FEDERAL UNIVERSITY OF ITAJUBÁ
GRADUATE PROGRAM IN
ELECTRICAL ENGINEERING

Evaluating Public Policies for Fair Social Tariff of Electricity in Brazil using an Economic Market Model

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Itajubá, December of 2020

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Doctoral thesis submitted to the Graduate Program in Electrical Engineering as part of the requirements for obtaining the title of Doctor of Science in Electrical Engineering.

Concentration Area: Electrical Power Systems

Advisor: PhD. Benedito Donizeti Bonatto
Co-advisor: Dr. Hector Arango (in memoria)

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Abstract

Using an economic model of the electricity market (TAROT - Optimized Tariff) that represents the regulated market of distribution of electrical energy, this theses presents an evaluation of public policies for fare social tariffs of electricity in Brazil. It was considered the scenario of increasing number of prosumers (residential consumers who have self generation of electricity) in 2 of the 5 major regions of Brazil. The Brazilian regions have very different socioeconomic characteristics. However, the current electricity regulation is the same for all concessionaires. Because of the ineffectiveness of the existing tariff policy discount, in this work a new public policy is proposed, allowing the use of regulation in a different way in order to obtain the best result for Brazil and particularly for the poor population that today are not able to enjoy the benefits of electricity due to high tariff values. It is also discussed how this can contribute in a positive way to improve the income distribution in these regions, which is evaluated by using the Gini index.

Key-words: Economic model of the electricity market, Electric sector regulation, Social tariff of electric energy, Gini index, Distributed generation.

List of Figures

List of Tables

Lista de abreviaturas e siglas

ANEEL *National Electric Energy Agency*

ECA *Economic Value Added to Consumers*

EVA(R) *Economic Value Added to the Company (EVA is a registered trademark of Stern Stewart)*

EWA *Economic Value Added to Society*

TSEE *Electricity Social Tariff*

CDE *Energy Development Account*

TAROT *Optimized Tariff*

GD *Distributed generation*

RPT *Periodic Tariff Review*

PRORET *Tariff Regulation Procedure*

CCEE *Electricity Chamber of Commercialization*

Contents

1 Introduction

1.1 Motivation

Electricity has become a fundamental resource for the development of a nation and has a great influence on the well-being of its population. According to [EPE, 2020] in 2017, more than 22,000 TWh of energy were consumed in the world, as can be seen in Figure 1, which shows that North America is responsible for 21% energy consumption while South and Central America together consume about 5.2%.

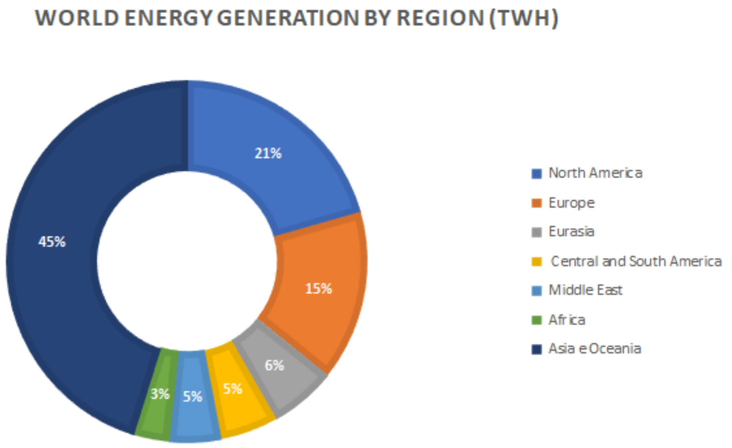


Figure 1 – World energy generation in 2017. [EPE, 2020]

Brazil is among the 10 largest generators and consumers of electricity in the world [EPE, 2020]. Some studies show that there is a relationship between energy consumption and the Gross Domestic Product (GDP), and in [CAMPO; SARMIENTO, 2013] it can be seen how these quantities are related in some countries. In the case of Brazil, in Figure 2 it is possible to observe the behavior of the GDP compared with the growth of energy consumption [CAMPO; SARMIENTO, 2013] and also its behavior when one or the other varies.

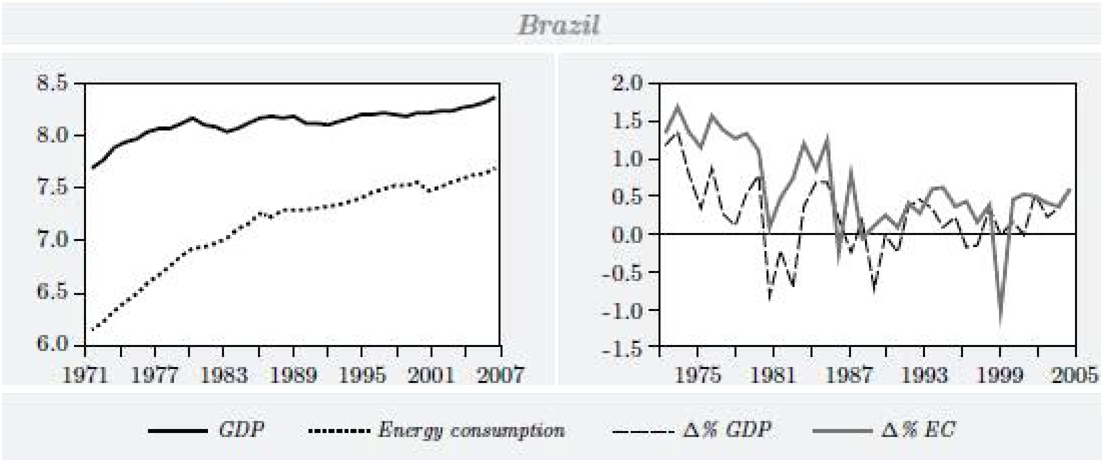


Figure 2 – Evolution of consumption of energy sources and GDP in Brazil. [CAMPO; SARMIENTO, 2013]

Brazil's GDP in 2019 was approximately R$ 7.3 trillion and each region of Brazil contributed differently to this figure. The region that contributes the most is the Southeast and the one that contributes the least is the North. In general, regions with high per capita GDP are more developed and have the population with the best quality of life. Unfortunately, social inequality in Brazil is still large, as shown in Figure 3. The study carried out in [Correia-Silva, David Costa and Rodrigues, Marcos, 2015] showed that, although the most developed regions consume more energy, this does not mean that they are more efficient in improving the region's social welfare.

When thinking about the distribution of energy in the country, it is seen that all regions are treated in the same way, without considering their socioeconomic particularities. The concession areas, as far as it is known, were defined without prior study. And so, when the techniques for calculating energy tariffs were defined, social differences between the regions of the country were neglected. Table 1-1 shows that energy tariffs do not differ much in terms of value for each region of Brazil, even though there is a huge economic and social difference between them illustrated in Table 1 and Figure 4.

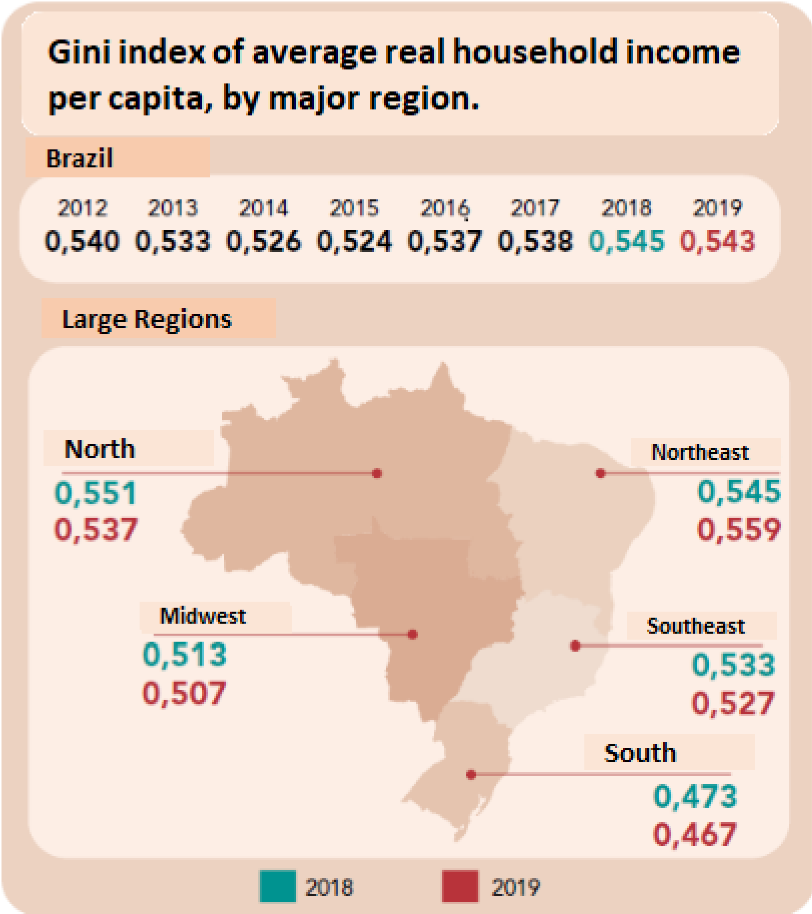


Figure 3 – GINI index variation in Brazil. [IBGE Social Statistics, 2020]

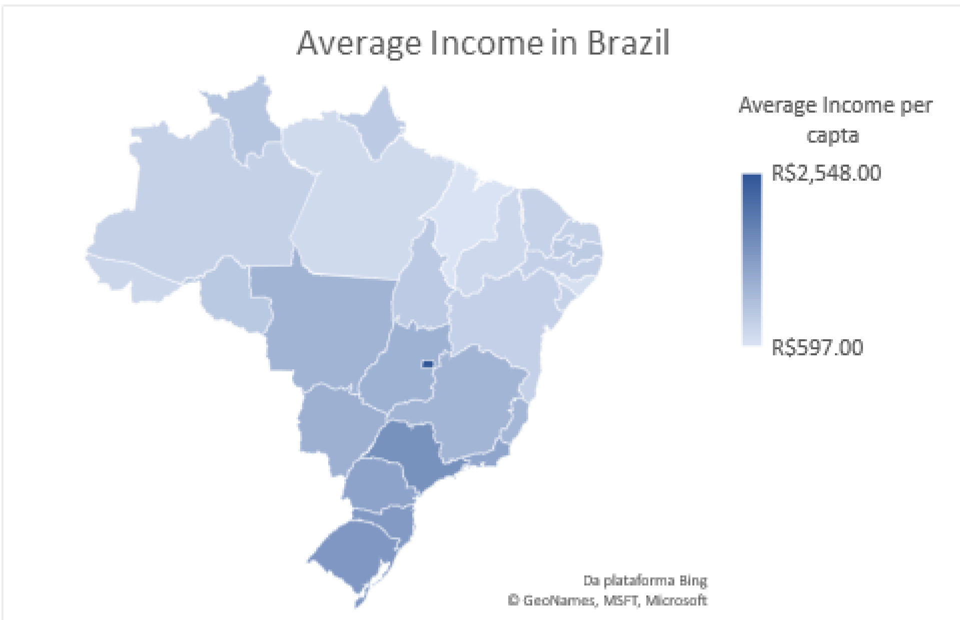


Figure 4 – Monthly per capita income of the population in 2019. [IBGE Social Statistics, 2020]

Table 1 – Average tariff and average income by region in 2017. [ANEEL, 2016; IBGE, 2017]

Region	State	Average income per capta	Average tariff [R$/MWh]
NORTH	Rondônia	R$ 957.00	R$ 628,79
	Acre	R$ 769.00	
	Amazonas	R$ 850.00	
	Roraima	R$ 1,006.00	
	Pará	R$ 715.00	
	Amapá	R$ 936.00	
	Tocantins	R$ 937.00	
NORTHEAST	Maranhão	R$ 597.00	R$ 546,82
	Piauí	R$ 750.00	
	Ceará	R$ 824.00	
	Rio Grande do Norte	R$ 845.00	
	Paraíba	R$ 928.00	
	Pernambuco	R$ 852.00	
	Alagoas	R$ 658.00	
	Sergipe	R$ 834.00	
	Bahia	R$ 862.00	
SOUTHEAST	Minas gerais	R$ 1,224.00	R$ 593,51
	Espírito Santo	R$ 1,205.00	
	Rio de Janeiro	R$ 1,445.00	
	São Paulo	R$ 1,712.00	
SOUTH	Paraná	R$ 1,472.00	R$ 579,06
	Santa Catarina	R$ 1,597.00	
	Rio Grande do Sul	R$ 1,635.00	
MIDWEST	Mato Grosso do Sul	R$ 1,291.00	R$ 599,23
	Mato Grosso	R$ 1,247.00	
	Goiás	R$ 1,277.00	
	Distrito Federal	R$ 2,548.00	
BRASIL	-	R$ 1,268.00	R$ 584,61

Therefore, the possibility of encouraging the creation of public policies [WINARNO; ALWENDRA; MUJIYANTO, 2016], [MARQUES; BRITO, 2017], [DAHAL; NADARAJAH, 2015] aims the maximization of social well-being considering the reduction of social inequality is envisaged.Tariff mechanisms already exist in Brazil to try to reduce the social difference that affects purchasing power and consequently the consumption of electricity. The Government has imposed measures so that all classes of the population have access to energy. There are some programs like: Luz para todos, Energy Development Account (CDE) and Electricity Social Tariff (TSEE), besides programs aimed at rural electrification. In order to promote renewable energies, incentives were created, such as PROINFA, which is a subsidy for renewable energies. Figure 33 shows the trend of tariff increases in the period of 2011–2020. By increasing the common residential electricity tariffs, the TSEE has also increased and this has led to even more socioeconomic discrepancy among these consumers. Table 2 presents the socioeconomics characteristics of the five geographical regions in Brazil, with their GINI index. The difference between regions is clear when data on average income and average energy tariff are analyzed. Although the tariff value is close, the impact on average income in each of these regions is quite different. The average income in the southern is almost double the average income in the northeastern. GINI index also makes clear the difference between regions.

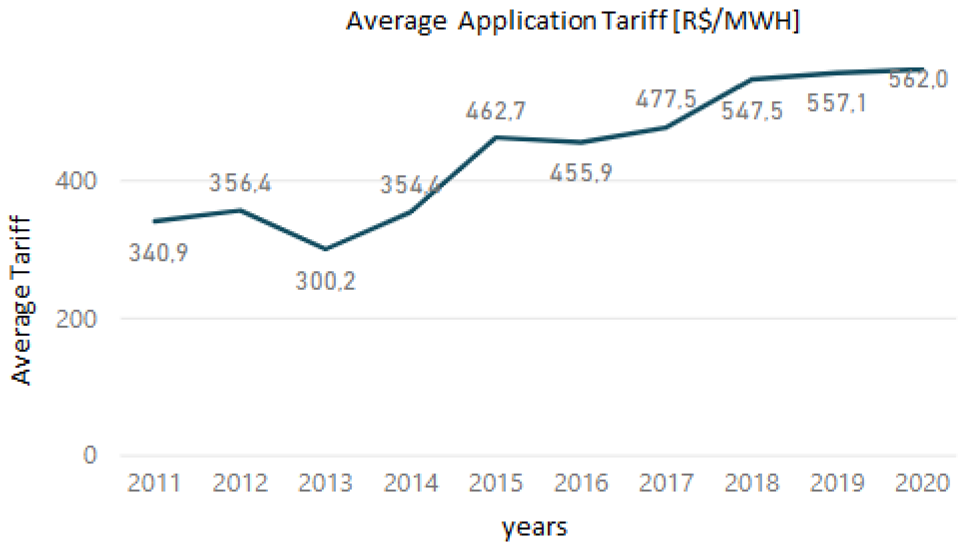


Figure 5 – Average energy tariffs over the years [IBGE, 2017]

Table 2 – Socioeconomic Characteristics of Brazil in 2019 [ANEEL, 2016; IBGE Social Statistics, 2020]

	GINI Index	**Population Distribution [%]**	**Average Income [R$]**	**Average Consumption of Electrical Energy [TWh]**	**Average Energy Tariff [R$/MWh]**
Midwestern	0.507	7.60	2,506.00	29.18	526.96
Southern	0.467	14.30	2,549.00	57.61	488.25
Southeastern	0.527	42.00	2,650.00	146.92	521.55
Northeastern	0.559	27.60	1,588.00	62.76	478.07
Northern	0.537	8.50	1,687.00	20.16	586.31
Brazil	0.543	100.00	2,308.00	316.48	511.49

The consumers who are most exposed to this trend of tariff increase are captive consumers (who can only buy energy from the concessionaire responsible for their region), more specifically the B1 residential ones. One way for these consumers to escape this unfavorable scenario is distributed generation, mainly photovoltaic (PV). As shown in Figure 6 the price of photovoltaic kits has fallen. Figure 7 presents a graph illustrating the percentage of Distributed Generation (DG) connections per consumption class in 2018. Generation distributed mainly by solar energy brings a series of benefits to society, such as: more jobs, lower energy tariffs for its users, cleaner and more sustainable energy in addition to the diversification of the energy matrix.

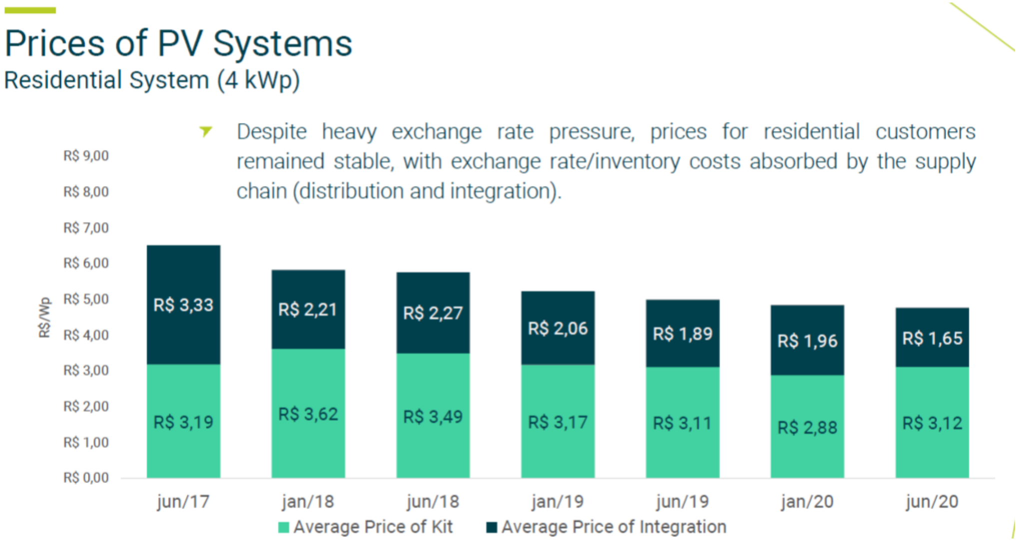


Figure 6 – Evolution of prices of PV systems in Brazil. [Greneer, 2020]

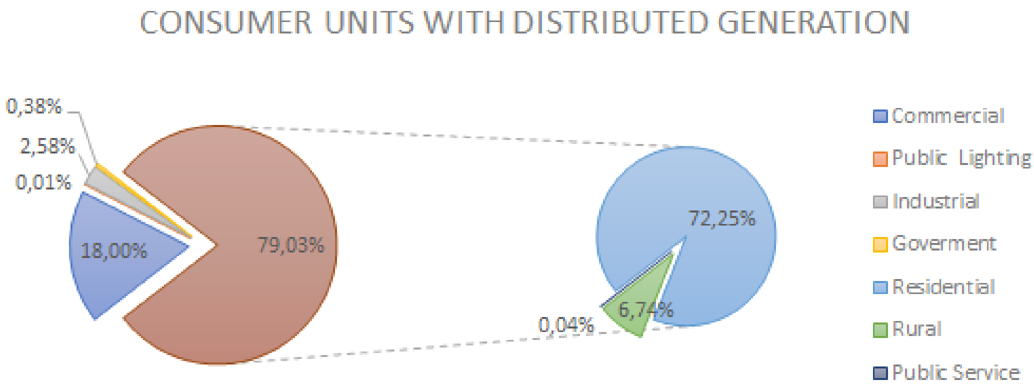


Figure 7 – Graph illustrating the percentage of DG connections per consumption class in 2018 [ANEEL, 2020b]

At first glance, it looks like a market that just aims to improve the life of brazilians, but "zooming in" on residential consumers, has the category of low-income residential consumers (B1-low income) who, as the name says, are consumers who do not have enough income to considered common consumers. However, unfortunately, the low-income residential consumer class and a big part of the Brazilian population are unable to use DG as a means for getting possibly cheaper electricity. That is, they will have to keep paying the growing concessionaire's tariffs. The impact of Distributed Generation (DG) on low-income consumers and its impact on energy poverty has been studied in various ways: there are studies about the effective way to overcome domestic energy poverty in developing regions using solar home systems [ZUBI et al., 2019], an Indian case also about solar home systems to reduce energy poverty [BHIDE; MONROY, 2011] and there is a study questioning if the renewable energy is affecting income distribution and increasing the risk of household poverty [PEREIRA; MARQUES; FUINHAS, 2019].

Table 3 indicates how many low-income consumer units there were in Brazil in each of its country regions in December of 2018, and how much was subsidized in this same month. It is easy to see that each region has a different number of low-income consumers, and the northeastern region is the one with the largest relative percentage number of low-income consumers and the southern region is the one with the lowest.

Table 3 – Monthly Evolution of Electric Energy Social Tariff (TSEE) in Brazil [ANEEL, 2016].

Tracking by Region 2018					
	Number of Consumers Units			Monthly Required Revenue	
Region	Income Residential	% Low Income/ Region	% Low Income/ % Total Low Income	Difference (R$)	%
Midwest	411,772	7.75	4.81	10,167,512.45	5.16
Southeast	2,120,577	6.38	24.79	50,900,428.45	25.82
South	521,402	5.00	6.10	11,903,791.58	6.04
Northeast	4,702,221	24.59	54.98	101,975,446.60	51.72
North	796,586	18.76	9.31	22,313,699.55	11.27
BRAZIL	8,552,558	11.80	100.00	197,160,879.09	100.00

All this effort to improve the market and promote broad population access to energy at more affordable prices (one of ANEEL's premises is precisely to aim for fair tariffs for consumers) aims to maximize collective socioeconomic well-being. When incentives such as low-income tariffs are proposed, the objective is to reduce social inequality in the electricity sector, or as known in Europe: "energy poverty". These measures generally burden consumers who are outside the class considered to be of low-income, and this causes a decrease in socioeconomic well-being since a large part of the population will have an increase in the tariff. There are government programs to promote distributed generation (GD) and boost this market by giving consumers the chance of producing renewable energy [ANEEL, 2012a; ANEEL, 2012b]. In addition, there is also an electrical energy social tariff (TSEE) program for the low-income population. However, socioeconomic characteristics are quite different in each region of Brazil, and because of this, the current public policies, which are a cross-subsidized, do not cause the same impact on all consumers (especially for the ones living in poor regions [OBERMAIER et al., 2012; PEREIRA; FREITAS; SILVA, 2010]).

1.2 Objectives and Contribution

This thesis intends to contribute to modeling a socioeconomic model that assesses the collective welfare and the best income distribution so that there is the best scenario, that is, the optimum, between the decrease in welfare, the increase in income distribution and how consumers in each region can be affected. Also, to review the application of the same public policies for all regions, and propose changes in its formulation, and decide which best public policy could be applied to improve the situation of those consumers. To achieve this objective, the following specific objectives were structured:

- Creation of a model that can relate prosumers, low-income consumers and common consumers and their respective energy tariffs with a focus on social electricity tariffs (TSEE).
- Simplified model to calculate the Gini index of the concession area studied before and after the application of the model.
- Proposal for different values of social energy tariffs
- Proposal for a new public policy and assess the impact of these policies on social welfare

1.3 State of Art

There are many works in the literature that discuss energy policies, economics and technological approaches such as energy efficiency measures and bioclimatic design strategies there are developed in order to improve thermal comfort in this social housing project and to reduce the energy consumption and expenses of their residents.

The institutional barriers and constraints toward higher efficiency are described. The results of this study shows that there is a high potential to increase energy efficiency in social housing in emerging countries like Brazil [BODACH; HAMHABER, 2010]. Profiling energy poverty for an effective energy policy once energy poverty is becoming ever more important for academia and policymakers. The study conducts fuzzy-set qualitative comparative analysis with the aim of constructing energy poverty profiles. None of the individual characteristics are able to explain energy poverty alone, although strong interrelations are present in the outcomes. They suggest that energy poverty is a structural issue, mainly arising from poor energy efficient buildings and/or labour market inefficiencies [PRIMC; SLABE-ERKER; MAJCEN, 2019], policy implications of energy poverty indicators and methodologies have been proposed in the literature to measure energy poverty are quite diverse. Some are subjective approaches based on personal or third parties' perceptions of affordable warmth at home, whereas others calculate objectively indicator.

There are still some limitations regarding those indicators that need to be overcome: namely, the consideration of housing expenses, and also the correct definition of energy needs [ROMERO; LINARES; LÓPEZ, 2018], socioeconomic indicators for the analysis of electricity distribution concessionaires in Brazil that were not taken into account in the division of the concession areas of electric power distribution in Brazil. Such indicators could allow the population to enjoy an optimum socioeconomic welfare, as it could adjust the concession areas to the social conditions of the population of Brazil [BENSO et al., 2018].

Studies about reconsidering energy poverty policies in the European Union, a policy approach able to support the transition from the current rising levels of energy poverty to a sustainable community with a greener and healthier future. With the analysis of energy prices, the policy framework and household income, was conduct a preliminary investigation of energy poverty was conducted from a macro-level perspective and associated policy interventions in the EU. They argue that member states facing above-average energy poverty are captured in an energy-poverty trap, whereby the existing energy-policy focus does not yield the desired results and the social policy is often too costly to implement due to the problem's magnitude.The main concern is that prioritising any of the policies may slow down the transition to a sustainable energy society [PRIMC; SLABE-ERKER, 2020].

Was made an overview of the political economy of energy poverty and what is the key challenges. A relationship between energy access and millennium development goals was elaborated, especially the connection between modern energy services and development, public health, gender empowerment, and the degradation of the natural environment. It notes that energy poverty has serious and growing public health concerns related to indoor air pollution, physical injury during fuelwood collection, and lack of refrigeration and medical care in areas that lack electricity.[SOVACOOL, 2012], a critical perspective on energy poverty policies in the European Union using evidence gathered from an international workshop and semi-structured interviews with decision-makers, experts and advocacy activists in Brussels and Sofia, establish the existence of a range of nascent efforts to address the issue at EU level.

Bulgaria has been good at implementing EU energy poverty relevant directives, however, policy makers speak a different language when it comes to direct energy poverty action. [BOUZAROVSKI; PETROVA; SARLAMANOV, 2012], an evaluation on fuel poverty policy in Northern Ireland using a geographic approach shows that anti-fuel poverty policies in the UK depend on loosely defined targeting and cannot accurately identify fuel poor households. New methods of targeting are necessary to improve fuel poverty policy. The paper uses Geographic Information System (GIS) techniques to evaluate the targeting of a domestic energy efficiency scheme in a small area level in Northern Ireland, based on the level of need. Policy activity and expenditure are compared with the level of need in an area. Results indicate that policy activity is only weakly associated with the level of need in an area, although policy appears to be well targeted in a few areas. Contrary to existing evidence, rural areas appear to be well served by policy, receiving above average numbers of retrofits and expenditure. [WALKER et al., 2013].

A study in Spanish households was made and aimed to measure the socioeconomic impact of energy poverty. They found that there is a relationship between the energy poverty media coverage and its impact,l the definition of households in a situation of energy poverty remains unresolved, energy poverty is less acute in the households located in rural areas and the local regulation influences the distribution of public or private aids to households.

The measurement of the socioeconomics impact of energy poverty in households in a territory represents the spatial dimension of the problem for the definition of local energy policies taking into consideration the evolution of different measures implemented over time, their limitations, scope and flexibility [SCARPELLINI et al., 2019], the energy poverty and relation with deprivation was studies in England and they used a statistical analysis. Findings demonstrate that energy poverty constitutes an additional and independent form of deprivation, which is not captured by the current Index of Deprivation. Energy poverty policy interventions should be designed at a local level, England Index of Multiple Deprivation needs redesigning to include energy access. Also, results are used to develop a classification matrix that identifies areas by their level of deprivation and energy poverty that can be mapped through a Geographic Information System at a Lower Super Output Area [MARCHAND et al., 2019], a stochastic model for energy poverty analysis was proposed to help the issue of lack of a common, effective way of measuring energy poverty has been detected as a major weakness in handling the energy poverty problem. One of the main causes has been the complexity of modeling the "required energy consumption" of households, as demanded by the official 10% indicator, and its replacement in calculations by the "actual energy consumption", which, as it is well known, underestimates the real needs of households. They use Greece as an example, and it is found that energy poverty reaches 70.4%, with income being the decisive factor affecting energy poverty at 63%, while other variables follow at significantly lower percentages. The findings can be used to assess in advance the effectiveness of energy poverty measures, making the model a valuable policy tool. [PAPADA; KALIAMPAKOS, 2018].

Structural energy poverty vulnerability and excess winter mortality in the European Union exploring the association between structural determinants and health.Energy poverty is structurally determined by broader political and socioeconomic conditions, the authors analyzed each EU-27 country through the creation of a structural energy poverty vulnerability (SEPV) index. A geographical pattern of structural energy poverty vulnerability was observed and the most vulnerable countries are located in eastern and southern Europe, excess winter mortality risk is higher in countries with greater vulnerability, acting on structural determinants of energy poverty can have an impact on health. [RECALDE et al., 2019], measuring energy poverty and identifying micro-level solutions in South and Southeast Asia the absence of adequate modern sources of energy inhibits the presence of decent living conditions, also considered Energy Poverty. Lack of availability, accessibility, and affordability are the main reasons behind this problem. The measure revealed the degree of problem in each country, with Cambodia being the most energy poor amongst the countries in the study and Thailand being the least energy poor. They developed detailed village-level case studies and analysed region-specific energy poverty, thus identifying the key root causes, and proposing effective solutions to eradicate the prevailing problem in these regions [KHANNA et al., 2019].

Several studies show that electricity is a product through which it is possible to reduce social inequality, even the Nobel prize of 2019 in Economics was awarded to three economists for their work, this year's researchers introduced a new approach to getting answers on ways to fight global poverty [The Royal Swedish Academy of Sciences, 2019].

In [TAVARES, 2003] and [AGUIAR et al., 2007] a study was carried out on the role of electricity tariffs in the reduction of inequality and one of the conclusions was that tariffs increased more than proportionally for the so-called low-income group, which is the most affected by inequality and tariff variation causing a low energy consumption by this class and without an improvement in inequality. These studies point to a higher rate increase than the minimum wage. Bearing in mind that the electricity sector is not responsible for achieving a better distribution of income, however, as an important part of the life of brazilians, it should contribute positively and should in no way accentuate such problems. When looking at the world, there are countries that also experience problems with social inequality and just like Brazil have public policies to try to equalize within their concession areas the problem of inequality through tariff subsidies [ENERGIA, 2014].

Argentina, which is dominated by thermal generation, is also divided into concession areas and has tariff subsidies that vary according to the province and the company responsible for that particular area. These subsidies are widespread and do not have a specific tariff for this, and depending on the concession area, there may be subsidies for ex-combatants, retirees and low-consumption customers.However, since 2014 there has been a reduction in subsidies that started with increases in the tariff of consumers with better purchasing power (larger residential consumers). And the reduction of subsidies tends to intensify [ENERGIA, 2014].

In Colombia, urban consumers are classified according to their socioeconomic situation. The tariff covers the costs of operating the system, being called CU (Unit Cost of Providing the Service) and if all urban consumers had the same social condition they would pay this tariff. However, as there are social inequalities, the tariff value is according to the classification of consumers, with the most favored paying more so that the less favored can have the tariff subsidy. These upper-class consumers, the industrial and commercial sectors, pay up to 20% more on the cost of providing services to finance subsidies [ENERGIA, 2014].

China has a history of promoting social justice through its tariff policy. Until 2008, the government was reluctant to increase the value of residential tariffs, but as their electricity sector depends on coal and the price of this input continued to rise, the government had to start granting tariff increases. This increase was achieved by dividing customers into three levels, and is not homogeneous across the provinces because of economic differences between them. The government has sought to rationalize tariffs and align prices of energy tariffs [ENERGIA, 2014].

In Europe in general, there are also subsidies for the poorest population, although the inequality in some of these countries is much smaller than that of Brazil, for example. In Portugal, there is a social tariff (discount on the tariff for access to low voltage electricity) that is applied to all consumers who prove they need a subsidy. In the United Kingdom there is also a subsidy program for residential consumers, it is not a specific tariff, but it is a discount and incentives that promote a lower tariff for low-income consumers. Although there are no major socioeconomic inequalities in the European Union, Europeans have been concerned with inequality in relation to the energy tariff and the use of this resource, a phenomenon called "energy poverty". This refers to the fact that part of the population is unable to enjoy all the benefits that energy can promote, as they are unable to spend a lot of energy because of the price of this service and, consequently, are at a disadvantage with consumers who can enjoy a greater amount of energy [Europian Commission, 2011].

A study carried out in the United Kingdom [WALKER; DAY, 2012] treats fuel poverty as a social injustice, as it is related to the compromised ability to access energy and its services (mainly to achieve heating) and to ensure that the population lives in a safe and healthy environment. It is a matter of injustice that is aggravated by the interaction between income, energy prices and housing.

In another study on this [LIDDELL et al., 2012], the authors measure and monitor fuel poverty taking into account the premise formulated in 1991 that only 10% of income should be spent with energy. By better understanding the origins of this threshold, it is possible to have a more critical view of why the UK's energy poverty targets have not been achieved, and this also allows for a more realistic approach to the goals for the future. They also exploit the disparity between geographic regions, which can exacerbate or alleviate fuel energy poverty.

In Brazil, this topic has also been and still is addressed, as in [OBERMAIER et al., 2012] and [PEREIRA; FREITAS; SILVA, 2011] where the energy poverty of rural consumers was assessed. The evaluation showed how renewable sources, photovoltaic type, influenced the reduction of social inequality in this group. As a criterion for measuring energy poverty by the first authors, some metrics were used, including the Gini index, which showed that there was an improvement with a reduction in the inequality of rural consumers studied by them.In the second, two rural regions in the northeast, which is the poorest region in Brazil, were analyzed, and indicative poverty indexes like Gini were not used. In this study, they used their own method and it was observed that rural consumers after being introduced to electricity increased consumption in a few years. This indicates an immediate social benefit for consumers through the services that electricity provides.

1.4 Thesis structure

The thesis is presented in 6 chapters, the first chapters being an overview of the literature that helps to understand the proposal of this thesis:

Chapter 1: **Introduction**. This chapter presents the motivations, objectives and contributions, the state of the art on the subject and the structure of the thesis.

Chapter 2: **Brazilian Electricity Sector**. This chapter describes the electric market, which is divided into a free market and a regulated market. The regulated market will be more detailed, as this covers the object of study, how it is divided and the residential tariff process. It has a specific section to deal with the social electricity tariff.

Chapter 3: **Distributed Generation**. This chapter talks about the evolution of alternative energy sources for the common population. In other words, it deals with residential consumers who generate their own energy.

Chapter 4: **Research Method**. This chapter presents the model that will be used to reach the objectives already mentioned. This is the TAROT (Optimized Tariff) model.

Chapter 5: **Simulation Results and analysis**. This chapter aims presents and discusses the simulated results of the proposed energy policy showing the variation in the main economic variables: tariff, income distribution, socioeconomic welfare.

Chapter 6: **Conclusion**. This chapter shows the research conclusions.

2 Brazilian Electric Sector

2.1 Initial considerations

The energy market has been changed over the years, always seeking to improve and adapt to the needs of Brazil. Today, the Brazilian electric market is structured based on Laws No. 10,847 and 10,848, of March 15th, 2004, and by Decree No. 5,163, of July 30th, 2004 that set the commercialization of energy open into two acts: free contracting environment (ACL) and regulated contracting environment (ACR). Figure 8 shows a division of the markets in the SIN (National Interconnected System). This chapter presents an overview of how the electricity market in Brazil works (free and regulated), how tariffs are determined and what public policies ANEEL has adopted to ensure that the entire population can have energy and can use it .

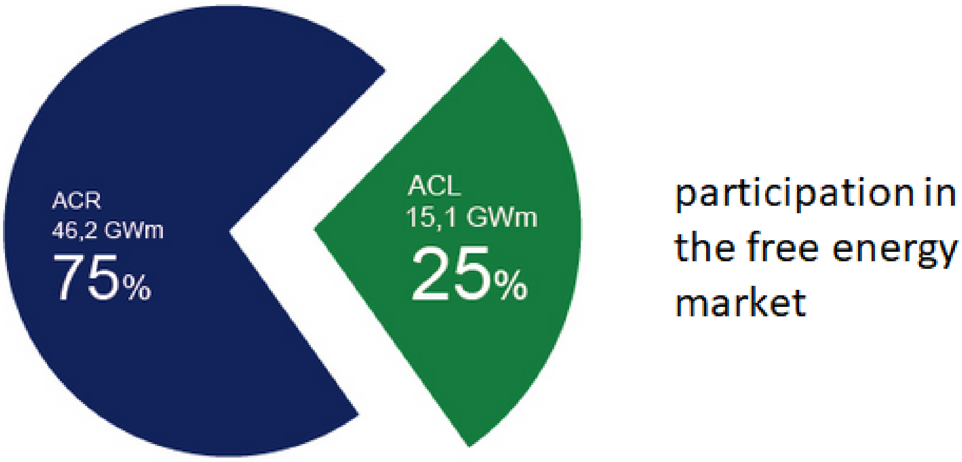


Figure 8 – Informative graph of the ratio of the amount of energy in each contracting environment [ANEEL, 2020b]

2.2 Free Market

According to [Energy Trading Chamber, 2017] and as can be seen in Figure 9 in the free market, also known as the free contracting environment (ACL), energy purchase and sale contracts are negotiated directly between concessionaires, permissionaires and authorized entities, generation companies, agents, traders, importers of electricity and free or special consumers, as long as they meet the conditions established for in the regulations. Also according to this document, "*All ACL and ACR contracts signed must be registered in the Electric Energy Trading Chamber (CCEE), as established in art. 56 of Decree nº 5.163 / 04, and in art. 7 of the Electricity Commercialization Convention*".

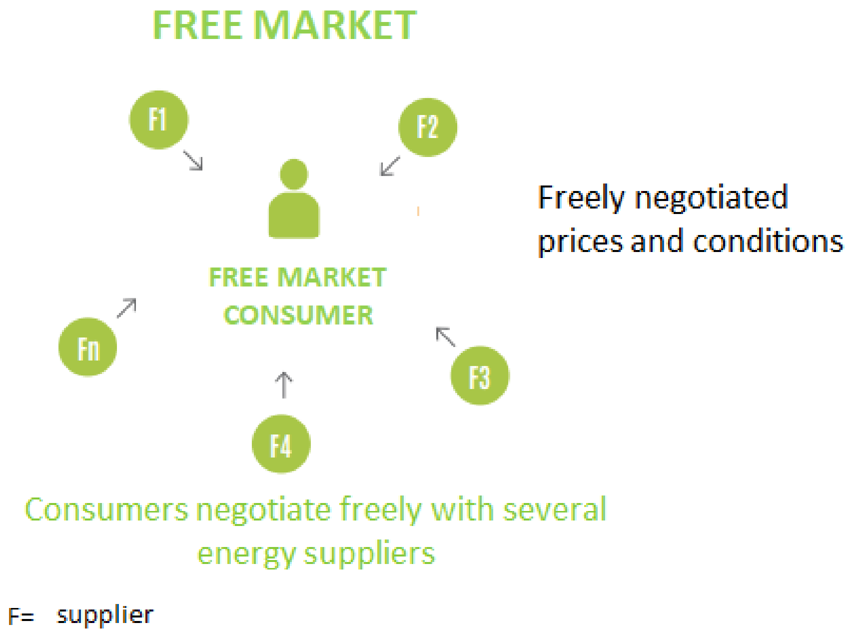


Figure 9 – ACL dynamics, adapted from [ABRACEEL, 2016]

The commercialized energy can be of two types: from encouraged sources or from non-encouraged sources. Similarly, there are 2 types of consumers in this market (see Table 2-1): free consumers and special consumers. To be a special consumer (which can be a unit or set of consumer units located in a contiguous area or with the same CNPJ), your load must be greater than or equal to 500 kW (sum of the contracted demands) and a minimum voltage of 2.3 kV . **The Special Consumer can only hire Incentive Energy.** In order to be a Free Consumer, each consumer unit must have a contracted demand of 3,000 kW and minimum voltage of 69 kV, for the electrical connection dated before July / 1995, or 2.3 kV, for connection after July / 1995. The Free Conventional Consumer can contract Conventional or Encouraged Energy.

Table 4 – Conditions to be free consumers [ANEEL, 2016].

Consumer	energy	minimum demand	minimum voltage	consumer connection date
Free	conventional or encouraged	3,000.00 kW	2.3 kV 69 kV	after 08/07/1995 before 08/07/1995
Special	encouraged	500.00 kW	2.3 kV	any time

2.3 Regulated Market

The Brazilian regulated market is regulated by the Brazilian Electricity Regulatory Agency (ANEEL) which has established the tariff calculation procedures for all distribution companies in the country. The premises followed by ANEEL ideally aim for fair tariffs for consumers and for the electricity companies. Therefore, public policies are designed to make sure that the population will have access to electrical energy and the regulatory contractual requirements will be guaranteed for the concessionaires [ANEEL, 2011].

The regulated contracting environment (ACR) works via long-term regulated bilateral contracts between sellers (independent generators and producers) and distributors, the purchase of energy through the CCEE. Each distributor informs the Ministry of Mines of Energy the amount of energy it needs before each auction, so that the demand can be contracted. After all the demand is contracted, the purchased energy is divided among the distributors according to the needs declared by each one. Thus, the basis for passing on the costs of purchasing energy to the tariff is the price resulting from the various bids to acquire all energy, which is divided among all distributors. The energy distribution agents in this market are divided between concessionaires and permit holders. There are particularities in their contracts that differentiate them from each other, but both have the natural monopoly of their concession areas.

2.3.1 Concession Areas

Distribution is a regulated natural monopoly, that is, when a single company is able to offer a good or service to an entire market at a cost less than two or more companies (energy, water, gas, for example). The Concession Law in its Art. 23 presents the clauses of the contracts referring to the object, area and concession term, the mode, form and conditions of service provision, quality, service price, among others. The Ministry of Mines and Energy, in the case of the electricity sector, is the granting authority of the concession contracts of the distributors and according to the current rules (decree N 8461 of 2015) the validity of each one is 30 years and can be extended for another 30 years , if approved by ANEEL. As far as it is known, there was no criterion for determining the areas to be bid for each concession. A good indication of this is the heterogeneity in relation to the extent and number of consumers in each existing concession area. Figure 2-3 illustrates the distribution of concessionaires in the brazilian territory. And it is readily apparent that the north and northeast in general have only one distributor per state, while most states in the south and southeast have at least two distributors.

Divided between permissionaires and concessionaires, there are more than 90 active concession contracts and each establishes clear rules regarding tariff, regularity, continuity, security, timeliness and efficiency in the quality of services and the service provided to consumers.According to ANEEL, distribution concession contracts must comprehensively serve the entire market, and there can be no exclusion of low-income populations or areas of lower population density. The tariff is calculated according to the same rules for each and every concession area. Each concession area must have only one tariff in its entire length, and some of these tariffs may have discounts according to the consumption class.

Figure 10 – Distributors according to the corporate group to which they belong and their respective concession areas. [ANEEL, 2018]

2.3.2 Types of consumers

Consumer units are classified into two tariff groups: Group A and Group B. The difference between them is the service voltage class. Group B is serviced at a voltage below 2,300 volts (low voltage).

In general, houses, stores, bank branches, small workshops, residential buildings, most commercial buildings and most federal public buildings are in this class, since most of them are serviced at voltages of 127 or 220 volts.They can be divided into subgroups, according to their activity, as shown below:

- Subgroup B1 - residential and low income residential;

- Subgroup B2 - rural and rural electrification cooperative;
- Subgroup B3 - other classes;
- Subgroup B4 - public lighting

For consumers served at high voltage, above 2,300 volts, such as industries, shopping centers and some commercial buildings, the classification is Group A. The subdivision of this group is related to the level of service, as shown below.

- Subgroup A1 for the voltage level of 230 kV or more;
- Subgroup A2 for the voltage level from 88 to 138 kV;
- Subgroup A3 for the 69 kV voltage level;
- Subgroup A3a for the voltage level from 30 to 44 kV; Subgroup A4 for the voltage level
- from 2.3 to 25 kV;
- Subgroup AS for underground system.

In general, Group A consumers can operate in the free energy market, while Group B is mandatory to be in the regulated market.

2.4 Electricity Tariffs in Regulated Market

ANEEL establishes that the distributors must operate in economic and financial balance (a matter that will be discussed later). To this end, was developed the PRORET (Tariff Regulation Procedures) which has a normative character and regulates the tariff processes and ensures that both the distributor operates more efficiently and covers its costs as consumers have quality energy at fair prices promoting low tariffs.

To define the value of the Tariff, basically 4 costs are considered:

- Cost of purchasing energy
- Energy transport (transmission and distribution)
- Sector charges and taxes (PIS / COFINS, ICMS among others)
- Energy distribution

These costs can be divided into an unmanageable installment (Parcel A) and another manageable installment (Parcel B):

- Parcel A: Energy Purchase, Transmission and Sector Charges
- Parcel B: Energy Distribution (operating costs, cost of capital among others related to the distributor itself)

Figure 11 expresses the participation of each parcel as well as the taxes for the tariff calculations.

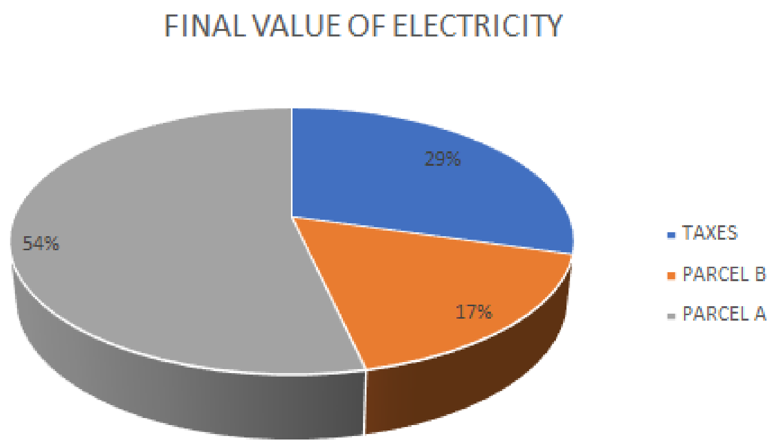


Figure 11 – Composition of costs for the calculation of the tariff [ANEEL, 2012a]

These costs and the tariff amount go through tariff processes, which include Annual Tariff Adjustments (RTA) and Periodic Tariff Review (RTP). The RTAs are carried out between the RTPs and are intended to maintain the distributor's economic-financial balance, by applying an inflationary index.

The RTP generally takes place every four years (tariff cycle), and that id when the financial parameters for the cycle are established until a new RTP is made for the next cycle and so on. All costs and revenues and tariffs are determined so that in the year of RTP the company is in economic-financial balance. Figure 2-5 illustrates this tariff cycle.

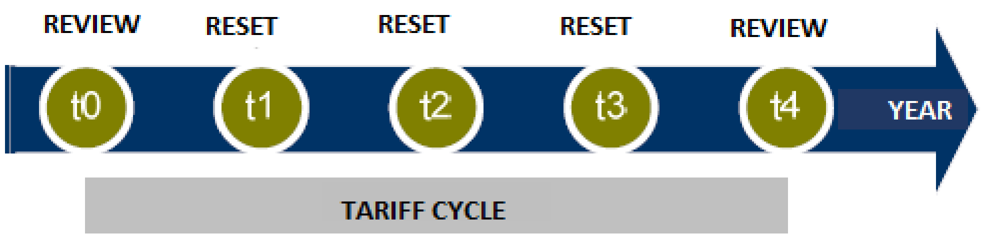


Figure 12 – Tariff cycle scheme [ANEEL, 2012a]

The tariff processes can be divided into 2: The Tariff Level, which stipulates which revenue is necessary to cover all costs and gains allowed by the regulator and the Tariff Structure that defines in fact which tariff should be applied to each class of consumption, the tariff can be summarized as the ratio between the required revenue and the billed market (amount of energy sold) by the distributor. The distributor classifies its service in two ways, one as a supplier of electricity and the other as a holder of the physical environment (distribution network). This difference occurs because some consumers can choose their suppliers (free consumers) of energy regardless of the concession area in which they are located. And there is no need to create an exclusive distribution line for each customer, so the existing one of each distributor is used and it charges a fee only for the use of its network. Captive consumers also pay for the use of the distribution system. This tariff is called the Tariff for the Use of Distribution Systems (TUSD).

For the energy supplier, the tariff is related to the amount of energy purchased at the auction to supply its captive customers and is called the Energy Tariff (TE). How much will be charged for each of the above tariffs depends on the tariff modality that each consumer is inserted. Figure 2-6 illustrates the different modalities and which consumers they are aware of. These modalities are:

Group A: High Voltage consuming units (Subgroups A1, A2 and A3), Medium Voltage (Subgroups A3a and A4), and underground systems (Subgroup AS):

- Blue Hour: different rates for electricity consumption and power demand, according to the hours of use of the day (tariff stations). Available to all subgroups of group A; and
- Green Hour: different rates for electricity consumption, according to the hours of use of the day (tariff stations), and a single power demand tariff. Available for subgroups A3a, A4 and AS.

Group B: Low Voltage consumer units, Residential (Subgroup B1), Rural (B2), Other Classes (B3) and Public Lighting (B4)

- Conventional ”Monômia”: single tariff for electricity consumption, regardless of the hours of use of the day; and
- White Hour: differentiated electricity consumption tariff, according to the hours of use of the day (tariff stations). It is not available for subgroup B4 and for the Low Income subclass of subgroup B1.

Other users:

- Distribution: tariff applied to distributors that access other distributors. Characterized by hourly tariff for power demand and energy consumption for group A, and single energy consumption tariff for group B; and
- Generation: tariffs applied to generating centers that access the distribution systems, characterized by a single power demand tariff.

2.5 Sector Charges

Sector charges, as shown below, are part of Parcel A of distributors' costs. And according to ANEEL: *"Sector charges are understood as the unmanageable costs borne by distribution concessionaires, instituted by law, whose transfer to consumers is due to the guarantee of the contractual economic-financial balance"*.

These charges are:

- Energy Development Account - CDE;
- Incentive Program for Alternative Sources of Electric Energy - PROINFA;
- Financial Compensation for the Use of Water Resources - CFURH;
- System Service Charges - ESS and Reserve Energy - EER;
- Inspection Fee for Electric Energy Services - TFSEE;
- Research and Development - RD and Energy Efficiency Program - PEE; and
- Contribution to the National System Operator - ONS

Among these, items CDE and PROINFA stand out for this thesis, as they are programs that aim to subsidize various public policies in the sector.

CDE is a dedicated fund Law No. 10,438, of April 26th, 2002, by Decree No. 7,891, of January 23th, 2013, and aims to cover the universalization of the electric energy service through the concession of tariff discounts to several users (low income, rural; Irrigating; public water, sewage and sanitation services; incentive energy generation and consumption, etc.), low tariffs in isolated electrical systems (Fuel Consumption Account - CCC), competitiveness of generation of electric energy from the national coal source, among others.

PROINFA, on the other hand, pursuant to Decree No. 5,025, of March 30, 2004, aims at incentives to increase the participation of alternative renewable sources in the production of electric energy, privileging small hydroelectric plants, wind power plants and biomass thermoelectric projects.

CDE resources should come from the annual quota payments made by agents that sell electricity to the final consumer, with annual payments made under the Use of the Public Good - UBP, payments of fines imposed by ANEEL, the transfer of resources from the General Budget of the Union - OGU. However, on ANEEL's own website, it appears that all consumers of the SIN (National Interconnected System) contribute to the apportionment of tariff subsidies. Figure 13 shows how much was required from the concessionaires' revenue to finance the subsidies. and also that the amount is mostly paid by consumers (CDE Quotas - use)

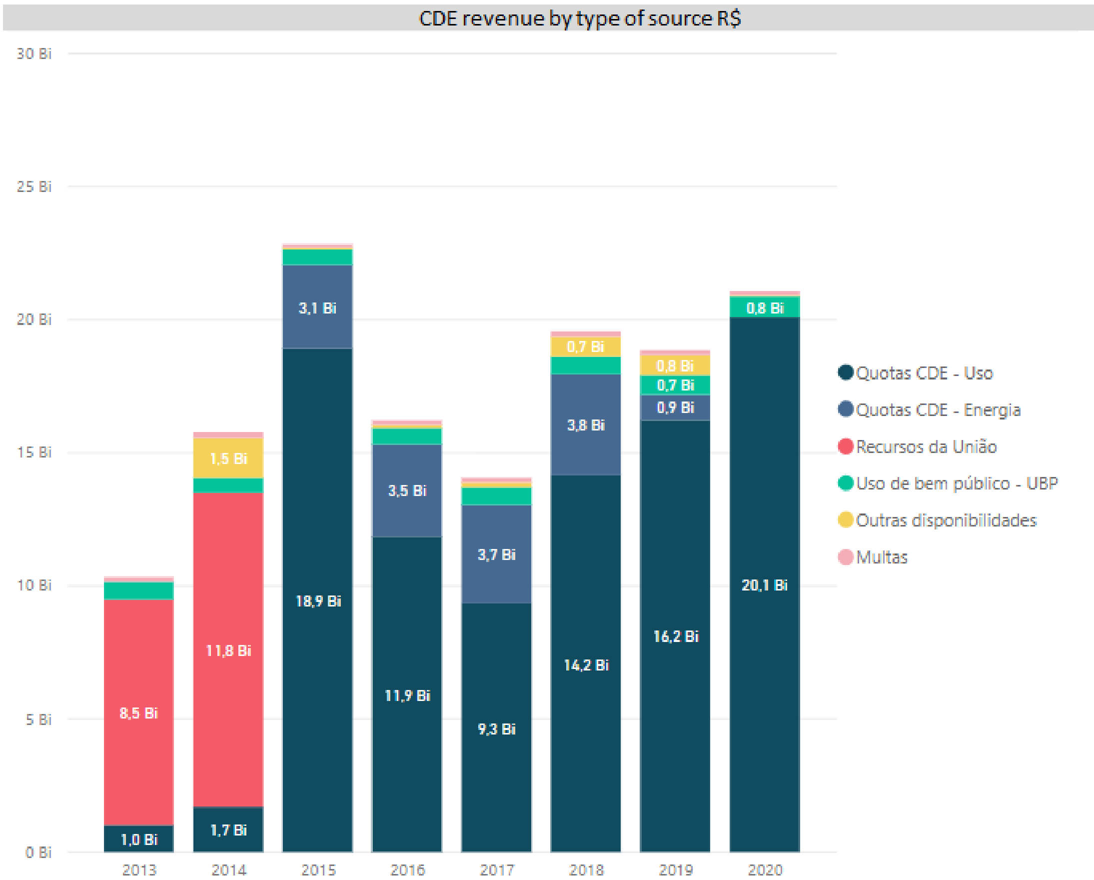


Figure 13 – Energy Development Account over the years [ANEEL, 2020a]

2.5.1 Social Electricity Tariffs - TSEE

In [TAVARES, 2003] a retrospective is made of how social tariffs were treated until 2003. In Table 2-1 it is presented how the criteria for determining the low income bracket were and how the benefits were provided. It is possible to observe that the term "Low Income" started to be adopted only in 1996, before that all residential consumers received some type of benefit.

Currently in Brazil, the Electrical Energy Social Tariff (TSEE) is regulated by Law Nr. 12212 of 2010 and by Decree Nr. 7583 of 2013. It covers the Group B consumers, more specifically the group B1-Low Income, Indigenous and Quilombola. It consists of tariff discounts incident over the conventional residential tariff as shown in Table 6.

According to Law number 12,212, residential consumers who meet the requirements below can benefit from TSEE:

- Family enrolled in the Single Registry for Social Programs of the Federal Government - a social program named ”cadastro único”, with per capita monthly family income less than or equal to half the national minimum wage; or
- Who receives the Benefit of Continued Provision of Social Assistance - BPC, under the terms of Arts. 20 and 21 of Law No. 8,742, of December 7, 1993; or
- Family enrolled in the Single Registration with monthly income of up to 3 (three) minimum wages, who have a disease or disability whose treatment, medical or therapeutic procedure requires the continued use of devices, equipment or instruments that, for its functioning, requires electric power consumption.

Consumers who meet one of these requirements should go to their distributor and request a change to the low-income residential sub-class. The distributor will check the information and if everything agrees it will make the change.

Table 5 indicates how many low-income consumers there were in Brazil in 2018 and how much was subsidized in that same year.

Table 5 – Monthly Evolution of Electric Energy Social Tariff (TSEE) in Brazil [ANEEL, 2016].

TSEE Monthly Evolution - Brazil					
2018					
Reference	Number of Consumer Units			DMR - Monthly Required Revenue Difference (R$)	%
	Total Residential	low income residential	% low income /% Residential		
January	70.888.141	8.780.654	12.38	201.410.463,67	8,30%
February	70.960.816	8.797.015	12.39	197.836.461,37	8,15%
March	71.110.347	8.867.520	12.47	200.876.932,40	8,28%
April	71.266.459	8.932.630	12.53	203.136.894,11	8,37%
May	71.769.294	8.889.644	12.38	201.075.043,71	8,29%
June	71.827.243	8.807.495	12.26	199.765.894,04	8,23%
July	71.656.116	8.804.549	12.28	194.198.225,58	8,00%
August	71.831.022	8.909.002	12.40	198.707.087,17	8,19%
September	72.013.073	9.106.015	12.64	206.198.275,34	8,50%
October	72.103.663	9.081.110	12.59	210.868.026,85	8,69%
November	72.341.725	9.131.654	12.62	214.906.290,63	8,86%
December	72.508.342	8.552.773	11.79	197.166.175,78	8,13%
BRAZIL TOTAL				2.426.145.770,65	100%

Table 6 – Energy Consumption and Discount Percentage [ANEEL, 2012a]

Monthly Consumption Parcel of Electrical Energy (MCP)	**Discount**
MCP $\leq$ 30 kWh	65%
30 kWh $<$ MCP $\leq$ 100 kWh	40%
100 kWh $<$ MCP $\leq$ 220 kWh	10%
MCP $>$ 220 kWh	0%

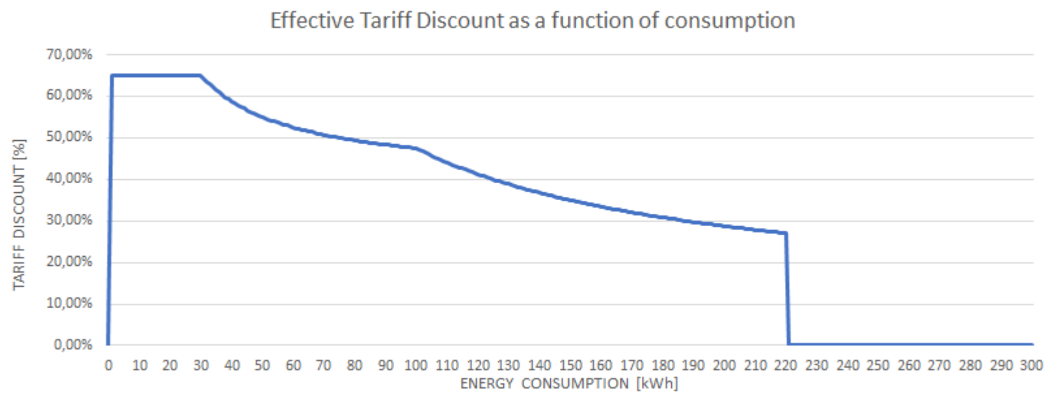


Figure 14 – Graphic of cumulative percentage of discount according to Table 6

Being the percentages of the Social Electricity Tariff () applied cumulatively (according to Table 6), then a low-income consumer with a total monthly consumption of 220 kWh would have:

65% discount on the tariff over 30 kWh ——–> (0.35*Tariff)*30 kWh = 10.5*Tariff.

40% discount on the tariff over 70 kWh ——–> (0.60*Tariff)*70 kWh = 42*Tariff.

10% discount on the tariff over 120 kWh ——-> (0.90*Tariff)*120 kWh = 108*Tariff.

They will then pay a total electricity bill of: (10.5+42+108)$*$Tariff = 160.5*Tariff, whereas for a common consumer the electricity bill would be: 220*Tariff.

This chapter shows at a glance how the tariff structure of the regulated sector is, how consumers are divided and classified in relation to service tension and also that each one contributes in a specific way to the tariff. It shows that although no socioeconomic factor is taken into account when calculating tariffs for distributors, the sector is concerned with the poorest population and tries to remedy the situation by creating discounts and cross-subsidies so that part of the population is not completely without access to electrical energy. However, the socioeconomic situation in Brazil in general, there is still a great inequality between the concession areas. The discounts listed in Table 6 are cumulative as illustrated in Figure 14 and yet, as can be seen in Table 5, and Table 7 the electricity consumption by low-income consumers is lower than that of common consumers and the average discount on the electricity bill is only R$ 20. It is very clear the difference in the consumption among regular and low-income consumers since the value of the discount is very low. Due to the clear differences among regions, applying this small discount in the electricity tariff for the low energy consumption class does not seem to be a very effective public policy.

Table 7 – Consumption and average discount in 2018l [ANEEL, 2016].

Consumption and Average Monthly Discount - Brazil			
2018			
Reference	Average Residential Consumption (kWh)	Average TSEE Consumption (kWh)	Average Discount TSEE(R$)
jan/18	169.17	122.18	22.92
fev/18	164.77	118.22	22.47
mar/18	167.69	120.02	22.63
abr/18	167.68	122.03	22.72
mai/18	160.45	118.97	22.6
jun/18	154.69	11.89	22.66
jul/18	151,15	113,66	22,03
ago/18	151.00	115.45	22.28
set/18	155.62	118.57	22.62
out/18	160.94	123.27	23.2
nov/18	164.03	127.22	23.52
dez/18	163.11	121.8	23.03
Year	160.86	119.86	22.72

3 Distributed Generation

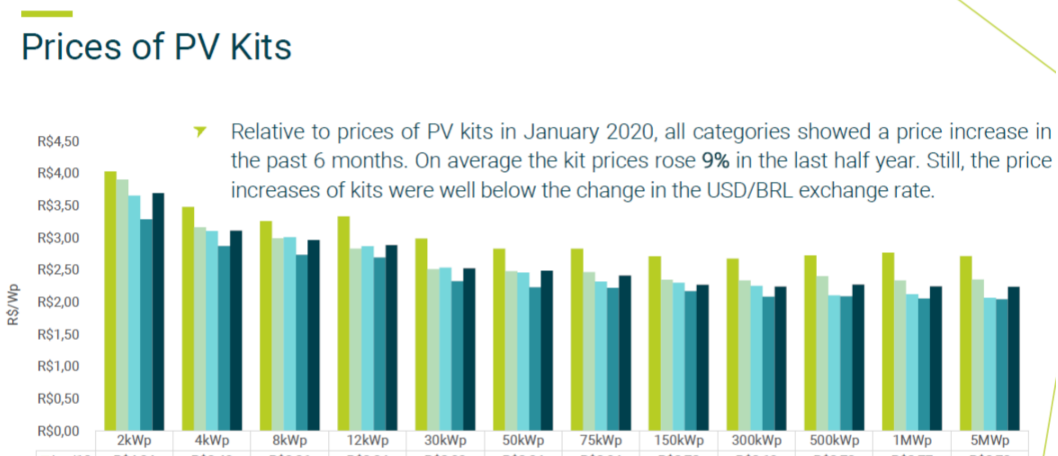
3.1 Initial Considerations

The concept of distributed generation is already consolidated and disseminated worldwide [LUO et al., 2014; KUANG; LI; WU, 2011; FRATE; BRANNSTROM, 2017]. This chapter will address how distributed generation is being treated in Brazil, and present its advantages and disadvantages for the system and especially for society.

3.2 The Distributed Generation in Brazil

The distributed generation started to be more widespread in Brazil after the implementation of REN 482/2012 and later reissued by the normative resolution 687/2015, which established the energy compensation system as well as the general rules for the access of distributed micro and mini generation. This system allows energy that is not consumed by the consumer unit to be injected into the distributor's network, and the consumer will receive an energy credit (kWh) valid for 5 years and can be used to reduce consumption at other tariff stations or on an energy bill for a period of 60 months. There are still other alternatives for the use of credits: the consumer can use it in other units previously registered that are within the same concession area and characterized as remote self-consumption, it can be shared generation or multiple consumer units (condominiums) since they are in different locations from the point of consumption.

In Brazil, distributed micro generation is characterized by having an installed power less than or equal to 75 kilowatts (kW) and the mini generation with an installed power greater than 75 kW and less than or equal to 3 megawatts (MW) for water sources, or 5 MW for the others [ANEEL, 2014]. The growth of distributed generation can be attributed to economic factors, such as the drop in the price of photovoltaic modules in recent years, as shown in Figure 15. And also to fiscal factors, such as incentives from public policies that may vary from state to state.



	2kWp	4kWp	8kWp	12kWp	30kWp	50kWp	75kWp	150kWp	300kWp	500kWp	1MWp	5MWp
jun/18	R$4,04	R$3,49	R$3,26	R$3,34	R$2,99	R$2,84	R$2,84	R$2,72	R$2,69	R$2,73	R$2,77	R$2,72
jan/19	R$3,91	R$3,17	R$3,00	R$2,84	R$2,52	R$2,49	R$2,47	R$2,35	R$2,34	R$2,41	R$2,34	R$2,36
jun/19	R$3,66	R$3,11	R$3,02	R$2,87	R$2,54	R$2,47	R$2,32	R$2,31	R$2,26	R$2,11	R$2,13	R$2,07
jan/20	R$3,29	R$2,88	R$2,74	R$2,70	R$2,33	R$2,24	R$2,23	R$2,17	R$2,09	R$2,09	R$2,06	R$2,05
jun/20	R$3,70	R$3,12	R$2,97	R$2,89	R$2,53	R$2,49	R$2,42	R$2,28	R$2,25	R$2,28	R$2,25	R$2,24

Figure 15 – Average price of photovoltaic kits [Greneer, 2020]

In general terms, distributed generation provides benefits for the electrical system, with the possibility of highlighting the postponement of investments in expansion in the distribution and transmission systems, the low environmental impact and the diversification of the energy matrix. However, there are also disadvantages associated with the increase in distributed generation, including: increased complexity of operation of the distribution network, difficulty in charging for the use of the electrical system, the need to change the operating procedures, control and safety of the distributors.

Another important point is that for consumer units in group B, payment of the availability cost will be mandatory even if the energy injected into the network is higher than consumption. The amount to be paid, in Brazilian Real, will be equivalent to the consumption of 30 kWh (single phase), 50 kWh (two phase) and 100 kWh (three phase).

Figures 16 and 17 show the evolution of generation distributed in Brazil, where it is noted that there has been a considerable evolution in the number of connections. In Figure 17, it is clear that some states are ahead in relation to the number of GD connections. Figure 3-2 illustrates the participation of each consumption class, and it can be highlighted the participation of residential B1 consumers with more than 70% of the number of connections to date.

Regarding installed power, the commercial sector has gained prominence. Today, the largest installed power is commercial consumers, as shown in Figure 18. Making a panorama of Brazil, Figure 19 shows that the South and Southeast regions registered the largest number of installations, with Minas Gerais, São Paulo and Rio Grande do Sul being the most prominent states and North and Northeast the smallest indexes, with Acre, Amapá and Roraima presenting the lowest number of installations.

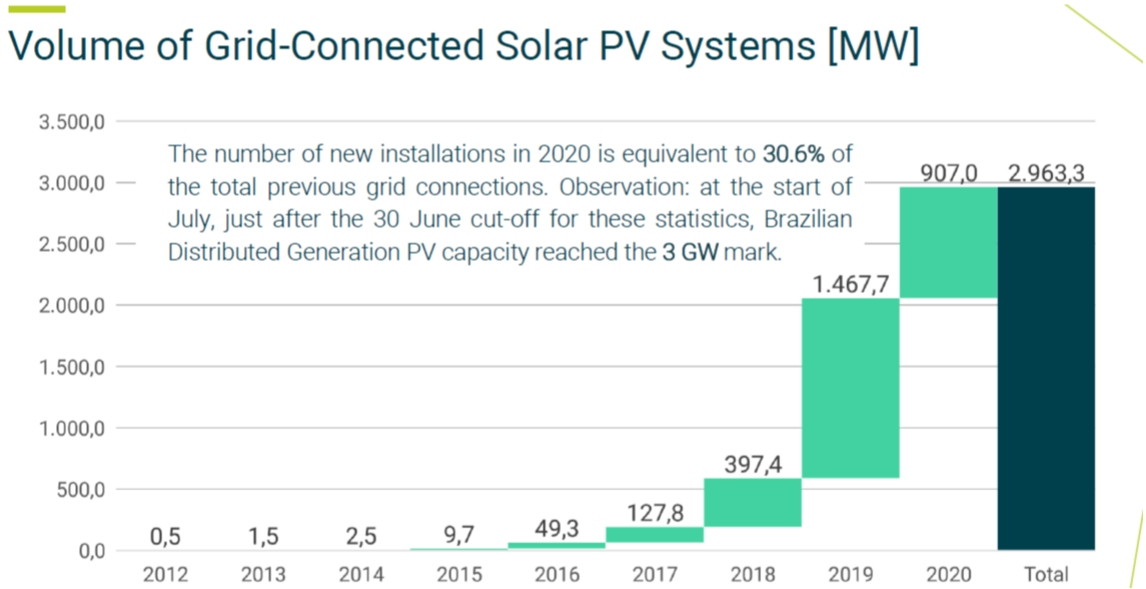


Figure 16 – Evolution of the number of distributed generation connections in Brazil [Greneer, 2020]

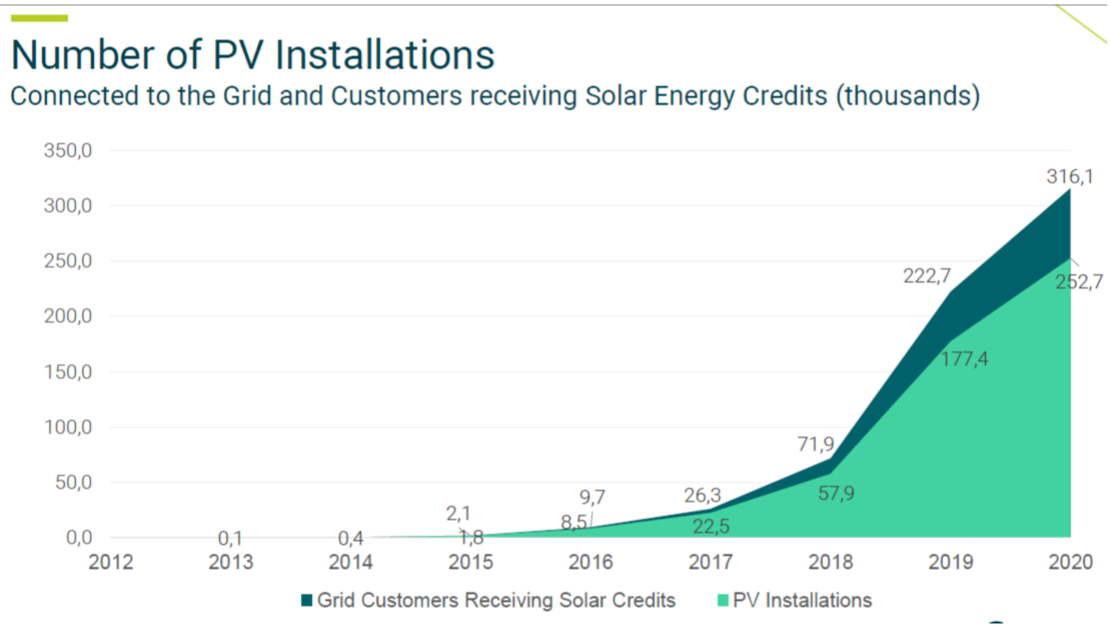


Figure 17 – Graph illustrating the distribution of the number of GD connections by consumption class [Greneer, 2020]

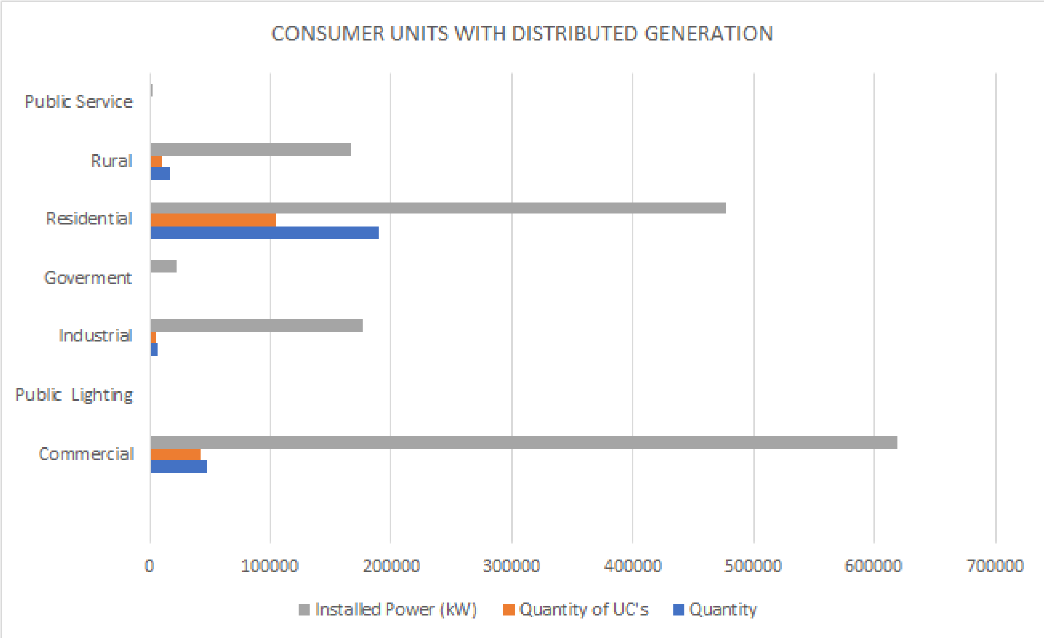


Figure 18 – Graph of the number of consumer units with DG, the installed power, the number of UC's (in blue) and how many UC's receive discounts (in orange) [ANEEL, 2020c]

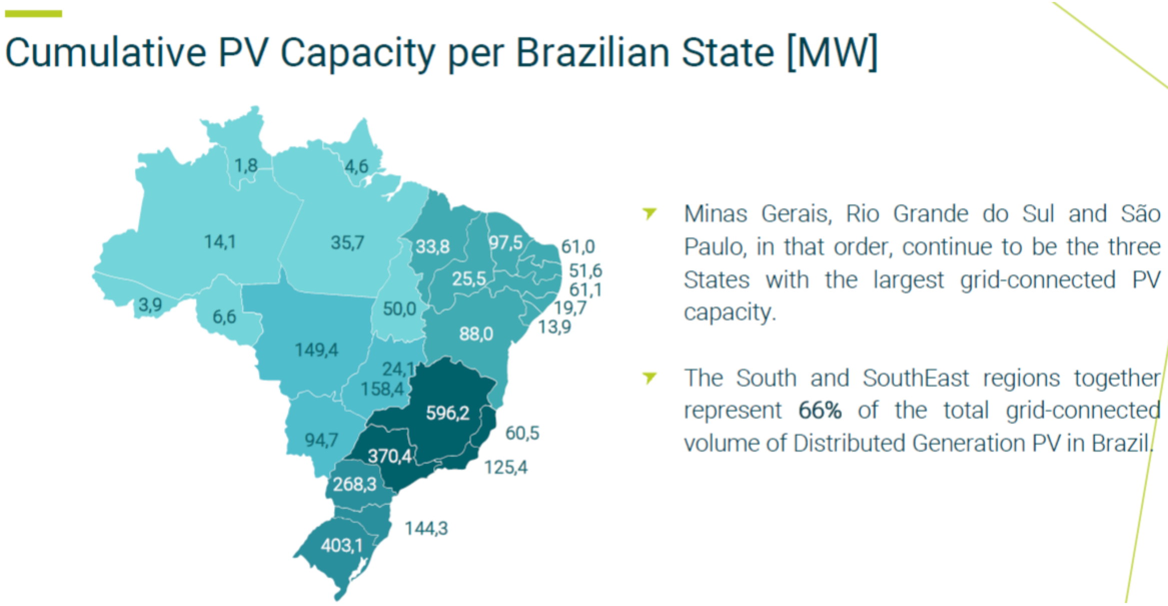


Figure 19 – Graph of cumulative PV capacity by Brazilian state in 2020 [Greneer, 2020]

It also highlights the social advantages that the distributed generation adds. Minimizing the environmental and social impacts of the surroundings that are related to the construction of plants, especially hydroelectric plants, which need a large area for construction, possible flooding of areas already occupied by communities, the displacement of these communities to other locations both by building plants and by passing transmission lines. Due to socio-environmental changes, some projects are under pressure so that there is no more reservoir to reduce these impacts. With a distributed generation this is not necessary. The improvement in health quality due to the non-emission of gases (in the case of thermoelectric plants), the generation of new jobs in places where GD is growing, according to [36] it is estimated that there will still be growth that can create new jobs.

One of the most important advantages is the reach of GD (if you choose the photovoltaic source). It is known that there are regions in Brazil where there is no electrification, and are generally considered to be rural areas that are distant from distribution points and transmission lines do not exist or are already at their capacity limit. As GD can be installed by its consumer, considered isolated systems, where there is no interconnection with the electrical system, these regions can enjoy the benefits of electricity that the population with access already have [GÓMEZ; SILVEIRA, 2015; SLOUGH; URPELAINEN; YANG, 2015].

The installation for the urban population (usually mostly connected to the interconnected system through distributors) generates mainly a reduction in the electricity bill. Such facilities can become a disadvantage for other consumers who do not have DG facilities. With these consumers producing their own energy and no longer consuming the energy already purchased by the distributor, it can generate an increase in the tariff for the others. One concern is low-income B1 consumers who are included in the tariff increase, as their tariffs are linked to the tariff of ordinary B1 consumers.

It can be assumed, taking into account the data in the graphs and knowing that GD is an incentive alternative, that the trend of this generation is to grow even more. With technological developments, photovoltaic panels can become increasingly attractive to residential consumers with not so high purchasing power. However, it is unlikely that the entire population will be able to be self-producing, and therefore will need supply from distributors, especially the low-income population. In the next chapter, a market model will be presented where this matter will be addressed.

4 Research Method

4.1 Initial Considerations

TAROT (Optimized Tariff) is a method developed by Professor Hector Arango over 20 years ago to improve the understanding of how the regulated electricity sector works. TAROT is a didactic tool, however, it has already been used in several relevant circumstances [CORTEZ et al., 2020; ARANGO et al., 2019; ARANGO et al., 2018; ARANGO et al., 2016; MACIEL, 2016]. With TAROT, it was possible to quantify the socioeconomic well-being of the electric energy market and thus carry out studies that allow us to see if certain public policies, standards, regulatory frameworks or any other measure that changes the sector's rules are improving or worsening and still show how the interaction between agents (GOVERNMENT, CONSUMERS or CONCESSIONAIRE) be. In this work, the TAROT will be used together with the Gini Index, where it will be determined which will be the optimum (within the electric market) between the increase in the tariff for part of residential consumers and the consequent decrease for another part in order to reduce the energy poverty that also ends up promoting a better income distribution.

4.2 TAROT

As already mentioned, TAROT is a model that represents the regulated electricity market. It is presented in the form of a flowchart, as shown in Figure 4-1. The flowchart allows visualizing the economic flows of the market in the electric sector in relation to the following agents:

- Government - Included in taxes and sector charges.
- Consumers - They are included in the utility, in the ECA, which is the surplus of the consumer and although it does not appear directly in the flowchart, they are also represented in the tariff.
- Concessionaire - They are represented by OPEX, CAPEX, revenue and EVA.
- Society - EWA is socioeconomic well-being.
- ANEEL - The order of the flowchart represents how the regulation of this market is carried out.

Following the flowchart, the first component is Utility (U), which is associated with consumer satisfaction in consuming a certain good or service. It can also be related

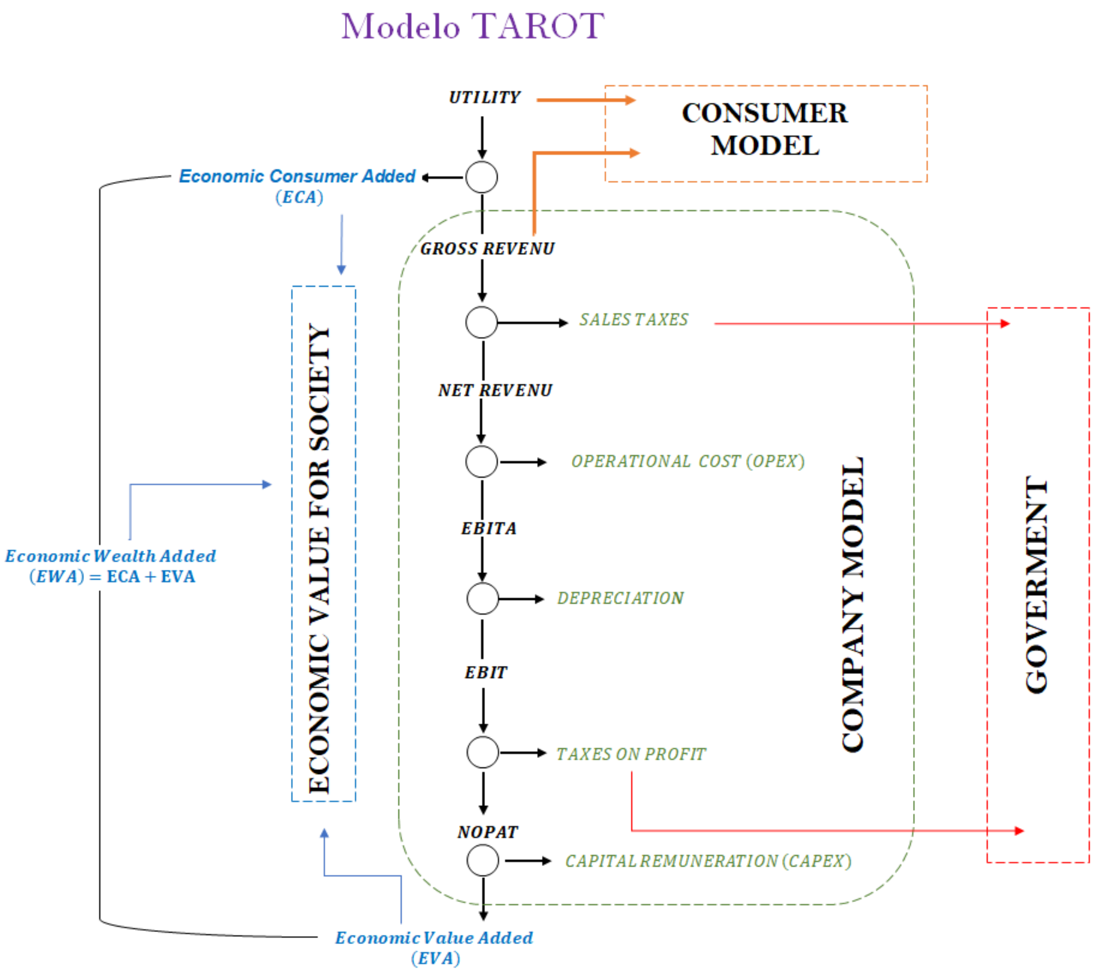


Figure 20 – Flowchart of the TAROT model [CORTEZ et al., 2020]

to how willing consumers are to pay for a good or service (B&S) (willingness to pay), which impacts the consumer's eagerness (a). Like almost everything in the world, there comes a time when the increase in the consumption of a good or service no longer adds the same satisfaction (or need), the consumer's is not willing to buy increases in quantity, having satiety (b) from the consumer for product, the product of this work being the amount of Electricity consumed. The economic utility (U) of electricity can be related to the avidity and satiety of the electricity consumer (E), being expressed by:

$$U(E) = aE - (\frac{b}{2})^2 \tag{4.1}$$

The price paid for energy (E) is called the tariff (T) and can be considered an economic sacrifice that the consumer makes to obtain the benefit of using electricity. On the other hand, for producers, this consumer sacrifice represents their benefit, that is, their revenue (R), which is represented by the following equation:

$$R(E) = aE - bE^2 \tag{4.2}$$

Analyzing the concepts of utility and revenue, the difference between them represents the consumer surplus ECA (Economic Consumer Added) or Surplus (S). Energy (E) is very useful for its consumers, so even though the purchase of a quantity (E) is a sacrifice at a Tariff (T), the benefit is greater than the sacrifice, that is, the idea of paying less than you think something is worth adds value to the purchase.

$$ECA(E) = U(E) - R(E) \tag{4.3}$$

The same is true for producers, but the variable to be considered is the cost $C(E)$. As already mentioned, revenue represents a gain for producers, however, to deliver energy to consumers there is a cost necessary to produce it, that is, there is a cost. This difference between how much was spent to produce the energy and deliver it and how much was produced by it (R) is the surplus of the producer EVA [46].

$$EVA(E) = R(E) - C(E) \tag{4.4}$$

The purchase and sale of energy takes place through the interaction of agents (consumers and producers) in this electricity market sector and converges until an equilibrium price is reached, this price being called the market price, or tariff (T) [47]. With a tariff (T) established for the purchase of energy, revenue (R) can be expressed as:

$$R(E) = T(E) - E \tag{4.5}$$

Within this context of ECA and EVA already explained, it is understood that all these agents are part of society, and, therefore, the sum of the producer and consumer surplus, ECA and EVA, respectively, form the value of socioeconomic well-being. EWA (Economic Wealth Added) created by the service. It is written:

$$EWA = ECA + EVA = (U - C) + (R - C) = U - C \tag{4.6}$$

The parameters a and b represent the consumer eagerness and the satiety, and are calculated using data from the tariff regulatory review process and consumer characteristics, by Equations (4.7) and (4.8), respectively:

$$a = (1 + \frac{1}{\varepsilon}) * T \tag{4.7}$$

$$b = \frac{E}{(\varepsilon * T)} \tag{4.8}$$

where: ε-consumers demand-price elasticity (assumed $\varepsilon = 0.055$).

The necessary costs are estimated according to the amount of energy sold and parameters equivalent to (a) and (b), in this case (m) and (n) respectively and an independent component of E.

$$C(E) = C_0 + mE + (\frac{nE^2}{2}) \tag{4.9}$$

Rational consumers always seek to maximize their surplus, and with this rational economic thinking it is possible to find Marginal Utility (UM), deriving Equation 4.1:

$$\frac{dU}{dE} = UM = T = a - bE \tag{4.10}$$

This allows to write the energy according to the tariff:

$$E = \frac{(a - T)}{b} \tag{4.11}$$

Replacing Equation 4.10 in 4.5, the Revenue is placed according to the energy sold.

$$R = T * E = (a - bE) * E = aE - bE^2 \tag{4.12}$$

In the specific case of the regulated electricity sector, the modeling of these expenses is a simplified approximation of all costs involved this activity. General costs are considered, such as operating costs, cost associated with losses and depreciation costs of assets.

Using Equation 4.9 and knowing that the total expenses and the dependence of each cost component in relation to the quantity supplied (E) and investments in the physical system or network (B), one can determine the cost function that the energy producer (distributor) has, denominated (G):

$$G = eE + \frac{p * E^2}{B} + d * B \tag{4.13}$$

where: eE — purchase of energy and operating costs,

$(p * E^2)/B$ — costs of technical and non-technical losses

dB — it is associated to depreciation of investments

e, p, d — are adjustable coefficients that aim to approximate the costs to the real situations.

All these costs have so far been directly linked to the activity of buying and selling energy. However, as already stated in Chapter 2, there are other costs to be considered in the model.

Income tax ($IRPJ$) is, according to tax legislation, a proportional part of the so called Taxable Profit ($EBIT$) which is the result of subtracting costs (C) from revenue (R). The government establishes a rate (t) on this profit. That is:

$$IRPJ = EBIT * t = t(R - C) \tag{4.14}$$

After the tax is collected, what is left is called NOPAT - *Net Operating Profits After Tax*. From there, the capital remuneration (Y) (shareholders) is withdrawn:

$$Y = r_w * B \tag{4.15}$$

where r_w is the coefficient of return on invested capital (WACC) [48] established by ANEEL.

When the company is in economic-financial equilibrium (EEF), when capital is paid, there is no excess or lack of money. That is, $EVA = 0$.

Therefore, it have the total market cost:

$$C = \underbrace{G}_{\text{spending}} + \underbrace{t(R - C)}_{\text{Tax}} + \overbrace{r_w * B}^{\text{capital remuneration}} \tag{4.16}$$

Or yet:

$$C = tR + (1 - t) * \left(G + \frac{r_w B}{1 - t}\right) \tag{4.17}$$

Isolating the terms referring to depreciation and return on capital, we have:

$$C = tR + (1 - t) * \left[eE + \frac{p * E^2}{B} + B * (d + \frac{r_w}{1 - t})\right] \tag{4.18}$$

Where:

$$K = d + \frac{r_w}{1 - t} \tag{4.19}$$

Next:

$$C = tR + (1 - t) * \left[eE + \frac{p * E^2}{B} + B * k\right] \tag{4.20}$$

The following statement can be made: Every parcel containing investment B will be minimal when the value of B is optimal B^*, that is:

$$\frac{\partial C}{\partial B} = 0 \rightarrow p\frac{E^2}{B^2} = k \tag{4.21}$$

Rewriting:

$$B^* = \left(\frac{p}{k}\right)^{\frac{1}{2}} * E \tag{4.22}$$

$$z^* = tR + (1-t) * \left[eE + \frac{p * E^2}{\left(\frac{p}{k}\right)^{\frac{1}{2}} * E} + \left(\left(\frac{p}{k}\right)^{\frac{1}{2}} * E\right) * k\right] = \left(e + 2 * (pk)^{\frac{1}{2}}\right) * E \tag{4.23}$$

$$c = e + 2 * (pk)^{\frac{1}{2}} \tag{4.24}$$

Having defined the model's cost structure, Figure 4-2 illustrates a flowchart of the model and its components.

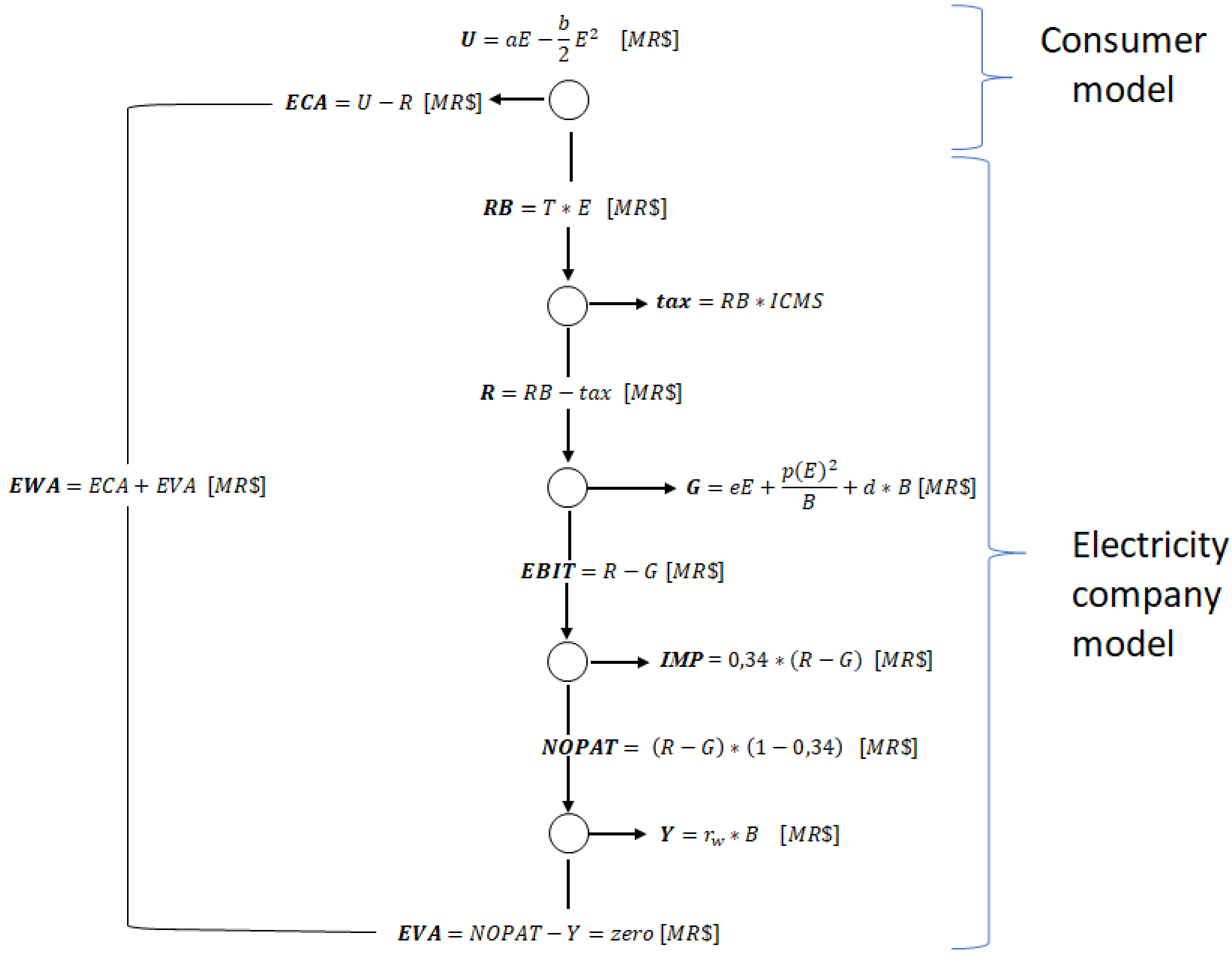


Figure 21 – Economic flow diagram of a regulated electricity distribution market [PEREIRA et al., 2013].

4.2.1 The Influence of Income on Consumption

In order to modeling the influence of individual disposable income (Y) on the quantity consumed, it is convenient to express (E^*) as :

$$E^* = p - qT \tag{4.25}$$

where (p, q) are notions parallel to the consumer's eagerness and satiety ($p = ab^{-1}$, $q = b^{-1}$).

The role of income is manifested by its effects on preference. Common sense says to express them as an increase in p and a decrease in q. In other words, the higher income stimulates eagerness and postpones satiety.

Assuming that the consumer is faced with multiple goods and services ($B\&S$), whose prices form a vector Θ, the individual buys a basket $\underline{Q}$, where each element is the quantity of a $B\&S$, and each basket offers a utility.

$$U = \underline{A}'\underline{Q} - \frac{1}{2}\underline{Q}'\underline{\underline{B}}\,\underline{Q} \tag{4.26}$$

Where $\underline{\mathrm{A}}$ is an eagerness vector and $\underline{\underline{\mathrm{B}}}$ is a satiety vector.

On the other hand, the person has a Y income. It can be said then:

$$\underline{\Theta}'\underline{Q} \leq Y \tag{4.27}$$

If the ideal basket exceeds the income in cost, the sign (=) is worth.

$\boxed{M\acute{A}XU\text{, subject to: } \underline{\Theta}'\underline{Q} = Y}$

This is a problem of optimal conditioning, which can be resolved through the Lagrange method, which has the function:

$$\mathcal{L} = U - \lambda(\underline{\Theta}'\underline{Q} - Y) \tag{4.28}$$

Imposing the annulment of the derivative:

$$\frac{\partial \mathcal{L}}{\partial \underline{Q}} = \underline{A} - \underline{\underline{B}}\,\underline{Q} - \lambda\underline{\Theta} = 0 \tag{4.29}$$

Next:

$$\underline{Q} = (\underline{A} - \lambda\underline{\Theta})\underline{\underline{B}}^{-1} \tag{4.30}$$

λ being an auxiliary scalar variable and that can be explained by imposing the income restriction:

$$\underline{\Theta}'\underline{Q} = \underline{A}'\underline{\underline{B}}^{-1}\underline{\Theta} - \underline{\Theta}\,\underline{\underline{B}}^{-1}\underline{\Theta}\lambda = Y \tag{4.31}$$

Finally:

$$\lambda = \frac{\underline{A}'\underline{\underline{B}}^{-1}\underline{\Theta} - Y}{\underline{\Theta}\,\underline{\underline{B}}^{-1}\underline{\Theta}} \tag{4.32}$$

Replacing 4.32 in 4.30 results:

$$\underline{Q} = \left(\underline{A} - \frac{\underline{A}'\underline{\underline{B}}^{-1}\underline{\Theta} - Y}{\underline{\Theta}\,\underline{\underline{B}}^{-1}\underline{\Theta}} * \underline{\Theta}\right)\underline{\underline{B}}^{-1} \tag{4.33}$$

A user's consumption vector is obtained according to:

- Your Y income ;
- Your preference for $B\&S's(A, B)$
- The prices of $B\&S'S$.

4.3 The distribution company, *prosumers* and low-income consumers

The superposition of distributed generation with social tariffs will be experienced using the model previously explained in order to study the distribution company. Since the energy purchased by the concessionaire is sized for its entire periodic tariff review (RTP) process, it relies on all consumers to have the necessary revenue to achieve economic-financial balance. Figure 24 shows the economic flow diagram for the company in the scenario without a *prosumer*.

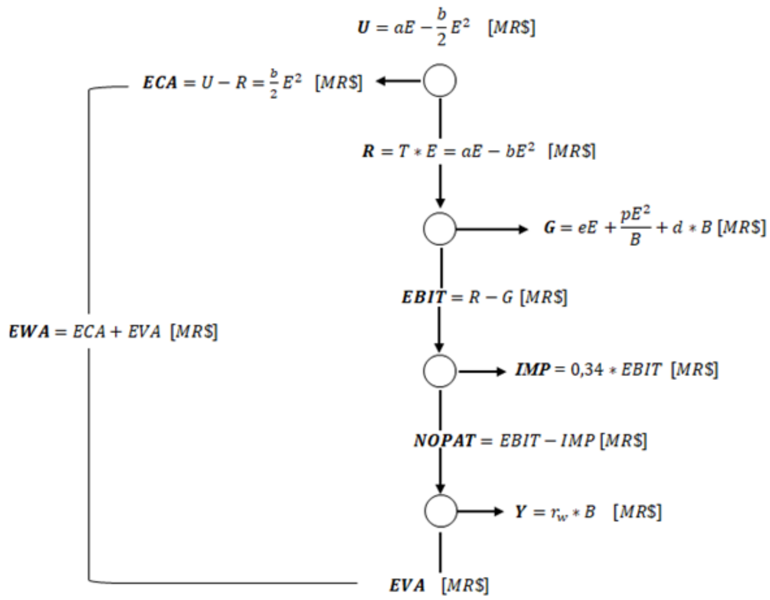


Figure 22 – Economic flow diagram of a regulated electricity distribution market with EVA= 0 [PEREIRA et al., 2013].

In view of the upward trend in electricity tariffs (mainly in scenarios with tariff flags) observed in Figure 4-4 and as mentioned in the previous chapter, the costs for installing photovoltaic panels have fallen, making it more attractive to change consumer B1 to prosumer. In other words, there is a confluence of assistance based on the benefit of the less affluent and the entrepreneurship of those who accept to become mini producers of electricity.

Assuming that a δ percentage of consumers migrate to their own generation, the distributor's revenue will no longer be sufficient to cover all costs and, therefore, will have losses ($EVA < 0$). Figure 23 shows the economic flow diagram that represents this scenario.

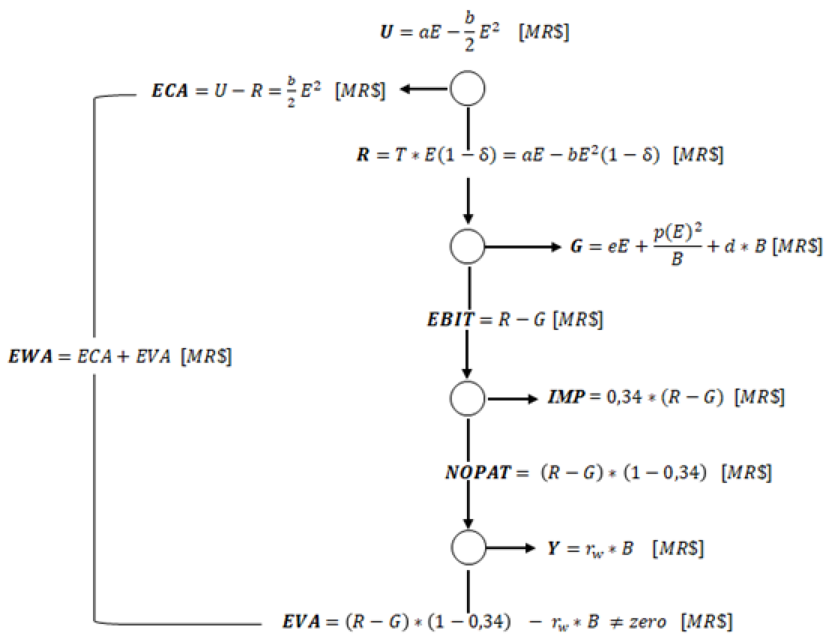


Figure 23 – Economic flow diagram of a regulated electricity distribution market [PEREIRA et al., 2013].

For the company to regain balance, it would be necessary to pass on this lack of revenue (to cover all costs with the purchase of energy) to consumers who continued to depend on the distributor. It is clear that there must be an increase in the tariff for this to be possible. An increase in the rate of B1 consumers reflects directly on the rate of low-income B1 consumers, as they earn a percentage discount from the B1 rate. This would generate a phenomenon that can be called "reverse Robin Hood"which allows a consumer who has GD to zero or almost zero his account, while his neighbor who does not have GD ends up paying the costs of his connection, the 'wire '. According to the president of ABRADEE (Brazilian Association of Electricity Distributors) Nelson Leite, this phenomenon is perverse for the distributor and for those without GD [53].

With that in mind, and to ensure that low-income residential consumers will not suffer from the insertion of prosumers, nor will the company suffer losses, we have:

The reference of electricity tariff (T_R) - After calculating the TAROT parameters for a distribution company, it is possible to determine the optimized tariff without separation between the types of consumers. The reference tariff (T_R) is the smallest tariff that consumers B1c and Low would pay (all prosumers, B1c and Low pay for the energy purchased (E)).

Splitting the percentage of energy between prosumers (δ) and common consumers

(1-δ), one can determine the value of the tariff needed to be paid by prosumers assuming that the common consumers continue to pay the reference tariff. The company's revenue can then be rewritten as in Equation (4.34):

$$R = T_{pro} * E_T * \delta + T_R * E_T * (1 - \delta) \tag{4.34}$$

Putting Equation 4.35 in terms of the tariff:

$$R = E_{pro} * T_{pro} + T_R * \left(\frac{a - T_R}{b}\right) * (1 - \delta) \tag{4.35}$$

The cost equation can be modeled according to Equation 4.13, placing the costs according to the amount of energy that the distributor must buy for its captive consumers:

$$G = e * E_T * (1 - \delta) + \frac{p * E_T^2}{B} * (1 - \delta) + d * B \tag{4.36}$$

$$G = e * \left(\frac{a - T_R}{b}\right) * (1 - \delta) + \frac{p * \left(\frac{a - T_R}{b}\right)^2}{B} * (1 - \delta) + d * B \tag{4.37}$$

Where: E_pro - Prosumers energy T_pro - Rate for prosumers - Percentage of energy due to prosumers (assumed, for this academic study as 10%) E_T - Common consumers $B1$ energy

So,

$$EBIT = R - G \tag{4.38}$$

Next:

$$IMP = EBIT * 0.34 \tag{4.39}$$

It can be said that NOPAT will be:

$$NOPAT = EBIT * (1 - 0.34) \tag{4.40}$$

Capital remuneration:

$$Y = r_w * B \tag{4.41}$$

And finally, EVA:

$$EVA = EBIT * (1 - 0.34) - r_w * B \tag{4.42}$$

To guarantee EEF:

$$EVA = EBIT * (1 - 0.34) - r_w * B = 0 \tag{4.43}$$

Replacing Equations 4.35 and 4.37 in 4.43:

$$EVA = (R - G) * (1 - 0.34) - r_w * B = 0 \tag{4.44}$$

$$EVA = \left[E_{pro} * T_{pro} + T_R * \left(\frac{a-c}{b}\right) * (1-\delta) - e * \left(\frac{a - T_R}{b}\right) * (1-\delta) + \frac{p * \left(\frac{a-T_R}{b}\right)^2}{B} * (1-\delta) + d * B \right] * (1 - 0.34) - r_w * B = 0 \tag{4.45}$$

Knowing all the variables in Equation 4.45 except the value of T_{pro}, it is possible to obtain the amount that prosumers must pay so that there is EEF (Economic-Financial Balance) and low-income consumers continue paying the same.

Now, the model can be deeper detailed in revenue and energy consumption type, for 3 types of consumers: $B1c$ -common consumers, Low-low-income consumers and Prosumers (those who produce their own energy). Thus, knowing the percentage of energy consumed by Low-income consumers (β) with respect to common consumers, the company's revenue can be rewritten according to the energy used by each consumer class and the energy tariff paid by each of them, as presented in Equation (4.47):

$$E_T = (1-\delta) * \left[(1-\beta) * \underbrace{\left(\frac{a - T_{B1c}}{b}\right)}_{\boxed{\mathrm{E}_{B1c}}} + \beta * \underbrace{\left(\frac{a - T_R(1 - disc)}{b}\right)}_{\boxed{\mathrm{E}_{low}}} \right] \tag{4.46}$$

Then, there is the new revenue:

$$R = E_{pro} * T_{pro} + (1-\delta) * \left[(1-\beta) * \left(\frac{a - T_{B1c}}{b}\right) * T_{B1c} + \beta * \left(\frac{a - T_R(1-disc)}{b}\right) * T_R(1 - disc) \right] \tag{4.47}$$

Therefore, costs will be:

$$G = e * E_T * (1-\delta) + \frac{p * E_T^2}{B} * (1-\delta) + d * B \tag{4.48}$$

$$G = e*(1-\delta)*\left[(1-\beta)*\left(\frac{a-T_{B1c}}{b}\right)+\beta*\left(\frac{a-T_R(1-disc)}{b}\right)\right]+\frac{p*\left((1-\delta)*\left[(1-\beta)*\left(\frac{a-T_{B1c}}{b}\right)+\beta*\left(\frac{a-T_R(1-disc)}{b}\right)\right]\right)^2}{B}+d*B \tag{4.49}$$

Where:

β - Percentage of energy consumed by Low-income consumers.

E_{B1c} - Energy consumption by common consumers

E_{Low} - Energy consumption by low-income consumers

T_{B1c} - Tariff of common consumers

$disc$ - Tariff discount

So,

$$EBIT = R - G \tag{4.50}$$

Next:

$$IMP = EBIT * 0.34 \tag{4.51}$$

It can be said that NOPAT will be:

$$NOPAT = EBIT * (1 - 0.34) \tag{4.52}$$

Capital remuneration:

$$Y = r_w * B \tag{4.53}$$

And finally, EVA:

$$EVA = EBIT * (1 - 0.34) - r_w * B \tag{4.54}$$

To guarantee EEF:

$$EVA = EBIT * (1 - 0.34) - r_w * B = 0 \tag{4.55}$$

Replacing Equations 4.35 and 4.37 in 4.43:

$$EVA = (R - G) * (1 - 0.34) - r_w * B = 0 \tag{4.56}$$

$$\begin{split} EVA = {} & \Bigg[E_{pro} * T_{pro} + (1 - \delta) * \left[(1 - \beta) * \left(\frac{a - T_{B1c}}{b}\right) * T_{B1c} + \beta * \left(\frac{a - T_R(1 - disc)}{b}\right) * T_R(1 - disc)\right] \\ & - e * (1 - \delta) * \left[(1 - \beta) * \left(\frac{a - T_{B1c}}{b}\right) + \beta * \left(\frac{a - T_R(1 - disc)}{b}\right)\right] + \frac{p * \left((1 - \delta) * \left[(1 - \beta) * \left(\frac{a - T_{B1c}}{b}\right) + \beta * \left(\frac{a - T_R(1 - disc)}{b}\right)\right]\right)^2}{B} + d * B\Bigg] \\ & * (1 - 0.34) - r_w * B \end{split} \tag{4.57}$$

The intent prosumers consumption tends to be low and their compensation mechanism for the surplus of generated energy uses the same tariff in the present regulation. So, only the common consumers are overcharged due to the tariff percentage of discount applied to get the TSEE. Using Equation (4.47) and knowing that the discount at TSEE will be given on the reference tariff (T_R), the only term to be determined is the common energy tariff (T_{B1c}). Thus, it can be determined how the public policy impacts on all common consumers. For this it is given the discount that is already considered in Table **??**. It was chosen the value of 10% and the value of 65%. A suggestion of new public policy is to withdraw the tax over sales (ICMS) ceasing to be a cross-subsidy, as will be demonstrated later.

Figure 24 presents a flowchart with the steps of the study.

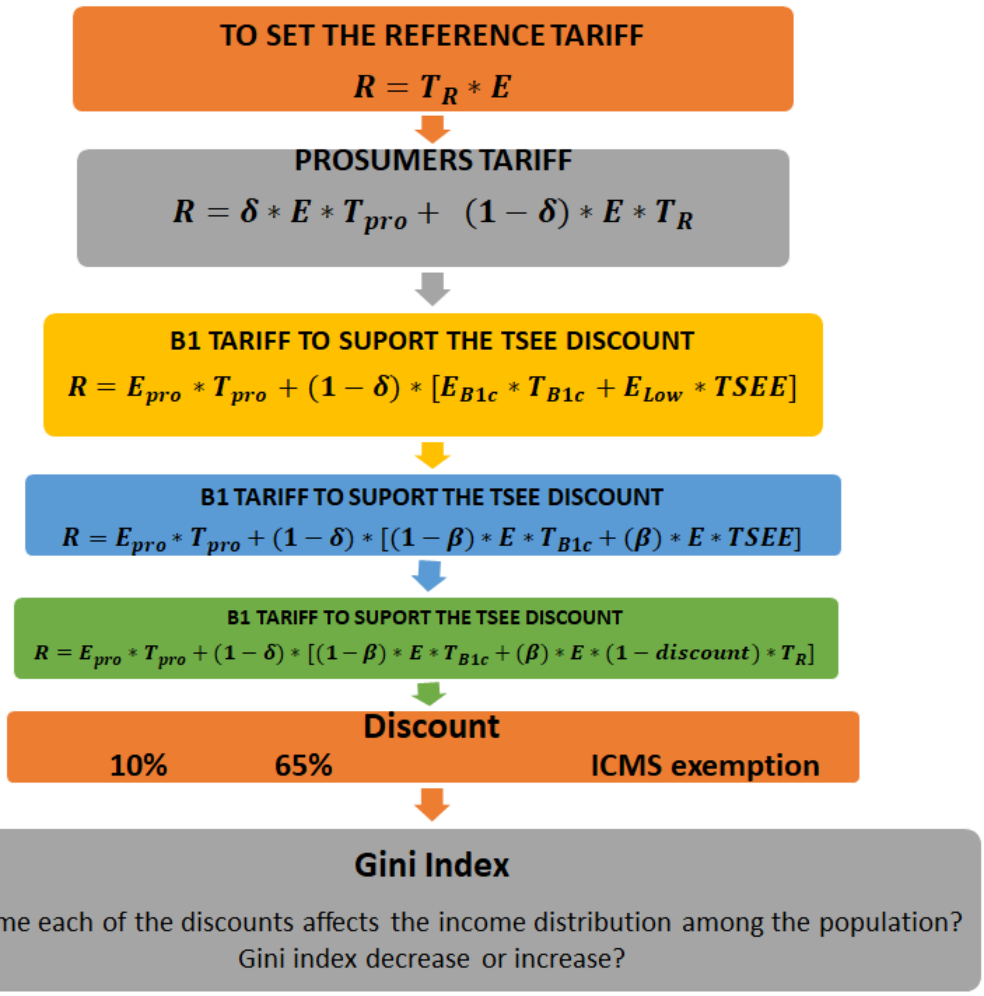


Figure 24 – Flowchart of the steps implemented in this study.

In order to assess the income distribution, it is used the GINI index, since this is a widely used method for evaluating inequality in income distribution as exemplified in [BURRELL, 1992; WENLI; PING; ZHIGANG, 2016; GASTWIRTH, 1972].

4.3.1 The measure of inequality: Gini Index

This is a time when it is no longer possible to ignore the ecological and environmental impact on economic thinking. This impact extends to economic engineering to the extent that the merit of the projects is affected by the ecological and environmental consequences of their implementation.

Such consequences affect individuals collectively, that is, they impact society as a whole.

To measure social effects, it is necessary to study the aggregates of individuals in their statistical composition, such as income, age and another variables. The objective is to explain the basic principles of this approach.

Economic engineering deals with projects, especially those that are inserted in corporations in order to make them more efficient and beneficial, both internally and in their social role.

But how to express the company's effect on society? For this, first of all, it is essential to study the composition of individual aggregates, that is, how they are distributed in the social environment to which they belong.

Starting with the composition of a group of individuals in terms of their income, in general, these groups involve a large number of them, so it is convenient to define a continuous variable (v) that goes from zero to the total number of members. Thus, the income of the nth individual can be expressed as 4.59:

$$\int_{n-1}^{n} y(v)dv \tag{4.58}$$

$y(v)$ being the group's income distribution. And still,

$$z = \int_{0}^{n} y(v)dv \tag{4.59}$$

such as total group income, or accumulated income.

If all y_n incomes are equal, the income distribution is perfectly uniform. As the y_n incomes differ, the distributions will be less uniform, until the extreme case of having a single individual or family holding the total disposable income [51]. When the accumulated proportion of income (z) varies as a function of the cumulative proportion of the population (p), with individuals being ordered by increasing values of income, there is the Lorenz curve [52], illustrated in Figure 25.

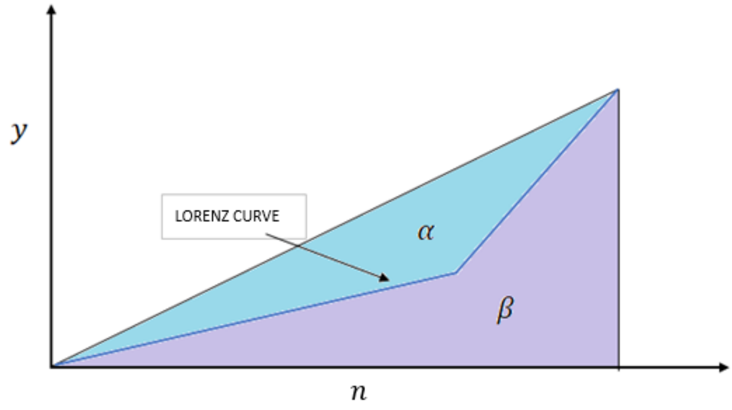


Figure 25 – Lorenz curve illustration

By definition, Gini's Index (or Coefficient) is a relationship between the area of inequality, indicated by α and the area of the triangle. Therefore:

$$Gini = \frac{\alpha}{\alpha + \beta} \tag{4.60}$$

Figure 26 represents the difference in Gini Index when the population receive some income benefit.

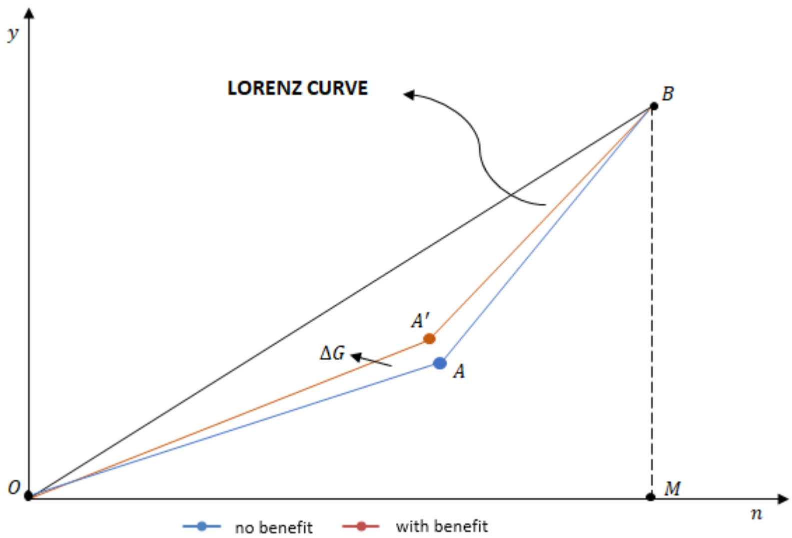


Figure 26 – Lorenz curve illustration

$$G = \frac{OAB}{OBM} \tag{4.61}$$

$$G' = \frac{OA'B}{OBM} \tag{4.62}$$

$$\Delta G = G - G' = \frac{OA'BA}{OBM} \tag{4.63}$$

Note that perfect equality implies that the area of 45º is the Lorenz curve itself and in the case of maximum inequality, the Lorenz curve is superimposed on the horizontal axis until the last element that has positive income. Thus, the limits of the Gini Index are $0 \leq G \leq 1$, with 0 being the maximum equality and 1 the maximum inequality.

4.3.2 Simplified Model to Represent Income Distribution

It is assumed that the share ($\alpha < 0.50$) of the wealthiest inhabitants receives total income equal to the share ($\gamma > 0.50$) of the country's total income. Figure 27 and the observations made in sub-chapter 4.3.2 illustrate the simplified model.

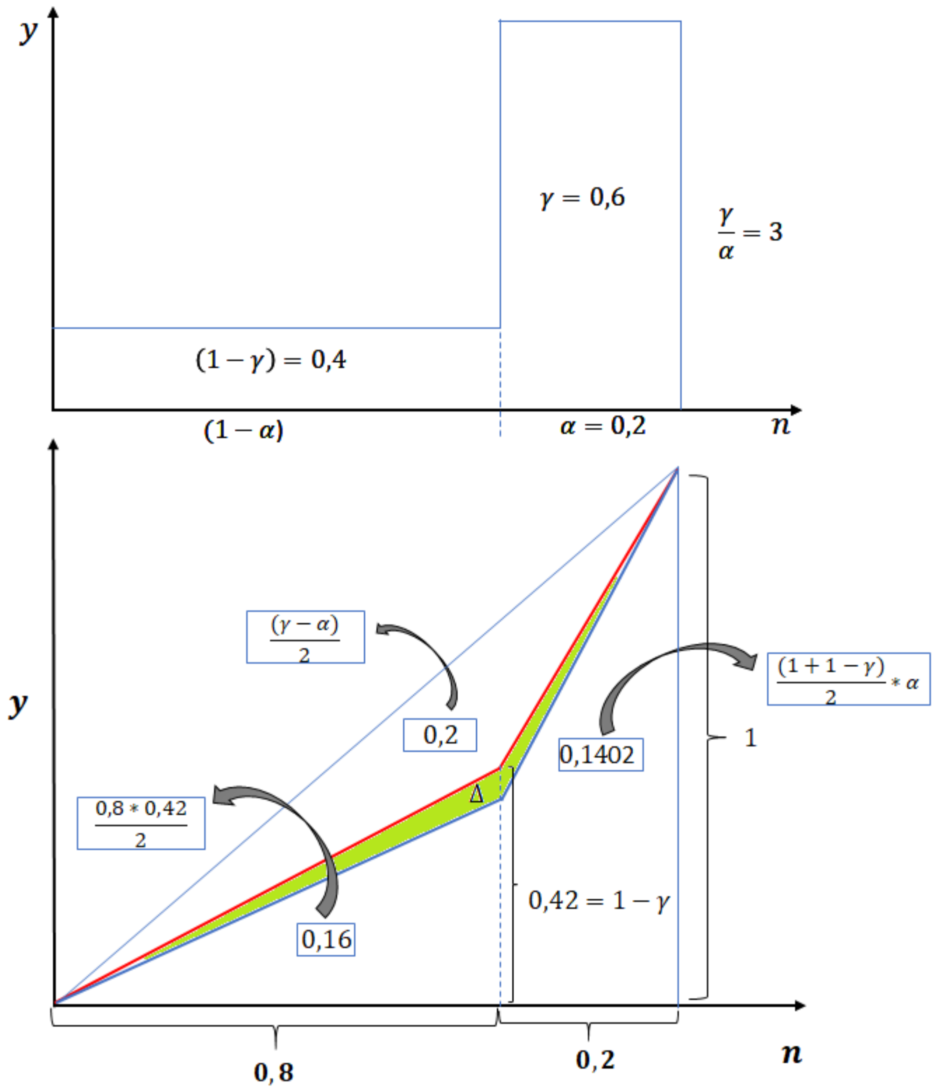


Figure 27 – Simplified model to Represent Income Distribution

Next:

$$Gini = \frac{0.2}{0.2 + 0.3} = 0,4 \tag{4.64}$$

where Δ = Total value of the low-income discount.

When the tariff value is increased for a large part of the population favoring another part, the socioeconomic value tends to fall, as it increases the sacrifice of consumers to obtain the same amount of energy. However, this difference ends up providing an increase in the income of the less favored, since they have in the reduction of the tariff the increase in their income because, if before they used to spend X with the electric bill, now they will spend $X - \Delta X$. In addition to the possibility of having more access to electricity and all the conveniences it provides. Then, it can be said that there was a relative transfer of income from the richest to the poorest, and this indicates a reduction in the inequality. For this study, the distribution of income was based on [IBGE, 2017] and it was assumed that only 10% [OKUSHIMA, 2017] of their income was spent on electricity bills.

4.4 Model Application

It is taken as an example, a fictitious distribution company whose parameters represent the distribution company and the consumers, respectively. Data from Tables 8 and 9, which are based on a typical company at the Brazilian electricity sector, will be used for didactic purposes and ease of calculations.

Table 8 – Regulated Distribution Company parameters

Parameters	Value
Remuneration Base (BRC)	1080 $[MR\$]$
Cost and Operations Factor (e)	240 $[MR\$/TWh]$
Loss Factor (p)	3600 $[MR\$^2]/[TWh^2]$
Depreciation Factor (d)	0.1
Capital Remuneration Rate (r_w)	9.9%
Tax on Net Income (t)	34%

Table 9 – Consumers' parameters

Parameters	Value
Eagerness (a	4800 $[R\$/MWh]$
Satiety (b)	500 $[R\$/MWh^2]$
consumed Energy (E)	9 $[TWh]$

Using Equation 4.24, the tariff for this context (reference tariff) is calculated:

$$c = e + 2 * (pk)^{\frac{1}{2}} = 240 + 2 * (3600 * 0,25)^{\frac{1}{2}} = 300[R\$/MWh] \tag{4.65}$$

With the values of the parameters, it is possible to calculate the economic flow diagram of the TAROT model for the concessionaire in EEF when there is no presence of prosumers, as illustrated in Figure 28.

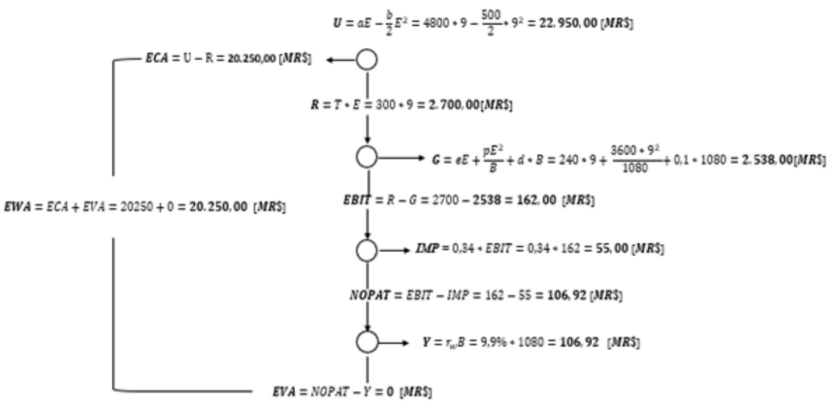


Figure 28 – Monetary flowchart of a regulated company.

Now supposing that half of the consumers ($\delta = 0.5$) have become prosumers and produce all the energy they need, that is, they do not consume energy from the network and do not inject energy into the network, and even the ordinary consumers (who cannot or do not want to be prosumers) will continue to pay the same amount as before and assuming that eagerness and satiety will be the same for everyone. it is possible to determine the rate that prosumers must pay.

$$E_Pro = 9 * \delta = 9 * 0.5 = 4.5[TWh] \quad E_T = \left(\frac{a-c}{b}\right) * (1 - \delta) = 4.5[TWh]$$

$$\delta = 0.5 \quad c = R_T = 3000[R\$/MWh]$$

Using Equations 4.35 to 4.45, it get the economic flow diagram of Figure 29.

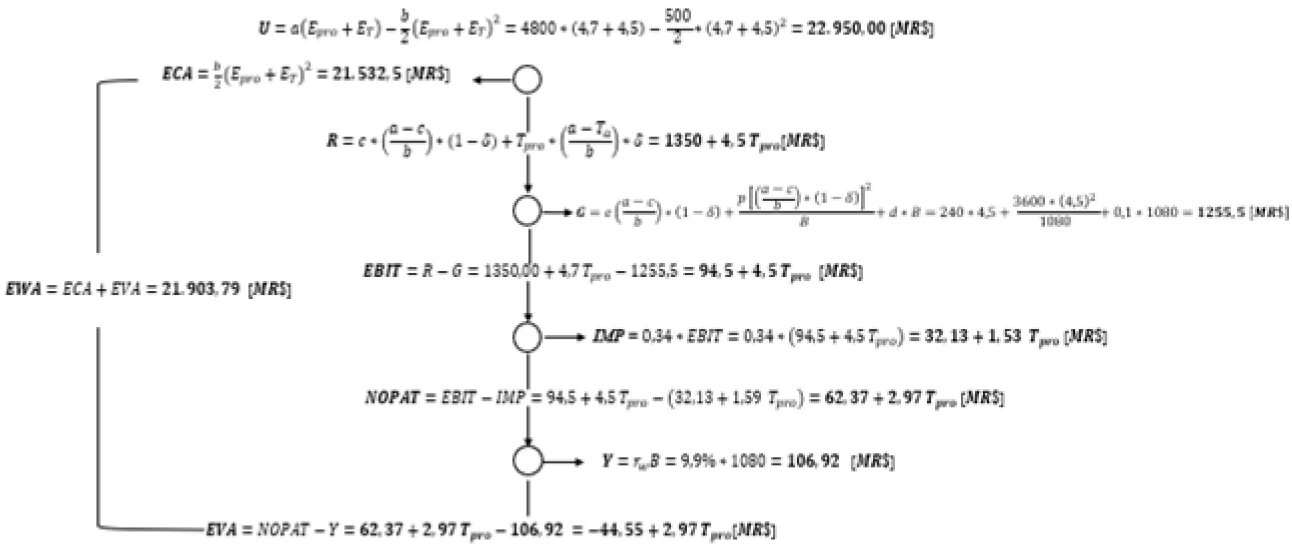


Figure 29 – Diagram of economic flows of a regulated company with prosumer.

By making $EVA = 0$, it can determine the price of the prosumers' tariff:

$$T_{pro} = \frac{44.55}{2.97} = 15[R\$/MWh]$$

Substituting the tariff value, it get the economic flow diagram shown in Figure 30.

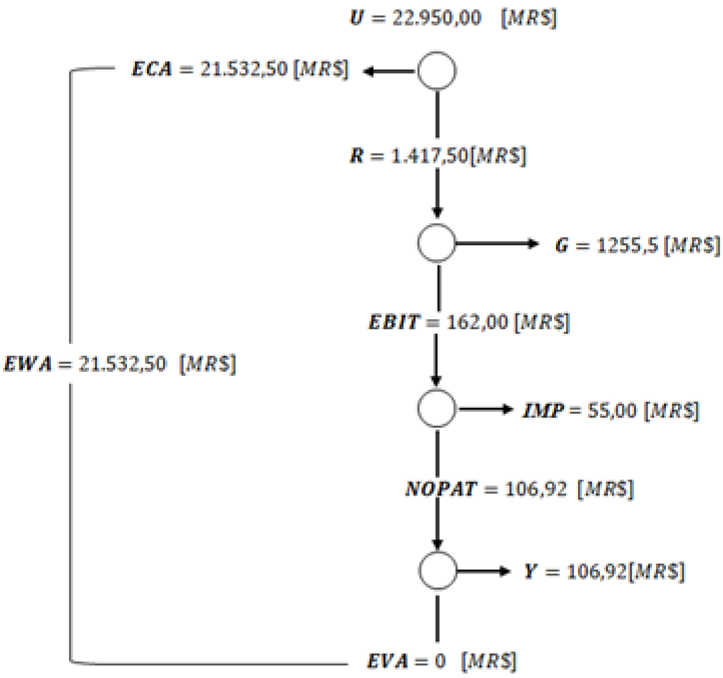


Figure 30 – Diagram of economic flows for prosumers and common consumers.

After the prosumers' tariff is determined, the amount to be paid by low-income consumers will be fixed as a discount on the reference tariff (c) before the prosumers. And so, it will be determined how much will be paid by common consumers.

With Equations 4.46 to 4.57, the market can be represented with prosumers, ordinary consumers and low-income consumers. Figure 31 shows the diagram of economic flows.

$$\beta = 0.15 \quad c = R_T = 3000[R\$/MWh] \quad disc = 50\%$$

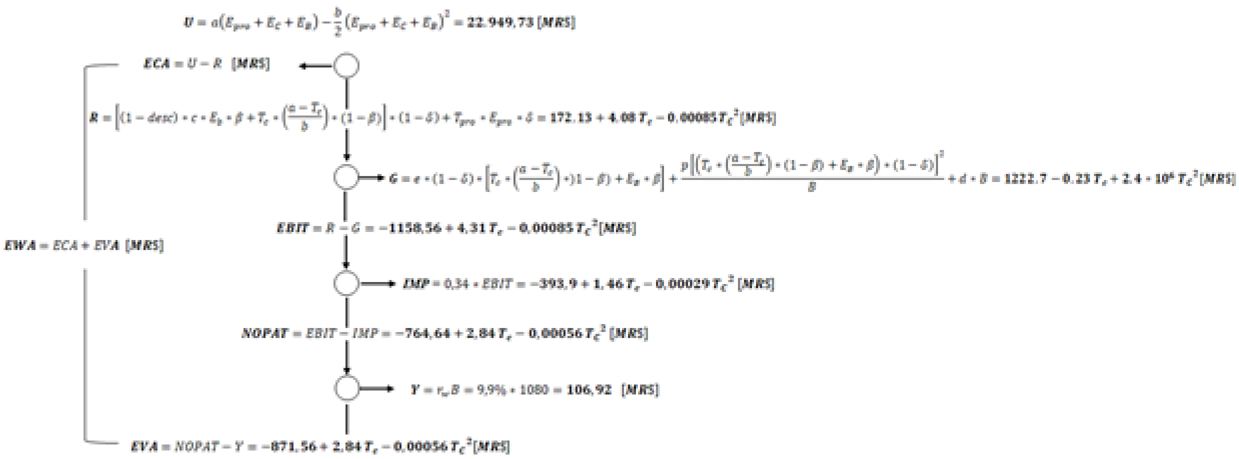


Figure 31 – Diagram of economic flows of a regulated company with prosumer, low-income and common consumers.

As can be seen in Figure 4-11 for EVA to be zero, you need to solve the second degree equation. From this resolution, the following value is found for tariff (T_{b1c} or T_c):

$$T_c = T_{B1c} = 327,52[R\$/MWh]$$

The social tariff remains a discount on the tariff of common consumers, and so its value is:

$$T_b = T_{low} = c * (1 - disc) = 300 * (1 - 50\%) = 150[R\$/MWh]$$

Replacing the value of T_{B1c} in the flowchart, Figure 4-12 is arrived at.

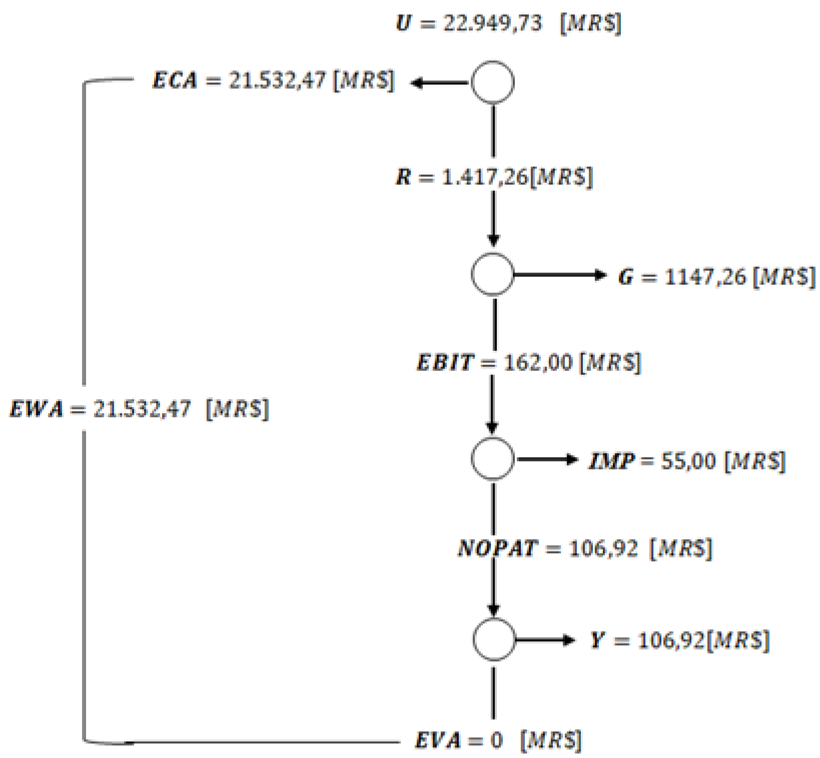


Figure 32 – Final diagram of economic flows of a regulated company with prosumer, low income and common consumers.

You can then see the change in social or “collective” well-being (EWA) when there is a division only between prosumers and ordinary consumers (where there is no tariff discount, since consumers were not discriminated between common and low-income), and when there is a separation of the 3 types of consumers studied (see Table 10).

Table 10 – Comparison between the discounted and not discounted models.

	Tariff discount		increase / decrease [%]
	ZERO	50%	
$E_T[TWh]$	4.5000	4.4991	-0.02
$E_{B1c}[TWh]$	3.8250	3.8016	-0.612
$E_{Low}[TWh]$	0.6750	0.6975	3.33
$EWA[MR\$]$	21,532.5	21,532.4728	-0.00013
$T_{B1c}[R\$/MWh]$	300.00	327.53	9.18
$R_T * (1 - disc)[R\$/MWh]$	300.00	150.00	50

One can also express the EWA as a ΔEWA:

$$\Delta EWA = -0.0272$$

Following the 50% reduction in the social electric energy tariff and assuming that the electricity bill represents a 10% expenditure on the income of less affluent consumers, that is, there will be a 5% reduction in energy expenditure, it is possible to say that there will be an equal increase in income. Thus, with the help of Figure 27, the new Gini Index for the population is calculated based on sub-chapter 4.3.2:

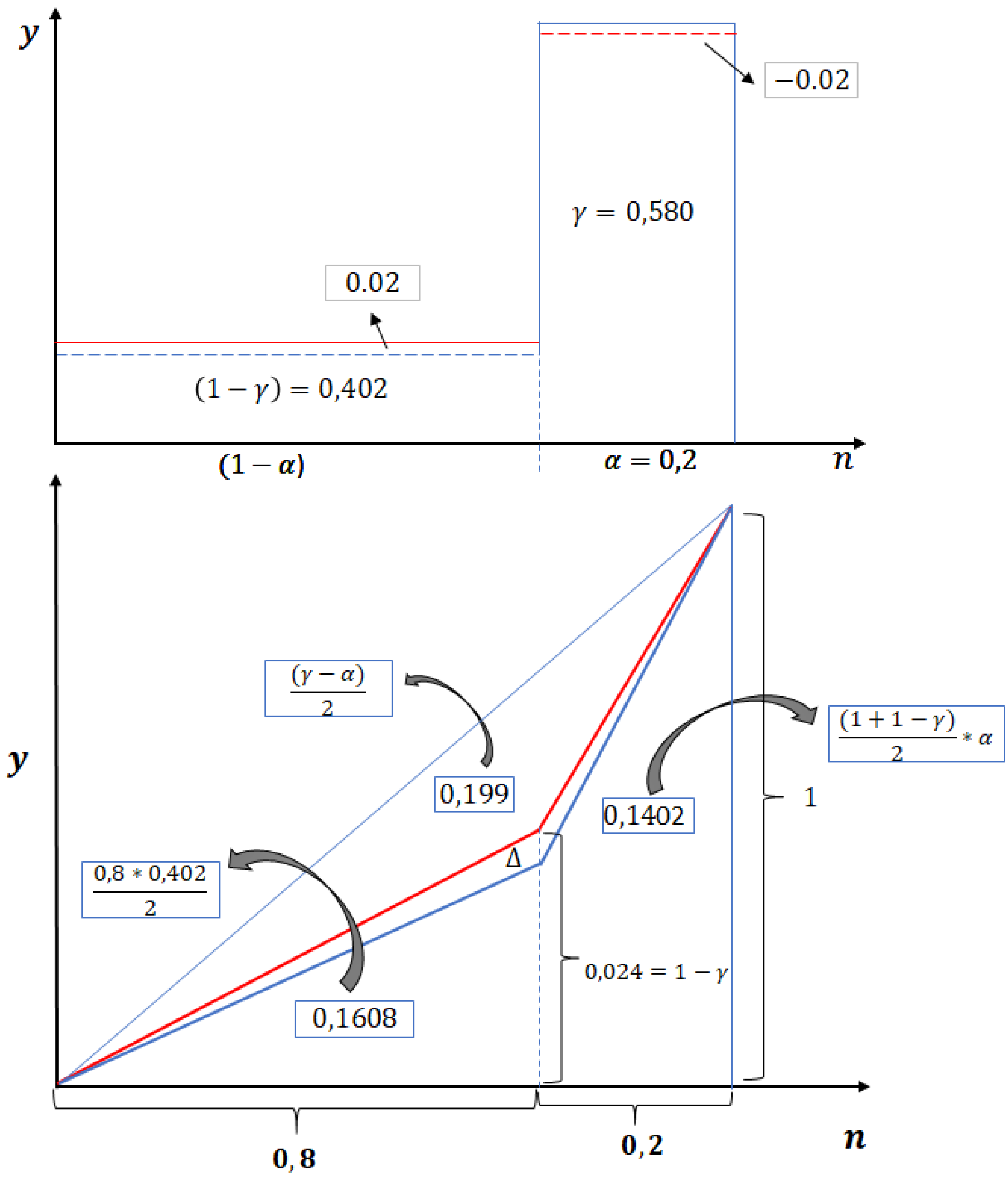


Figure 33 – Simplified model to represent the distribution of the new income.

$$NewGini = \frac{0.199}{(0.199 + 0.301)} = 0.398$$

Making a comparison between the values of the indexes it is possible to obtain the $\Delta Gini$:

$$\delta Gini = 0.4 - 0.398 = 0.002$$

Analyzing the value of τ considering the social and economic situation in Brazil, giving more importance to improving income distribution (and reducing "energy poverty" that is linked to the increase in energy consumption observed in Table 10) than the loss of collective well-being makes sense, as this creates a chance to reduce the gap between the less affluent population and the more affluent class.

This model will be applied to energy distributors in Brazil, one per state, to have a real overview of how how conditions are in each of these regions and to be able to deepen in some situations.

5 Real Case Study

In this section, the simulation will be carried out following the model proposed here for all states in Brazil, with one concessionaire per state chosen. Table 11 presents the data of the concessionaires as well as Table 12 presents the data of the consumers of each one of them.

Table 11 – Regulated Distribution Company parameters

	Parameters					
Distribution companies	**BRC** $[MR\$]$	r_w	**d**	**e** $[R\$/MWh^2]$	**p** $[R\$^2/MWh^2]$	**t** [%]
COELBA	12,898.65	7.5%	3.9%	366.02	29457.29	34
CELPA	4,364.37	8.1%	4.1%	341.59	42966.71	34
COSERN	1,590.19	7.5%	3.9%	322.17	9694.85	34
CELG	3,351.53	7.5%	3.8%	366.48	9075.14	34
CEMIG	15,355.84	7.5%	3.8%	392.70	23251.64	34
RGE	2,617.34	7.5%	3.6%	340.42	8136.71	34
EQUATORIAL PIAUÍ	617.17	7.5%	4.0%	340.42	10159.88	34
CELPE	6,246.99	8.1%	4.0%	333.32	28158.37	34
CEMAR	4,981.83	8.1%	3.8%	409.05	41367.54	34
ENEL CEARÁ	4,588.71	8.1%	3.8%	363.71	15429.11	34
COPEL	9,170.99	8.1%	3.7%	415.07	13231.76	34
CELESC	5,731.21	8.1%	3.8%	424.07	11203.29	34
CEA	756.47	8.1%	3.9%	217.85	102282.56	34
ELEKTRO	6,302.72	8.1%	4.0%	311.68	20543.33	34
EDP-ES	4,197.64	8.1%	3.9%	438.24	30226.99	34
ENEL-RJ	9,911.95	8.1%	4.3%	491.84	71348.54	34
AME	362.76	8.1%	3.7%	379.57	14087.14	34
CERR	31.34	8.1%	4.3%	196.61	58441.18	34
CERON	570.20	8.1%	4.2%	373.17	11160.87	34
ELETROACRE	230.02	8.1%	4.8%	399.27	9829.24	34
ETO	1,144.22	8.1%	3.7%	474.01	21269.87	34
EMS	3,051.25	8.1%	3.8%	408.56	27410.12	34
EMT	5,186.87	8.1%	3.7%	427.79	31757.00	34
ESE	1,294.45	12.3%	3.8%	380.16	12372.95	34
EPB	2,098.28	8.1%	3.9%	423.28	21480.36	34
CEAL	1,086.42	7.5%	4.0%	372.15	22869.63	34

Table 12 – Consumers' parameters

	Parameters				
Distribution companies	**E** $[TWh]$	**a** $[R\$nTWh]$	**b** $[R\$/TWh^2]$	**C** $[R\$nMWh]$	β
COELBA	19.868	9590.04	457.51	499.95	22%
CELPA	11.236	9766.55	823.93	509.16	29%
COSERN	5.578	7656.97	1301.24	399.18	22%
CELG	12.988	8451.52	616.77	440.60	4%
CEMIG	31.425	9813.68	296.01	511.61	9%
RGE	9.152	7866.19	814.70	410.09	5%
EQUATORIAL PIAUÍ	4.512	8045.11	1690.01	419.41	31%
CELPE	13.571	8986.26	627.66	468.48	25%
CEMAR	7.535	10974.97	1380.54	572.15	38%
ENEL CEARÁ	11.355	8888.50	741.94	463.38	31%
COPEL	23.217	9723.49	396.97	506.91	8%
CELESC	17.976	9760.55	514.66	508.84	3%
CEA	1.845	9110.66	4681.44	474.96	8%
ELEKTRO	13.054	8192.99	594.89	427.12	7%
EDP -ES	7.849	11088.05	1338.97	578.05	7%
ENEL-RJ	11.557	13599.19	1115.36	708.96	5%
AME	8.030	9098.59	1073.99	474.33	14%
CERR	0.186	7540.55	38392.53	393.11	11%
CERON	3.971	8800.20	2100.56	458.78	10%
ELETROACRE	1.284	9229.17	6813.78	481.14	15%
ETO	2.511	11329.48	4276.52	590.64	23%
EMS	5.176	10380.54	1901.09	541.17	14%
EMT	8.050	10936.83	1287.85	570.17	12%
ESE	3.144	9311.16	2807.08	485.42	27%
EPB	4.415	10378.70	2228.32	541.07	30%
CEAL	4.319	9410.33	2065.07	490.59	22%

To perform the simulations, the conditions shown in the Table 13 were considered:

Table 13 – Scenarios for the analysis of TSEE

	SITUATION 1	SITUATION 2
Prosumer (δ)	10%	10%
Common ($1-\delta$)	90%	90%
Common ($B1_c$)	$(1-\beta)$	$(1-\beta)$
disc	10%	65%
1-disc	90%	35%

For a better visualization of the results, these will be presented by region in Tables 14, 15, 16, 17 and 18.

Table 14 – Result of the simulation for the northeastern region.

	NORTHEASTERN								
	Bahia (BA)	**RN**	**Piauí (PI)**	**PE**	**Maranhão (MA)**	**Ceará (CE)**	**Sergipe (SE)**	**Paraíba (PB)**	**Alagoas (AL)**
	COELBA	**COSERN**	**CEPISA**	**CELPE**	**CEMAR**	**ENEL-CE**	**ESE**	**EPB**	**CEAL**
	10% DISCOUNT								
Reference Tariff [$R\$/MWh$]	499.95	399.18	419.41	468.48	572.15	463.38	485.42	541.07	490.59
T_{B1c} [$R\$/MWh$]	597.15	477.24	546.22	577.45	817.91	604.90	607.66	696.07	585.62
Tariff encrease [%]	19%	20%	30%	23%	43%	31%	25%	29%	19%
Low income [%]	22%	22%	31%	25%	38%	31%	27%	30%	22%
Average Income[$R\$$]	912.81	1,056.59	826.81	970.11	635.59	942.36	979.78	928.86	730.86
$TSEE$ [$R\$/MWh$]	174.98	139.71	146.79	163.97	200.25	162.18	169.90	189.37	171.71
T_{pro} [$R\$/MWh$]	6.70	3.85	3.95	6.76	8.16	4.98	5.26	5.89	5.92
Δ EWA	-0.0016%	-0.0023%	-0.0024%	-0.0019%	-0.0034%	-0.0024%	-0.0020%	-0.0023%	-0.0016%
Δ GINI	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003
τ	99.5555%	99.3504%	99.3137%	99.4694%	99.0322%	99.3068%	99.4264%	99.3489%	99.5572%
$E_{Low}[TWh]$	4.12	1.16	1.29	3.22	2.70	3.26	0.79	1.21	0.89
$E_{pro}[TWh]$	1.99	0.56	0.45	1.36	0.75	1.14	0.31	0.44	0.43
E_{B1c} [TWh]	13.76	3.86	2.77	8.99	4.08	6.95	2.04	2.76	2.99
	65% DISCOUNT								
Reference Tariff [$R\$/MWh$]	499.95	399.18	419.41	468.48	572.15	463.38	485.42	541.07	490.59
T_ B1_c [R$/MWh]	597.15	477.24	546.22	577.45	817.91	604.90	607.66	696.07	585.62
Tariff encrease [%]	19.4%	19.6%	30.2%	23.3%	43.0%	30.5%	25.2%	28.6%	19.4%
Low income [%]	22.2%	22.3%	30.6%	25.4%	38.4%	30.8%	26.9%	29.5%	22.2%
Average Income[$R\$$]	912.81	1,056.59	826.81	970.11	635.59	942.36	979.78	928.86	730.86
TSEE [$R\$/MWh$] 174.98	139.71	146.79	163.97	200.25	162.18	169.90	189.37	171.71	
T_{pro} [$R\$/MWh$]	R$ 6.70	R$ 3.85	R$ 3.95	R$ 6.76	R$ 8.16	R$ 4.98	R$ 5.26	R$ 5.89	R$ 5.92
Δ EWA	-0.07%	-0.07%	-0.1051%	-0.0806%	-0.1504%	-0.1062%	-0.09%	-0.10%	-0.07%
Δ GINI	- 0.026	- 0.026	- 0.026	- 0.026	- 0.026	- 0.026	- 0.026	- 0.026	- 0.026
τ	97.48%	97.47%	96.12%	96.99%	94.53%	96.08%	96.75%	96.31%	97.49%
E_{Low}**[TWh]**	4.12	1.16	1.29	3.22	2.70	3.26	0.79	1.21	0.89
E_{pro} **[TWh]**	1.99	0.56	0.45	1.36	0.75	1.14	0.31	0.44	0.43
E_{B1c} **[TWh]**	13.76	3.86	2.77	8.99	4.08	6.95	2.04	2.76	2.99

Table 15 – Result of the simulation for the northern region.

	NORTHERN						
	Pará (PA)	**Amapá (AP)**	**Amazonas (AM)**	**Roraima (RR)**	**Rondônia (RO)**	**Acre (AC)**	**Tocantins (TO)**
	CELPA	**CEA**	**AME**	**CERR**	**CERON**	**ELETROACRE**	**ETO**
	10% de desconto						
Reference Tariff [R$/MWh]	509.16	474.96	474.33	393.11	458.78	481.14	590.64
T_ B1_c [R$/MWh]	654.70	504.24	524.80	427.30	495.10	537.25	713.17
Tariff encrease [%]	29%	6%	11%	9%	8%	12%	21%
Low income [%]	29%	8%	14%	11%	10%	15%	23%
Average Income[R$]	R$ 806.76	R$ 879.67	R$ 842.08	R$ 1,043.94	R$ 1,136.48	R$ 889.95	R$ 1,055.60
TSEE [R$/MWh]	R$ 178.20	R$ 166.24	R$ 166.02	R$ 137.59	R$ 160.57	R$ 168.40	R$ 206.72
T_pro [R$/MWh]	R$ 8.38	R$ 12.86	R$ 4.74	R$ 9.83	R$ 4.28	R$ 4.09	R$ 5.83
EWA	-0.0023%	-0.0005%	-0.0009%	-0.0007%	-0.0006%	-0.0009%	-0.0017%
GINI	-0.003	-0.004	-0.004	-0.004	-0.004	-0.004	-0.003
	99.3499%	99.8755%	99.7860%	99.8246%	99.8405%	99.7656%	99.5262%
E_Low[TWh]	3.09	0.14	1.02	0.02	0.39	0.18	0.55
E_pro [TWh]	1.12	0.18	0.80	0.02	0.40	0.13	0.25
E_B1c [TWh]	7.02	1.52	6.21	0.15	3.19	0.98	1.71
	65% de desconto						
Reference Tariff [R$/MWh]	R$ 509.16	R$ 474.96	R$ 474.33	R$ 393.11	R$ 458.78	R$ 481.14	R$ 590.64
T_ B1_c [R$/MWh]	R$ 654.70	R$ 504.24	R$ 524.80	R$ 427.30	R$ 495.10	R$ 537.25	R$ 713.17
Tariff encrease [%]	28.6%	6.2%	10.6%	8.7%	7.9%	11.7%	20.7%
Low income [%]	29.5%	8.4%	13.6%	11.4%	10.5%	14.7%	23.4%
Average Income[R$]	R$ 806.76	R$ 879.67	R$ 842.08	R$ 1,043.94	R$ 1,136.48	R$ 889.95	R$ 1,055.60
TSEE [R$/MWh]	R$ 178.20	R$ 166.24	R$ 166.02	R$ 137.59	R$ 160.57	R$ 168.40	R$ 206.72
T_pro [R$/MWh]	R$ 8.38	R$ 12.86	R$ 4.74	R$ 9.83	R$ 4.28	R$ 4.09	R$ 5.83
EWA	-0.10%	-0.02%	-0.04%	-0.03%	-0.03%	-0.04%	-0.07%
GINI	- 0.023	- 0.026	- 0.026	- 0.026	- 0.026	- 0.026	- 0.023
	95.82%	99.19%	98.61%	98.86%	98.96%	98.48%	96.94%
E_Low[TWh]	3.09	0.14	1.02	0.02	0.39	0.18	0.55
E_pro [TWh]	1.12	0.18	0.80	0.02	0.40	0.13	0.25
E_B1c [TWh]	7.02	1.52	6.21	0.15	3.19	0.98	1.71

Table 16 – Result of the simulation for the midwestern region.

	MIDWASTERN		
	Mato Grosso do Sul (MS)	**Mato Grosso (MT)**	**Goiás (GO)**
	EMS	**EMT**	**CELG**
	10% DISCOUNT		
Reference Tariff [R$/MWh]	541.17	570.17	440.60
T_ B1_c [R$/MWh]	602.39	622.12	453.02
Tariff encrease [%]	11%	9%	3%
Low income [%]	14%	12%	4%
Average Income[R$]	R$ 1,291.00	R$ 1,247.00	R$ 1,277.00
TSEE [R$/MWh]	R$ 189.41	R$ 199.56	R$ 154.21
T_pro [R$/MWh]	R$ 6.63	R$ 7.12	R$ 3.71
EWA	-0.0002%	-0.0009%	-0.0007%
GINI	-0.003	-0.003	-0.003
	99.9349%	99.7401%	99.7903%
E_Low[TWh]	0.69	0.89	0.49
E_pro [TWh]	0.52	0.80	1.30
E_B1c [TWh]	3.97	6.35	11.20
	65% DISCOUNT		
Reference Tariff [R$/MWh]	R$ 541.17	R$ 570.17	R$ 440.60
T_ B1_c [R$/MWh]	R$ 602.39	R$ 622.12	R$ 453.02
Tariff encrease [%]	11.3%	9.1%	2.8%
Low income [%]	14.3%	11.9%	4.0%
Average Income[R$]	R$ 1,291.00	R$ 1,247.00	R$ 1,277.00
TSEE [R$/MWh]	R$ 189.41	R$ 199.56	R$ 154.21
T_pro [R$/MWh]	R$ 6.63	R$ 7.12	R$ 3.71
EWA	-0.04%	-0.03%	-0.01%
GINI	- 0.026	- 0.026	- 0.026
	98.52%	98.81%	99.63%
E_Low[TWh]	0.69	0.89	0.49
E_pro [TWh]	0.52	0.80	1.30
E_B1c [TWh]	3.97	6.35	11.20

Table 17 – Result of the simulation for the southeastern region.

	SOUTHEASTERN			
	Minas Gerais (MG)	**São Paulo (SP)**	**Espírito Santo (ES)**	**Rio de Janeiro (RJ)**
	CEMIG	**elektro**	**edp -ES**	**Enel-RJ**
	10% DISCOUNT			
Reference Tariff [R$/MWh]	511.61	427.12	578.05	708.96
T_ B1_c [R$/MWh]	546.94	448.51	608.71	734.34
Tariff encrease [%]	7%	5%	5%	4%
Low income [%]	9%	7%	7%	5%
Average Income[R$]	R$ 1,224.00	R$ 1,712.00	R$ 1,205.00	R$ 1,445.00
TSEE [R$/MWh]	R$ 179.06	R$ 149.49	R$ 202.32	R$ 248.14
T_pro [R$/MWh]	R$ 5.95	R$ 5.77	R$ 6.99	R$ 10.86
EWA	-0.0004%	-0.0004%	-0.0003%	-0.0006%
GINI	-0.003	-0.003	-0.003	-0.003
	99.8845%	99.8777%	99.9173%	99.8409%
E_Low[TWh]	2.72	0.84	0.53	0.54
E_pro [TWh]	3.14	1.31	0.78	1.16
E_B1c [TWh]	25.56	10.91	6.53	9.86
	65% DISCOUNT			
Reference Tariff [R$/MWh]	R$ 511.61	R$ 427.12	R$ 578.05	R$ 708.96
T_ B1_c [R$/MWh]	R$ 546.94	R$ 448.51	R$ 608.71	R$ 734.34
Tariff encrease [%]	6.9%	5.0%	5.3%	3.6%
Low income [%]	9.3%	6.9%	7.3%	5.0%
Average Income[R$]	R$ 1,224.00	R$ 1,712.00	R$ 1,205.00	R$ 1,445.00
TSEE [R$/MWh]	R$ 179.06	R$ 149.49	R$ 202.32	R$ 248.14
T_pro [R$/MWh]	R$ 5.95	R$ 5.77	R$ 6.99	R$ 10.86
EWA	-0.02%	-0.02%	-0.02%	-0.01%
GINI	- 0.026	- 0.026	- 0.026	- 0.026
	99.10%	99.34%	99.30%	99.53%
E_Low[TWh]	2.72	0.84	0.53	0.54
E_pro [TWh]	3.14	1.31	0.78	1.16
E_B1c [TWh]	25.56	10.91	6.53	9.86

Table 18 – Result of the simulation for the Southern region.

	SOUTHERN		
	Rio Grande do Sul (RS)	**Paraná (PR)**	**Santa Catarina (SC)**
	RGE	**COPEL**	**CELESC**
	10% DISCOUNT		
Reference Tariff [R$/MWh]	410.09	506.91	508.84
T_ B1_c [R$/MWh]	423.90	537.50	518.53
Tariff encrease [%]	3%	6%	1.9%
Low income [%]	5%	8%	3%
Average Income[R$]	R$ 1,635.00	R$ 1,472.00	R$ 1,597.00
TSEE [R$/MWh]	R$ 143.53	R$ 177.42	R$ 178.10
T_pro [R$/MWh]	R$ 3.48	R$ 4.59	R$ 4.24
EWA antes [R$]	34,119.08	106,991.63	83,156.00
EWA depois [R$]	34,115.14	106,969.47	83,150.58
EWA	-0.0115%	-0.0207%	-0.0065%
GINI	-0.003	-0.003	-0.003
	96.8085%	94.4144%	98.1727%
E_Low[TWh]	0.41	1.77	0.46
E_pro [TWh]	0.92	2.32	1.80
E_B1c [TWh]	7.83	19.12	15.72
	65% DISCOUNT		
Reference Tariff [R$/MWh]	R$ 410.09	R$ 506.91	R$ 508.84
T_ B1_c [R$/MWh]	R$ 423.90	R$ 537.50	R$ 518.53
Tariff encrease [%]	3.4%	6.0%	1.9%
Low income [%]	4.8%	8.2%	2.7%
Average Income[R$]	R$ 1,635.00	R$ 1,472.00	R$ 1,597.00
TSEE [R$/MWh]	R$ 143.53	R$ 177.42	R$ 178.10
T_pro [R$/MWh]	R$ 3.48	R$ 4.59	R$ 4.24
EWA antes [R$]	R$ 34,119.08	R$ 106,991.63	R$ 83,156.00
EWA depois [R$]	R$ 34,115.14	R$ 106,969.47	R$ 83,150.58
ΔEWA	-0.01%	-0.02%	-0.01%
$\Delta GINI$	- 0.026	- 0.026	- 0.026
	99.55%	99.21%	99.75%
E_Low[TWh]	0.41	1.77	0.46
E_pro [TWh]	0.92	2.32	1.80
E_B1c [TWh]	7.83	19.12	15.72

Considering the results obtained, Figures 34, 35, 36 show that it is possible to grant a greater discount on TSEE, without major losses for socioeconomic well-being. The reduction in tariffs also helps to improve energy consumption for the low-income population, although it is not a huge jump in consumption. This can be influenced by the parameters of avidity and satiety that have not been changed.

Another important point to be raised is the fact that each region has experienced a level of change. The North and Northeast regions showed a very large increase in the rates of common captives when given the 65% discount, this is due to the number of low-income in the concession area. The lower the income, the greater the impact on ordinary captive consumers. But still, if analyzed how much well-being has been lost and how much has been gained in income distribution it is worth doing, since in the function that puts δ EWA and Δ GINI together the value of τ indicates that well-being socioeconomic level has not decreased to the point that the priority has shifted to income distribution.

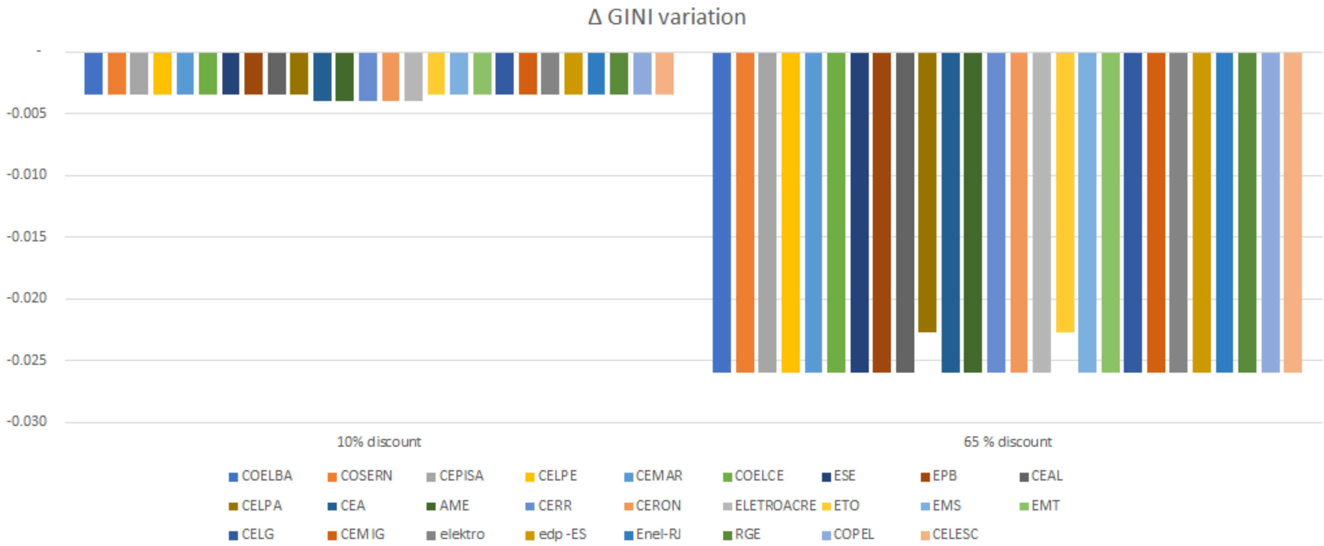


Figure 34 – Graphic of $\Delta GINI variation$.

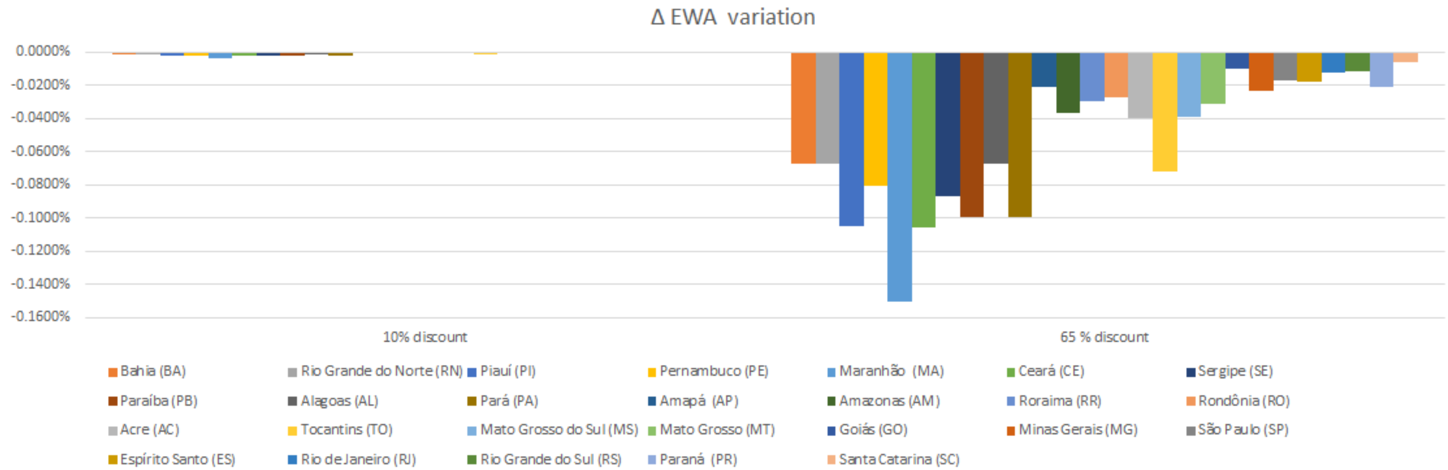


Figure 35 – Graphic of $\Delta EW Avariation$.

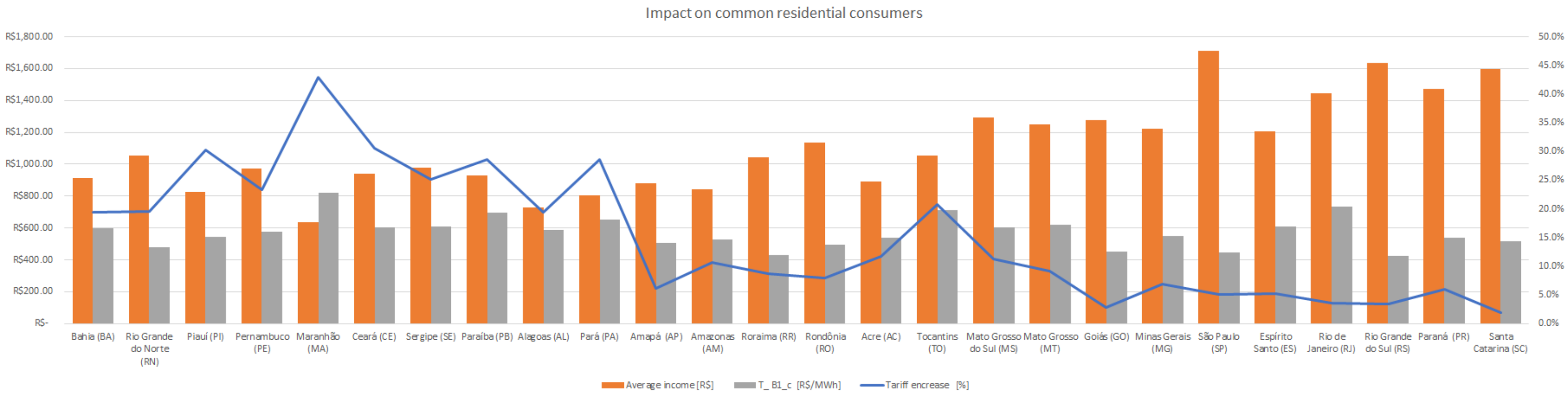


Figure 36 – Graphic of increase of tariff and the impact in the income.

5.1 New public policy

Analyzing the 5 regions, it can be seen that the northeast and south are the most discrepant ones and this is an indication that the socioeconomic differences already noted in the introduction, tend to extend to the energy market. In order to analyze the consumers of this region a little better, the simulation was redone with a change in the distribution of the population and also of the income to calculate the GINI index.

Figure 37 illustrates how the GINI Index was calculated for this analysis.

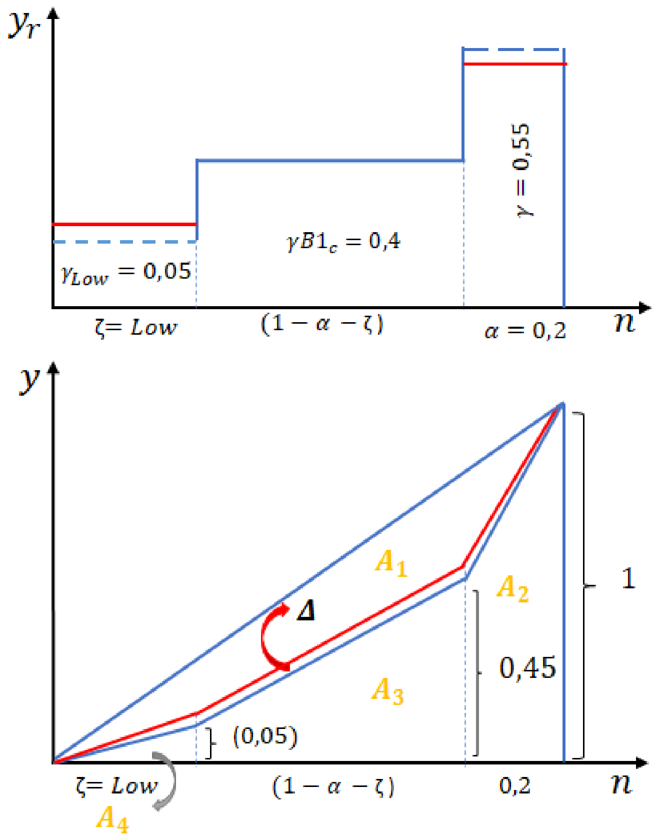


Figure 37 – Simplified GINI Index calculation.

For this specific study the Gini index is:

Δ = the difference between the GINI Index before and after the applied tariff discount, 'yr'= relative level of income, 'y'= cumulative percentage (or per unit) of income participation , 'n'= percentage (or per unit) of population, where: γ_{Low}—percentage (or per unit) of income related to Low-income consumers; γ—percentage (or per unit) of income related to wealthier consumers; $\gamma B1c$—percentage (or per unit) of income related to common consumers; ζ—Percentage (or per unit) of Low-income consumers, that is, the poorest consumers; α- percentage (or per unit) of the wealthiest consumers; (1-α-ζ)—cumulative percentage (or per unit) of the common consumers. It is assumed that the share ($\alpha < 0.50$) of the wealthiest inhabitants receives total inflows equal to the share (γ

> 0.50) of the total income of the country. In this study it was adopted α = 0.20 and γ = 0.55. The Table 19 and 20 brings the variable values for the new Gini value.

It was compared the lowest and highest discount allowed by the current regulation (Table 6) in comparison to the proposal of a new type of discount as a social electricity tariff: withdrawal of the ICMS (tax on the circulation of goods and provision of services), and then evaluated its effects on deconcentrating income to the entire population.

Table 19 – The cumulative percentage (or per unit) of income participation and the percentage (or per unit) of population for the northeastern region.

	Before Public Policy					
	γ	γ_{Low}	$\gamma B1c$	α	ζ	(1-α-ζ)
COELBA	0.55	0.05	0.4	0.20	0.22	0.58
COSERN	0.55	0.05	0.4	0.20	0.29	0.51
CEPISA	0.55	0.05	0.4	0.20	0.31	0.49
CELPE	0.55	0.05	0.4	0.20	0.25	0.55
CEMAR	0.55	0.05	0.4	0.20	0.38	0.42
ENEL CEARÁ	0.55	0.05	0.4	0.20	0.31	0.49

Table 20 – The cumulative percentage (or per unit) of income participation and the percentage (or per unit) of population for southern region.

	Before Public Policy					
	γ	γ_{Low}	$\gamma B1c$	α	ζ	(1-α-ζ)
RGE SUL	0.55	0.05	0.4	0.20	0.05	0.75
COPEL	0.55	0.05	0.4	0.20	0.08	0.72
CELESC	0.55	0.05	0.4	0.20	0.03	0.77

5.1.1 Southern Region

Observing Figures 38 and 39, it is possible to notice that in all types of tariff discounts there was an improvement in the GINI index, that is, there was a decrease in inequality of income distribution. The more negative the ΔGINI becomes, this means less income inequality. Also, the increase of energy price for the rest of consumers was less than 7% and looking into Figure 40 it is easy to see that the tariff increase for the common consumers seems to not have a strong impact on the income for the population of the southern region, since the impact on the electricity bill is small. The percentage of low-income consumers is less than 9% as shown in Figure 38, and all public policies applied had an improvement in GINI index despite the small drop in the socioeconomic welfare (Figure 41). However, the increase is connected to the number of low-income consumers, i.e., the higher the number of low-income consumers, the higher the tariff increase for common consumers. Figure 42 shows that these consumers spent less than 10% of their income on electrical energy. In Figure 41 it is possible to see that the sacrifice in the amount of average energy consumption in order to maintain the same electricity bill was not that severe, no matter which public policy is applied.

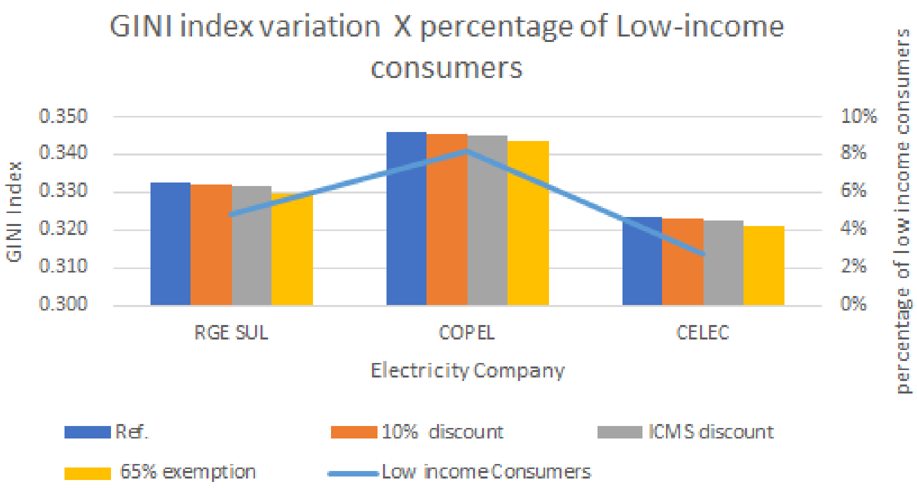


Figure 38 – The GINI index for each discount and the relation with the percentage of Low-income consumers for the southern region.

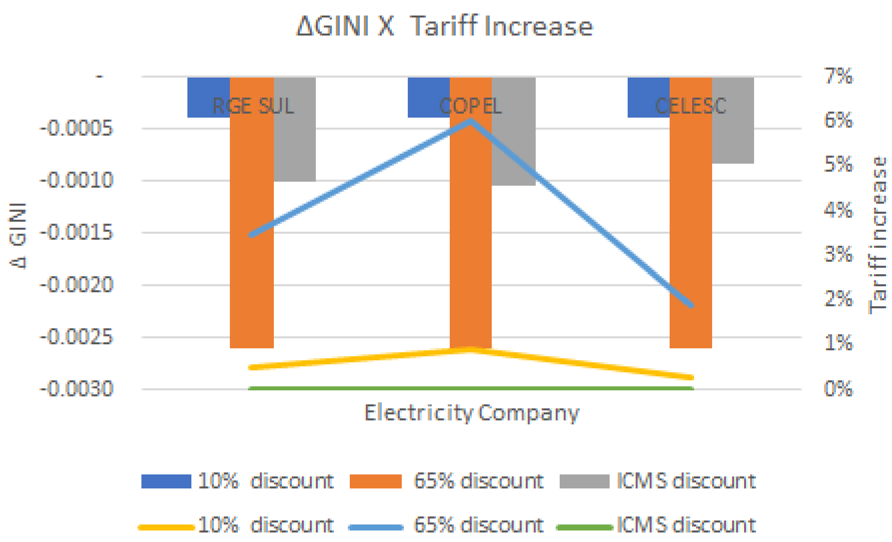


Figure 39 – The relation between tariff increase (on the right side) and the impact in the income (ΔGINI) (on the left side) for all consumers in the southern region.

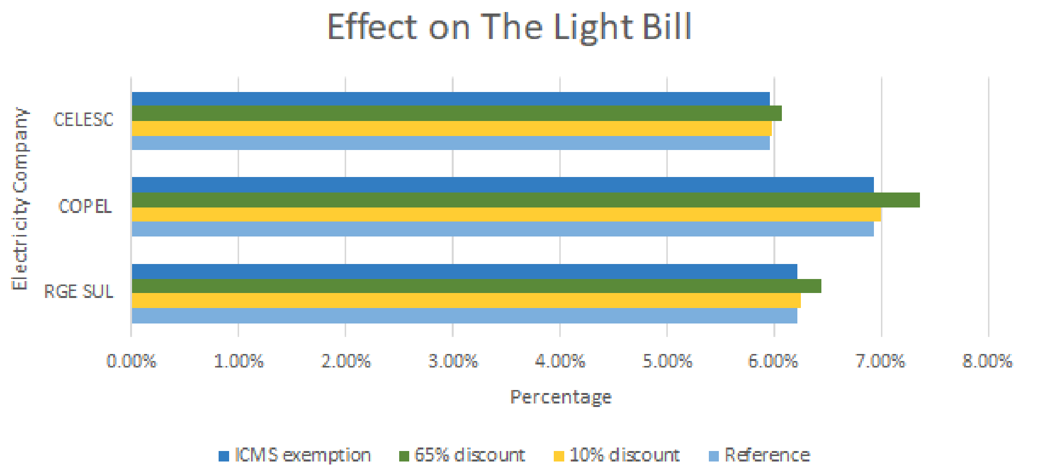


Figure 40 – The impact on the electricity bill when it is maintained the energy consumption in the southern region.

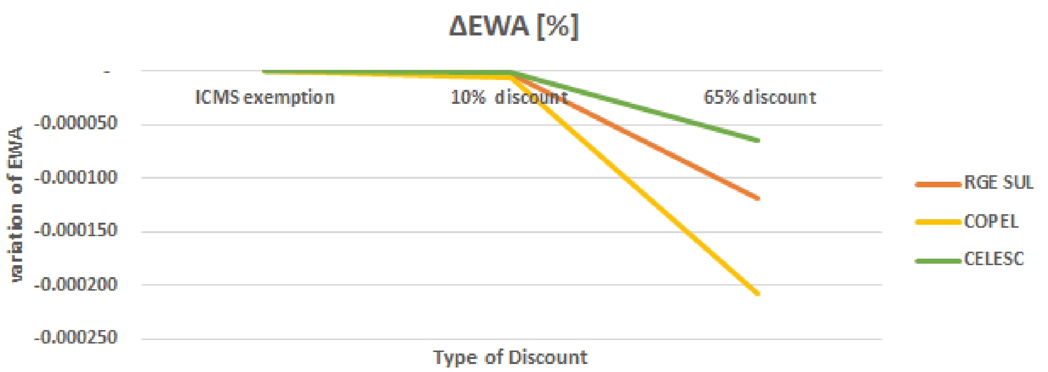


Figure 41 – Socioeconomic welfare for each situation of tariff discounts in the southern region.

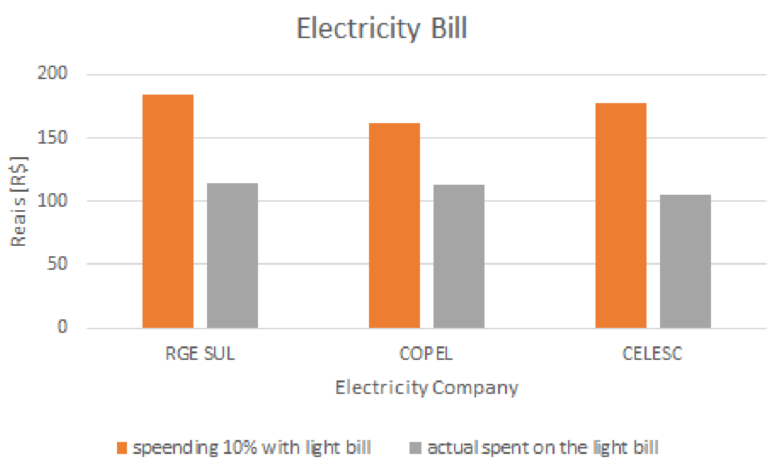


Figure 42 – Difference between the actual consumption of electrical energy and when it is spent 10% of the income with it in the southern region.

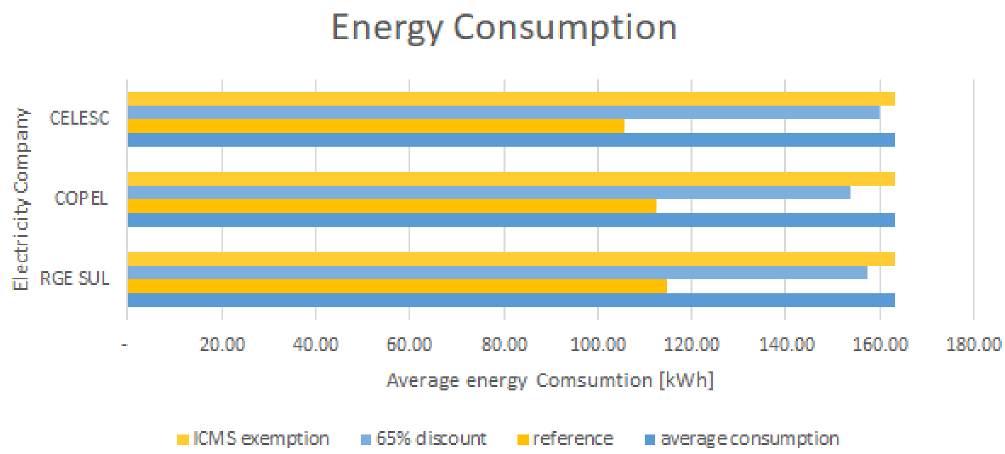


Figure 43 – Energy consumption in order to maintain the electricity bill due to the tariff increase in the southern region.

5.1.2 Northeastern Region

In this region, Figures 44 and 45 also show there has been an improvement in the GINI index for all types of tariff discounts, that is, there was a decrease in inequality of income distribution for this region too. Again, the more negative the ΔGINI becomes, this means less income inequality. In both regions, when 65% of discount is applied, more improvement the GINI index has, despite the small drop in the socioeconomic welfare (Figure 46). However, Figures 47–48 are a strong warning about the benefit for the poorest at the expense of the B1c consumer tariff for this region. People who do not have social conditions and are not able to receive TSEE will pay even more for their electrical energy. On the other side, when the ICMS was withdrawn, those people did not have to pay more and the low-income consumers could receive a discount. This way, it is possible to simultaneously improve the GINI index (Figure 45) despite the small drop in the socioeconomic welfare. The connection between the percentage of low-income consumers and the increase in tariff remains. Here, it is even more evident. Observing Figure 47, in order to maintain the same energy bill the sacrifice in the amount of energy consumption was higher in this region. For example, to CEMAR the sacrifice was almost 30% less energy consumed. Figure 48 shows that consumers have actually already spent more than 10% of their income on electrical energy. Therefore, any increase in their tariff implicates in a significant way in their average income. In Figure 47 it is clear the necessity to spend more if they want to maintain the average consumption of energy.

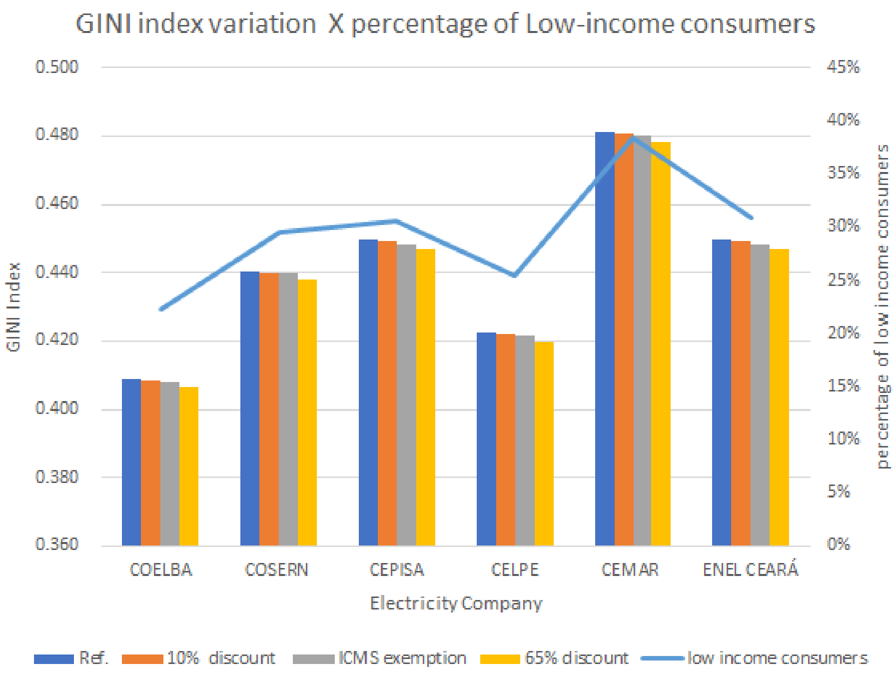


Figure 44 – The GINI index for each discount and the relation with the percentage of low-income consumers for the northeastern region.

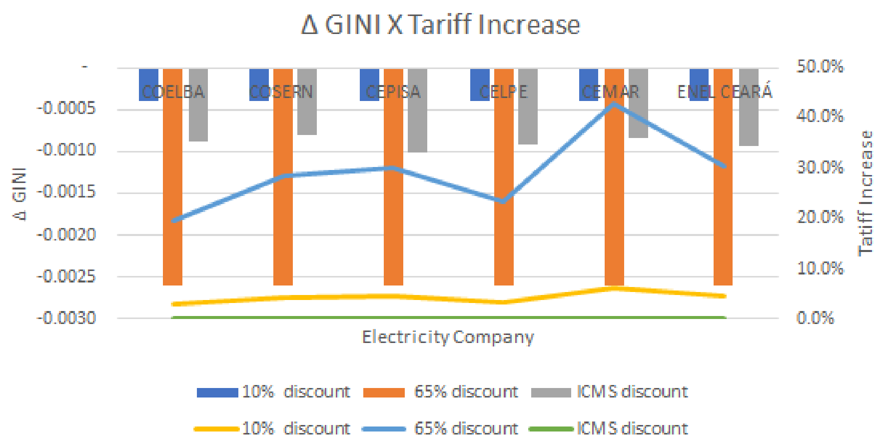


Figure 45 – The relation between the impact in the income (ΔGINI) (on the left side) for all consumers in the northeastern region and the tariff increase (on the right side).

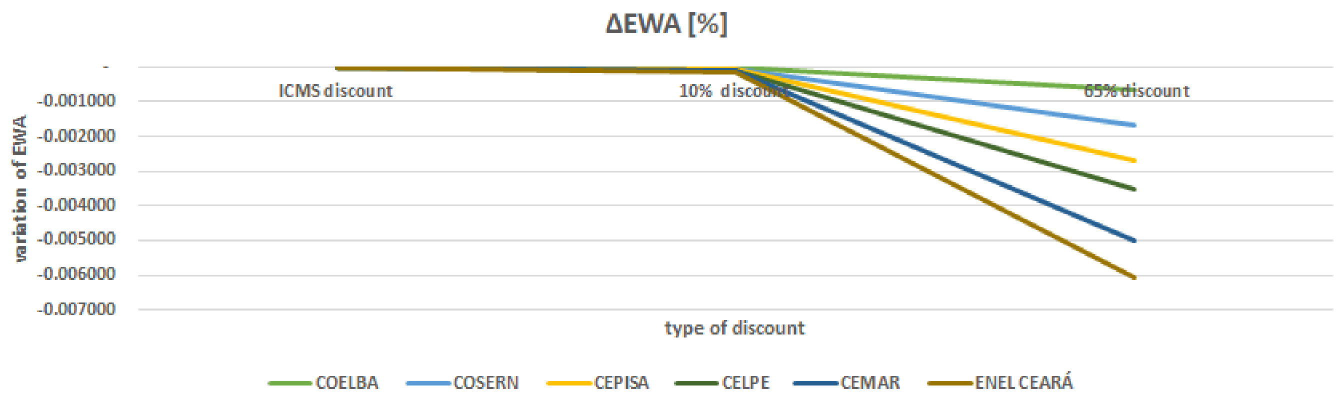


Figure 46 – Socioeconomic welfare for each situation of discounts in the northeastern region.

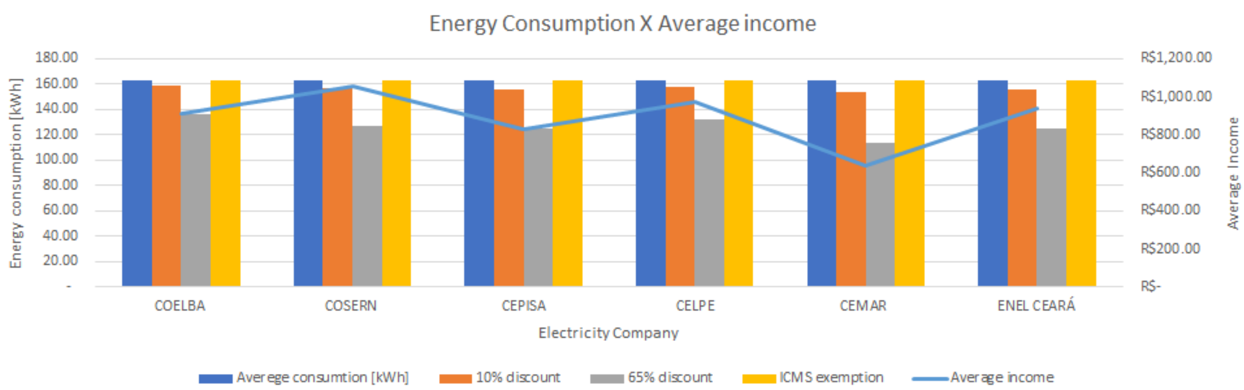


Figure 47 – Energy consumption in order to maintain the electricity bill due to the tariff increase in the northeastern region.

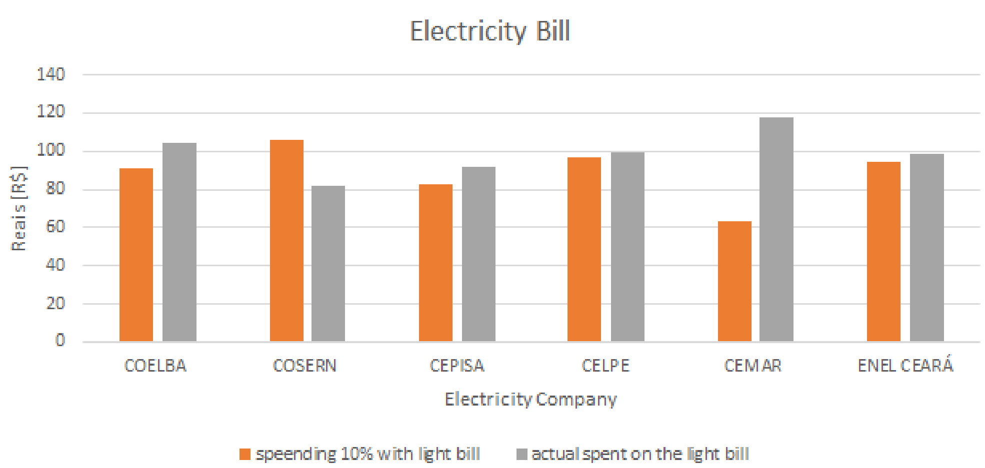


Figure 48 – Difference between the current consumption of electrical energy and when it is spent 10% of the income in the northeastern region.

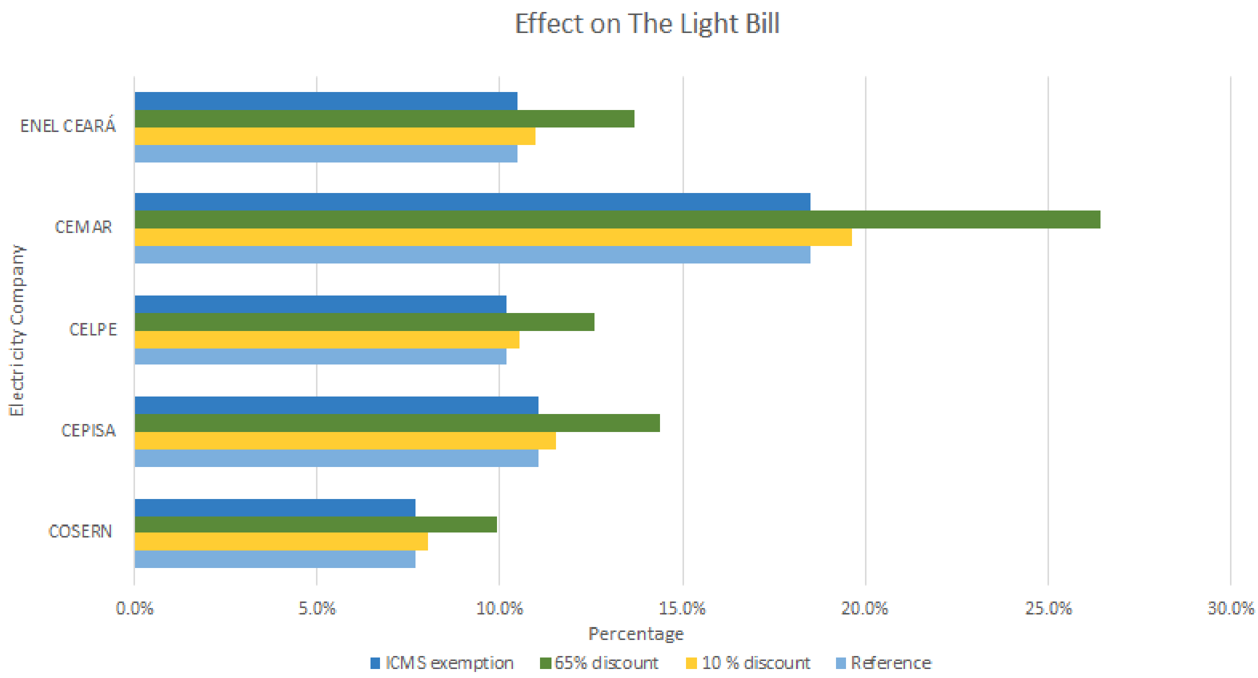


Figure 49 – The impact in electricity bill when it is maintained the energy consumption in the northeastern region.

6 Conclusions

This thesis has presented an evaluation of public policies for fair social tariffs of electricity in Brazil by using an economic market model. The TAROT economic model of the regulated electricity distribution market was used to review the discrepancies of the current public policies on the socioeconomic situation of two of the five regions of Brazil. The studied regions, northeastern and southern, present different responses to the application of the same public policy for social tariffs. In the northeast the population ends up being harmed in two of the three proposals to reduce the social tariff (because they either pay more and reduce their income or reduce their electrical energy consumption), while in the south all proposals have shown improvement it seems that is evident that it should be possible to apply different public policies in order to reduce energy poverty in the country.

Despite the fact that the greater the discount, the greater is the impact on combating inequality, the public policy of exempting the ICMS seems to be the best option for the northeastern region, as it is possible to give a better discount, (regardless the energy consumption) and not burden common consumers in this region, which has an average low-income and loses whenever there is an increase in the tariff. The present regulatory system applied in Brazil guarantees the Financial Economic Equilibrium (FEE) for all power distribution utilities throughout a Capital Assets Price Model (CAPM), under a stablished Weighted Average Capital Cost (WACC), being the electricity tariff calculated to meet this goal. Therefore, maintenance costs and prudent expansion investments are straight considered in the tariff. However, the electricity tariff has also been historically used to collect various taxes to the government (federal and state). Therefore, lowering or resigning from some taxes can be implemented as public policies without affecting the energy infrastructure.

In regions with a large gap in income and where most of the population is poor, tax withdrawal is more efficient for improving the GINI index and has a small effect on the socioeconomic welfare, being the best scenario for the northeastern region. This might be a better way to include the low-income population in electrical energy consumption, reducing energy poverty in the country, by changing the number of GINI index produced by cross-subsidies and tax waiver (removing ICMS from TSEE). Presently, due to the COVID-19 pandemics an emergency measure has been applied in Brazil. There is a new public policy, by provisional measure MP950/2020 made by the Brazilian Federal Government, applied for the low-income consumers that exempts those consumers whose consumption is up to 220KWh per month from any payment (100% discount) for 3 months. In the future, post-pandemics, the exemption from ICMS is a better measure to be implemented because, as already demonstrated, this policy is the one that brings the most benefits to society as a whole.

It is important to consider that in regions with high levels of poverty, there is not always an exact correlation between social public policy and its effect on the GINI index. Here, in this paper, a simplified study was carried out, in order mainly to alert about the application of public policies for the entire population in a large and diverse country without studying alternative and simplified public policies and their impacts on the population of each region. Further studies of what really represents the changes in income and social welfare are necessary, so that sociological theory can also be helpful for regulatory studies. When a social public energy policy is introduced, the ultimate goal is to produce a leveling in the degree of welfare (or ”happiness”) of the various layers of a society. This policy, in addition to displacing income, changes the structure of income utilization.

7 Future work

Make a greater discretization of income range, to be able to see how each income range is affected with the public policy of tariff discounts.

Use the ICMS discount to implement photovoltaic generation for low-income population and observe the effect for the population as a whole.

Invest in an exclusive ”photovoltaic farm”for low-income supply, and whether there would be permanent dishonor for the rest of the population.

8 Publications

BENSO, L.; BONATTO, B.; ARANGO, H.; CARVALHO, L. Socioeconomic indicators for the analysis of electricity distribution concessionaires. In: IEEE.2018 Simposio-Brasileiro de Sistemas Eletricos (SBSE). [S.l.], 2018. p. 1–5. 182

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