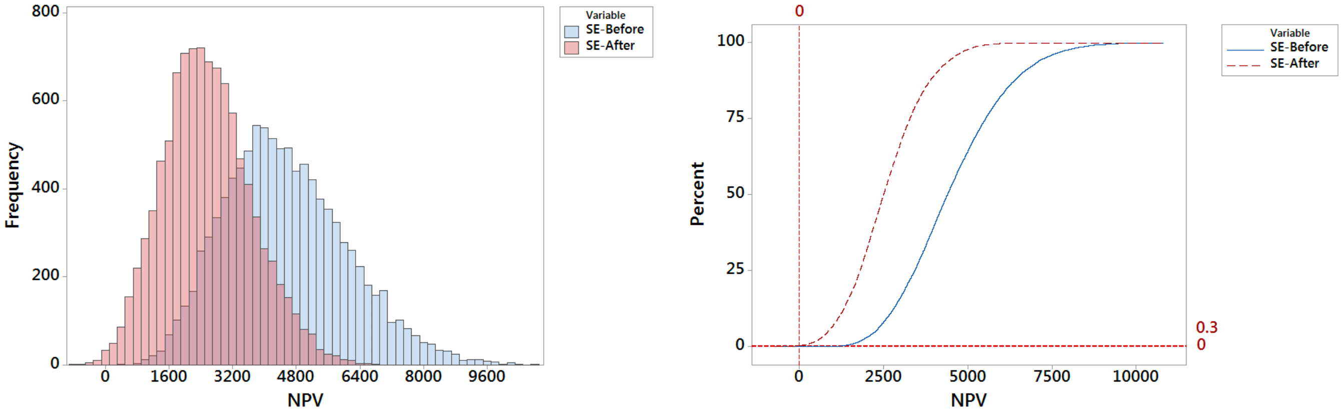


Figure 5. Probabilities of economic feasibility for the SE region.

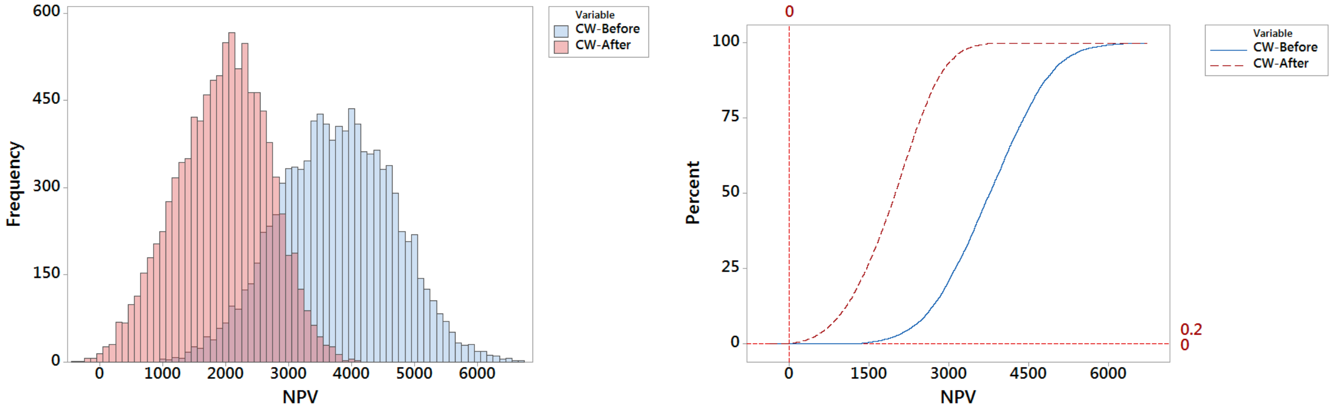


Figure 6. Probabilities of economic feasibility for the CW region.

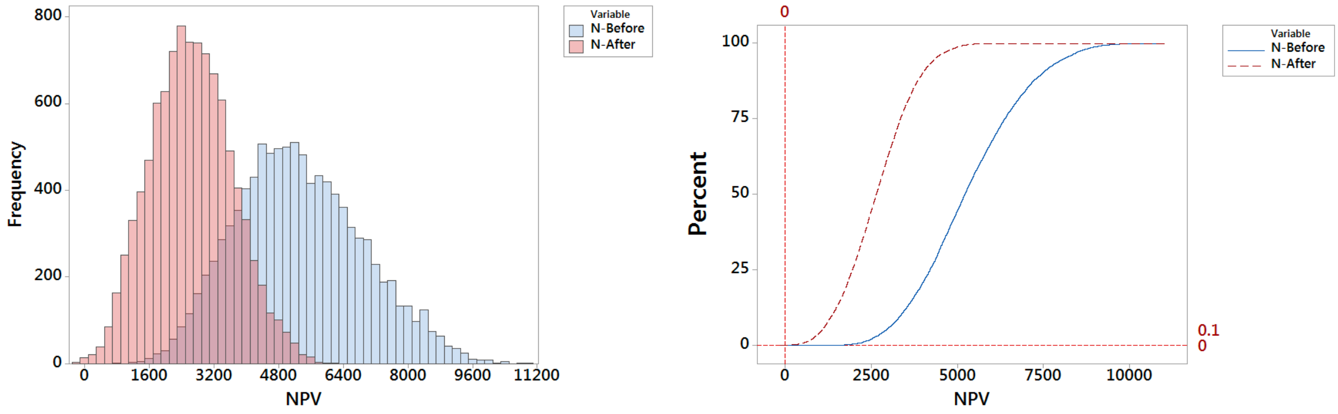


Figure 7. Probabilities of economic feasibility for the N region.

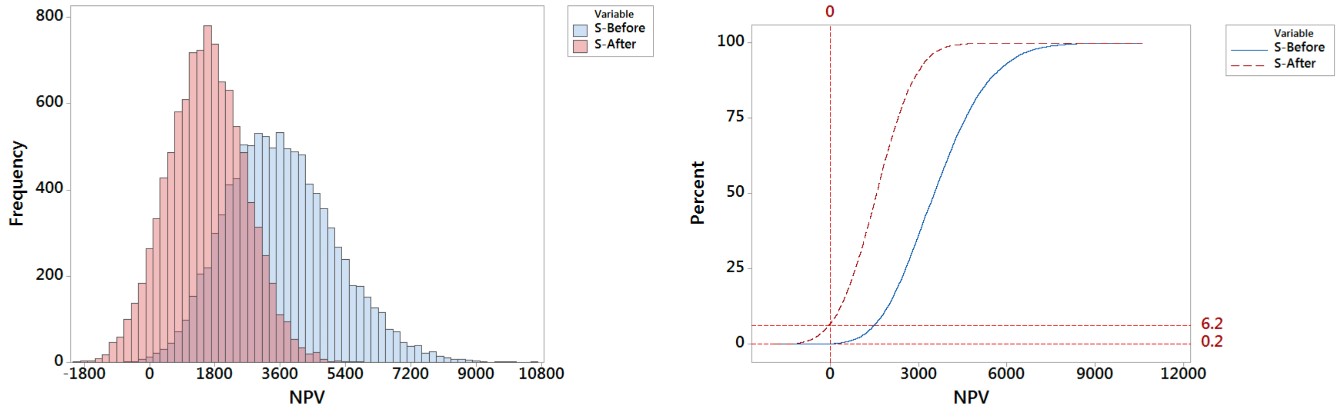


Figure 8. Probabilities of economic feasibility for the S region.

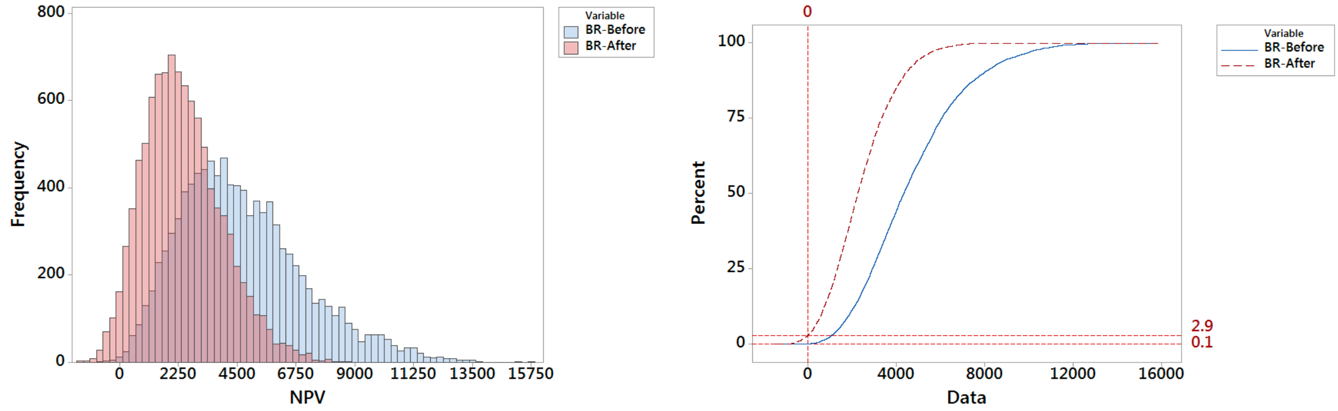


Figure 9. Probabilities of economic feasibility for the BR scenarios.

Furthermore, the results of the simulations for the NPV values were collected in all regions studied. Thus, the ANOVA (Analysis of Variance) test was performed, to identify if there are statistical differences between the average NPV values for the scenarios before and after the proposed change. The results are shown in Table 6, and the values obtained in these analyses for the statistical tests have p-values of 0.000. These results confirm that there are statistical differences between the analyzed average

NPVs for each scenario. Table 5 also shows the number of simulations (N), the NPV averages before and after, and the p-values for each region.

Table 6 - Results of the ANOVA test per region and scenario (before and after)

Region	N	Mean (Before)	Mean (After)	P-value *
NE	10,000	2,030.80	990.30	**0.000**
SE	10,000	4,537.15	2,573.63	**0.000**
CW	10,000	3,764.43	1,951.78	**0.000**
N	10,000	5,320.95	2,660.23	**0.000**
S	10,000	3,633.10	1,581.18	**0.000**
BR	10,000	4,685.18	2,429.68	**0.000**

* Values in bold show statistical significance.

The generated NPV distributions are shown in Figure 10, using boxplots. It is clear that the returns in the scenarios before the proposed regulatory changes are higher in average and variance. Additionally, we can see that there is a difference in the NPV average values for the regions under study.

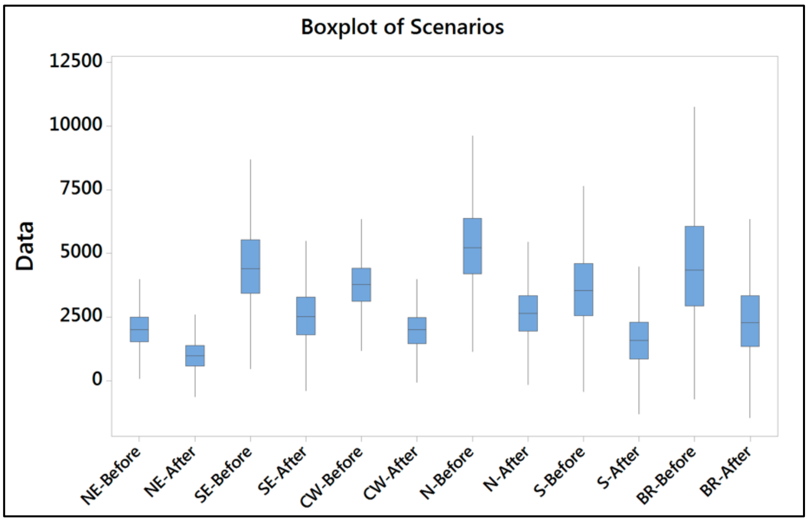


Figure 10 – Boxplots for NPV returns in the studied scenarios.

A first look at our data both before and after treatment (policy change) indicates that there exists a continuum of quite different distributed solar generation viabilities from the most favorable Northern region to the least favorable North-Eastern and Southern Regions. In order to evaluate if the individual regions are (pairwise) different, we applied Levene's test using these same simulation results for the NPV. This test allows to analyze if there is a statistically significant difference between the variances of the scenarios after the proposed changes. The variation comparison allows us to analyze the return dispersion for electricity consumers who invest in photovoltaic micro-generation in different regions. The results listed in Table 7 show that the difference in return variance is statistically significant among the regions. Furthermore, Table 7 shows the standard deviation values for each of the regions. This provides us with an indication of financial risk of distributed solar generation investment in particular Brazilian regions.

Table 7 - Results of Levene's test between the analyzed regions after the proposed regulatory changes.

Regions	St dev 1st region	St dev 2nd region	P-value
NE x SE	601.68	1,108.86	**0.000**
NE x CW	601.68	725.70	**0.000**
NE x N	601.68	1,006.06	**0.000**
NE x S	601.68	1,062.21	**0.000**
SE x CW	1,108.86	725.70	**0.000**
SE x N	1,108.86	1,006.06	**0.000**
SE x S	1,108.86	1,062.21	**0.000**
CW x N	725.70	1,006.06	**0.000**
CW x S	725.70	1,062.21	**0.000**
N x S	1,006.06	1,062.21	**0.000**

A stochastic analysis was conducted by varying the DR for the Brazil (BR) analysis, which considers the solar radiation, price, and demand in the whole country. For the BR case, and in addition to the stochastic variables presented in Table 4, we varied the DR from 6.5% to 20%. We used triangular distribution for the minimum, medium, and maximum values, which were 6.5%, 8% and 20%, respectively.

The histogram and Cumulative Distribution Function (CDD) are presented for the NPV analysis in Figure 11. The result was a 79.60% positive probability, translating to an economically viable project.

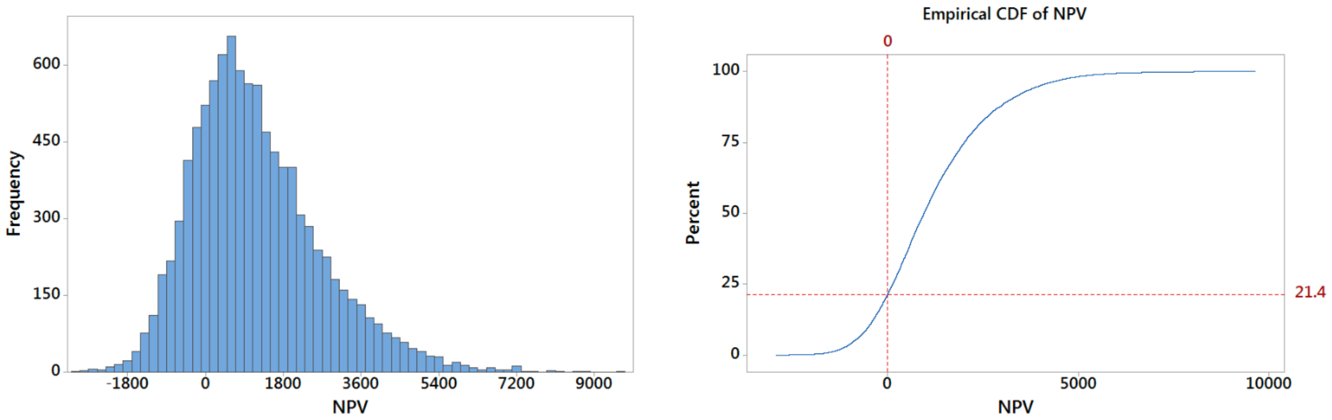


Figure 11 – Probability of economic feasibility by varying the DR for the BR (Brazil) case.

Holdermann et al. [40] examined the economic viability of small-scale, grid-connected photovoltaic units installed at residential and commercial locations in Brazil. Rocha et al. [33], analyzed the impact of tax exemptions from the circulation of goods and services tax, and the returns and risks from photovoltaic microgeneration project in different regions in Brazil.

Both studies found that the probability of viability of investments in photovoltaic micro-generation was lower. This was explained by the fact that equipment is more efficient, more durable, and cheaper, showing evidence of how technology has evolved in recent years. There has been an increase in energy prices in Brazil from 2014 to the present, making this technology more viable. Despite these positive points, the Brazilian photovoltaic industry has not progressed adequately and is still dependent on imported equipment, exposing investors to exchange rate related risk. Brazil does not have significant internal photovoltaic technology production, although it has large silicon reserves[41].

4. Conclusions

Residential DG solar units are clearly viable according to the deterministic NPV and IRR results, but other indicators should be considered, like the DPB value. Before the 43% rule takes effect, DPB is around 8 years. After the 43% rule takes effect, the DPB time is 12 years. This 12-year DPB time is still less then 15 years limit when the inverters need to be replaced.

Once again, we found a high probability of viability in the stochastic feasibility analysis, for both the before and after scenarios. Two additional statistical tests were carried out to prove that there are statistically significant differences for the NPV results. First, the ANOVA test, showed evidence that there is a significant difference between the average NPV results between the before and after scenarios for each region. The Levene test, showed that there are significant differences between the regions for scenarios after the proposed changes had been implemented.

If the 43% rule is approved DG solar units will ultimately be less financially attractive for residential and commercial use. The investments are viable; however, the excess profit was taken away and the return period is pushed back when analyzed by the DPB. This may discourage investors seeking a faster return on their investment.

The proposal of the 43% rule from ANEEL is understandable, in so far as it seeks to share the cost of the national grid among all consumers. Nonetheless, Brazil should consider other subsidies, as other countries have done, to help promote the development of RES in Brazil.

The results indicate that the northern region of Brazil is the best for installing DG solar units, despite having together with southern region the lowest average solar radiation. This was because there is high demand for energy in this part of the country, and because energy prices are quite high. The north-eastern region was the least economically viable region because there is low demand and energy prices are low, even though solar radiation is effectively higher. Still, the Northeast region had the smallest standard deviation for NPV. This means that the financial results for this region had the least oscillation and, therefore, the lowest investment risk for photovoltaic microgeneration. Our results clearly show that while solar radiation is an important factor, it is not the only factor determining economics viability of DG solar unit.

Varying the DR shows that 79.60% of all cases have positive NPVs. This prices out investors who are extremely conservative and who seek very high IRRs.

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Univerzita Karlova v Praze, Fakulta sociálních věd
Institut ekonomických studií [UK FSV – IES] Praha 1, Opletalova 26
E-mail : ies@fsv.cuni.cz http://ies.fsv.cuni.cz