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Analysis of the impact of COVID-19 pandemic on the Brazilian distribution electricity market based on a socioeconomic regulatory model

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ABSTRACT

This paper evaluates the impact of the COVID-19 pandemic on the Brazilian distribution electricity market by applying a socioeconomic regulatory model called Optimized Tariff Model. The model quantifies the impact of the pandemic on the consumer’s quality of life and also on the economic performance of power distribution companies. Results indicate that both consumers and power distribution companies have been significantly affected in Brazil, especially companies that did not have access to the public policy proposed by the government, as they exhibited economic losses of more than 1 (GR$) in total. After analyzing the impact of the new coronavirus and the actions of the government in this context, an alternative mitigation measure (public policy) is proposed based on the Optimized Tariff Model and its feasibility examined. The alternative mitigation measure is also compared to the public policy proposed by the government and proved to be advantageous in some respects such as making bank loans unnecessary.

1. Introduction

1.1. Motivation and incitement

According to [1], since the 2000s, SARS-CoV, and MERS-CoV were the first coronavirus outbreaks that resulted in socioeconomic losses. The SARS-CoV-2 coronavirus (which causes the COVID-19 disease) outbreak took place in 2019 and was classified by WHO (World Health Organization) as a pandemic, due to its significant and ongoing person-to-person spread in multiple countries around the world simultaneously [2]. To this point (April 2021), population access to vaccines is extremely limited, which is an extensive concern. Currently, more than 131 million COVID-19 cases have been confirmed, including more than 2.8 million deaths [3].

Due to the dimension of the problem and the general recommendation of maintaining social distance to minimize the risk of infection (along with government measures), consumption habits have changed considerably. Hence, it is fair to say that this public health issue has massive implications in the field of economics, due to its harm to producers, consumers, retailers, investors, and so forth. Putting things into perspective, [4] affirms that the global economy will shrink by 3% this year, which is the worst recession since the great depression of the 1930s. The electricity sector has been greatly affected by the pandemic, data from [5] projects a 5.7% drop in annual electricity demand in the US in 2020. In Brazil, a 6.6% drop in demand was verified by comparing April/2020 to April/2019 [6]. Both commercial and industrial consumption classes were heavily harmed (17.9% and 12.4% demand reduction, respectively), while, due to social isolation, the demand for the residential consumption class increased by 6.0%. The demand variation is so substantial that can in fact be seen from space [7].

The immediate, short-term consequences of the crisis in the electricity sector, especially in the distributors, have two main natures: the reduction of electricity consumption and the potential increase in defaults. However, the pandemic is also likely to affect non-technical losses (energy theft). According to [8], the rise in unemployment in Brazil caused by the pandemic led to an increase in non-technical losses, as there is a considerable correlation between these two factors.

It is extremely important to quantify the impact of the pandemic to...
understand the dimension of the problem, then, measures can be homologated by the government in order to mitigate it (e.g. public policies). In Brazil, the national electricity agency (ANEEL) homologated the COVID-account in July/2020, which authorizes bank loans by utilities to cover deficits or anticipate revenues. The agency established a limit of R$ 16.1 billion in loans, which must be paid in 60 months [9]. The justification of the regulatory agency is that without the COVID-account, the readjustment of electricity tariffs due to the negative impact of the pandemic on the utilities’ revenue would be passed on to consumers in just 12 months.

The COVID-account raises some questions / uncertainties, since an interest rate of 2.8% per annum must be paid by consumers without any kind of consent [10]. It is fair to say that it is not clear whether the COVID-account is a proper proposal to mitigate the impact of the pandemic in the electricity sector, and how much this will cost consumers precisely. Thus, more studies are needed in this regard, to support the development of long-term sustainable alternatives.

1.2. Literature review

1.2.1. Published work regarding the COVID-19 pandemic in the context of the electricity market / sector

Due to the relevance of the subject and its actuality, several studies that address the impact of the COVID-19 pandemic on the electricity market / sector have been found. Among publications, stand out: ref. [7] proposes a cross-domain solution (CDS) integrating traditional electricity data with public health and mobility data. Ref. [11] performs a comprehensive review on the implications for electricity demand and supply, affirming that the increased uncertainty of demand led to greater pressure on system operators. In [12], a different perspective is addressed, as it focuses on the opportunities of the pandemic related to sustainability transitions, research on electricity, and mobility. Ref. [13] studies the impact of the pandemic on load profiles, electricity consumption, and market prices in Italy, including the environmental aspects. Ref. [14] approaches the socioeconomic and technical issues faced by utilities. Then, a set of recommendations are presented to support the government / policymakers / utilities around the world. In [15], an overview of invested energy sources and environmental footprints in fighting the COVID-19 is provided. Ref. [16] analyzes hourly electricity demand data for the province of Ontario, which exhibited a clear curve flattening during the pandemic. Ref. [17] addresses the politics of sustainable energy transitions in the context of the pandemic. In [18], real-time monitoring of the economic impact of containment policies is performed. Ref. [19] reviews how governments in Africa have responded to the pandemic (public policies) in the energy sector. Ref. [20] analyzes variables that can indicate stress on the grid due to the pandemic. Ref. [21] addresses social justice and energy sovereignty, which are extremely important topics to improve the design of the energy system post-COVID-19. Ref. [22] analyzes the impact of the pandemic on energy insecurity, which is defined as the uncertainty that a household can pay its energy bills. In [23], the US bulk power system is analyzed during the pandemic on a range of topics, including supply reliability, generation, demand and prices. Ref. [24] argues that some of the impacts of the pandemic on electricity demand are temporary, while others are associated with longer-term changes. Ref. [25] focuses on energy policies to mitigate the impact of the pandemic on the renewables market. Ref. [26] assesses the link between people’s behavior and the consumption of natural gas, electricity and water in critical circumstances such as the pandemic. Besides pointing out the electricity demand variations in multiple countries, ref. [27] discusses how to stabilize demand, which is crucial to maintain economic / urban sustainability and might mitigate the pandemic impact. Based on descriptive statistical analysis, [28] demonstrates changes in consumption, generation, prices, and electricity imports / exports in European countries (the analysis focuses on Germany). However, results show that the German electric grid remains stable in terms of frequency. Ref. [29] discusses how Great Britain experienced periods of compromised grid stability during the pandemic due to high penetration of non-synchronous renewables, which led to a cost increase of ancillary services applied in the context of frequency regulation. Refs. [28,29] indicate regional differences in the impact of the pandemic, since Great Britain experienced stability issues unlike Germany. Ref. [30] ranks the demand variation of European countries. The overall conclusion is that the demand variation is closely related to the containment measures taken by the governments, as countries with severe restrictions are more affected.

Ref. [31] performs a careful literature review of recently published articles (39 articles) in the context of the COVID-19 pandemic and its impact on the electricity market. Publications are organized according to the study region and to the work emphasis. Among regions, there is a focus on North America, Europe and Asia with approximately 31%, 26% and 26% of analyzed papers, respectively. Africa, South America and Oceania are not addressed so frequently (approximately 10%, 5% and 3% of analyzed papers, respectively). Regarding the work focus, the range of topics is considerably vast (as evidenced in the last paragraph), however, public policies, electricity demand, prices and power quality issues are of great interest to researchers.

In the context of the Brazilian electricity market, ref. [32] performs a statistical analysis to assess the electricity demand trends for Brazil and its geographic regions. The results demonstrate that the electricity demand has decreased considerably in Brazil due to the pandemic. Ref. [11] also performs a demand variation analysis for several countries, including Brazil. The conclusion is similar to that of [32], i.e. the pandemic decreased electricity demand significantly. Refs. [11,32] are the only works found that directly address the Brazilian electricity market in context of the pandemic. Both studies focus on electricity demand variation, which is distinct from a socioeconomic analysis.

Publications regarding the COVID-19 pandemic and its impacts on the electricity market / sector contribute concurrently to propose mitigation measures and to better prepare for future pandemics / crises. A state-of-the-art review demonstrated a growing number of publications related to the pandemic, however, given the extent of the issue, there is room for many more studies. Moreover, there seems to be a lack of socioeconomic market models applied in this context, mainly considering the regulatory model of the Brazilian electric sector.

1.2.2. Published work regarding the Optimized tariff model

The Optimized Tariff Model (TAROT) has been applied continuously to model regulated electricity markets and proved to be highly efficient in this regard. Publications related to the TAROT model include the integration of distributed generation (DG) in the context of fixed tariffs [33], aggregated analysis of most Brazilian distribution companies [34], risk evaluation of distribution companies based on stochastic simulations [35], financial impact analysis of energy theft [36], impact of power quality on electricity markets [37], evaluation of public policies that encourage DG [38], etc. The considerable number of publications that apply the TAROT model is due to the ease of adapting the model to different contexts.

The TAROT model has not been applied in the context of the COVID-19 pandemic yet.

1.3. Contribution

The main contribution of this research is to apply the TAROT model in the context of the COVID-19 pandemic to analyze its impact on the Brazilian distribution electricity market. Based on the model, the effectiveness of the COVID-account proposed by the government can be evaluated. Moreover, an alternative measure to mitigate the impact of the COVID-19 pandemic on both utilities and consumers is proposed with the goal of maximizing the socioeconomic welfare created by the electricity market. Results show that the proposed public policy can be effective for some concession areas if applied properly. It is important to
note that the same public policy can generate different results depending on the utility under analysis and the concession area. Although the Brazilian electricity market is the object of study, the methodology presented in this paper can be applied for any regulated electricity market that deploys constant tariffs (Brazil was analyzed due to ease of collecting data). Hence, a meaningful contribution is expected in the context of the COVID-19 pandemic and also for possible future crises / pandemics. Fig. 1 summarizes this paper’s contribution.

1.4. Paper organization

Section 2 presents the basic concepts of the Optimized Tariff Model, its ideas, and equations. Section 3 briefly exhibits how the TAROT model’s parameters are obtained based on published data from the regulatory agency. Section 4.1 is dedicated to applying the TAROT model in the context of the COVID-19 pandemic and analyzing its impact on the Brazilian regulated electricity market. Section 4.2 presents an alternative measure (public policy) to mitigate the impact of the pandemic based on the TAROT model. Then, the proposed measure is applied to the Brazilian electricity market in order to verify its feasibility. The conclusions are presented in Section 5, followed by the acknowledgments and references.

2. The Optimized tariff model

The Optimized Tariff Model (TAROT) is widely used in regulated electricity market analysis due to its simplicity and flexibility. Fig. 2 exhibits the block diagram of economic flows of the classic TAROT model. The market players’ surpluses (consumers’ and power distribution company’s surpluses) are the outputs of the model, i.e. the economic benefits of each agent. The present section is dedicated to the calculation of these surpluses, which are used to analyze the impact of the COVID-19 pandemic in Section 4.1.

2.1. Consumer’s model

The energy economic utility, which measures the quality of life added by electricity consumption is given by:

\[
U = aE - \frac{b}{2}E^2 \tag{1}
\]

where

The parameter \(a\) is the avidity (willingness to consume energy);
The parameter \(b\) is the satiety (contentment with the consumed energy);
The variable \(E\) is the consumed energy.

The revenue of the power distribution company is expressed as:

\[
R = TE \tag{2}
\]

where

\(T\) is the energy tariff;
\(E\) is the consumed energy.
As shown in Fig. 2, the consumers’ surplus (ECA – Economic Consumer Added) is given by:

\[ ECA = U - R \Rightarrow \]

\[ ECA = aE - \frac{b}{2}E^2 - TE \]  

(3)

Logically, the consumers seek to maximize their surpluses, hence:

\[ \frac{\partial ECA}{\partial E} = 0 \Rightarrow \]

\[ T = a - bE \]  

(4)

In other words, the condition of the maximum surplus is when the marginal utility equals the tariff. From (3) and (4), the surplus can be written in terms of the consumed energy (E):

\[ ECA = \frac{b}{2}E^2 \]  

(5)

2.2. Regulated power distribution company’s economic model

The regulated power distribution company’s costs related to operational expenses, energy loss, and depreciation of the grid are expressed by:

\[ C_1 = eE + p\frac{E^2}{B} + dB \]  

(6)

where

\[ e, p, \text{ and } d \] are adjustable parameters;
\[ B \] is the grid investment;
\[ E \] is the consumed energy.
\[ eE \] models the operational expenses;
\[ pE^2/B \] models energy loss;
\[ dB \] models the depreciation of the grid.

The sales taxes and tributes over profits are equated in (7) and (8), respectively:

\[ TRIB_v = \mu R \]  

(7)

\[ TRIB_r = r(R - \mu R - C_1) \]  

(8)

where

\[ \mu \] is the sales tax parameter;
\[ R \] is the revenue;
\[ t \] is the tax fee;
\[ C_1 \] is the cost equated in (6).

The capital yield (Y) is proportional to the grid investments:

\[ Y = r_vB \]  

(9)

where \( r_v \) is the weighted average cost of capital (WACC).

By adding up (6), (7), (8), and (9), the overall power distribution company’s cost is found:

\[ C = tR + (1 - t) \left[ eE + p\frac{E^2}{B} + \mu R + Bk \right] \]  

(10)

where \( k \) is the “hurdle rate” for aggregation of value to the regulated company. Mathematically:

\[ k = \left( d + \frac{r_v}{1 - t} \right) \]  

(11)

The optimal grid investment is calculated by:

\[ \frac{\partial C}{\partial B} = (t-1) \left( \frac{pE^2}{B^2} - k \right) = 0 \Rightarrow B^* = \sqrt{\frac{pE}{k}} \]  

(12)

The power distribution company’s surplus (EVA – Economic Value Added) is expressed by:

\[ EVA = R - C \]  

(13)

where \( R \) is the revenue and \( C \) is the overall cost.

Finally, based on (2), (4), (10) and (12), (13) can be written in terms of the consumed energy (optimal grid investments are considered):

\[ EVA = (1 - t) \left[ (a - \mu a - c_1)E + (\mu b - b)E^2 \right] \]  

(14)

where the parameter \( c_1 \) is used for convenience as stated in (15):

\[ c_1 = e + 2\sqrt{\mu k} \]  

(15)

2.3. Overall socioeconomic model

The socioeconomic welfare (EWA – Economic Wealth Added) measures the overall benefit of society arising from the transaction of electricity, i.e. the socioeconomic welfare is defined as the sum of the consumers’ surplus with the power distribution company’s surplus. Mathematically:

\[ EWA = ECA + EVA \]  

(16)

where \( ECA \) is equated in (5) and \( EVA \) is equated in (14).

The maximization of the socioeconomic welfare, which is the main goal of the regulatory agencies (e.g. ANEEL, the Brazilian regulatory agency) is obtained by (17):

\[ EVA = 0 \]  

(17)

Equation (17) guarantees a state of financial economical equilibrium (FEE) for the power distribution company, since all its costs can be paid, hence (17) implies a sustainable electricity market. Simultaneously, maximum affordability for consumers is ensured. Based on (14) and (17), the optimal consumed energy can be easily obtained. After obtaining the optimal consumed energy, the marginal utility concept equated in (4) can be used to calculate the optimal electricity tariff, which in theory should be homologated by the regulatory agency in order to achieve market optimization.

3. Obtaining the parameters

This section is dedicated to the calculation of the model’s parameters, by applying a similar methodology to that proposed in [33]. Some data are required to obtain the parameters. In Brazil, these data are provided by the regulatory agency (ANEEL) through reports of tariff distribution processes [39].

The demand elasticity quantifies the impact that a price variation has on the quantity of energy consumed. This concept can be used to obtain the avidity parameter (\( a \)). Firstly, the basic equation of demand elasticity is pointed out:

\[ \epsilon = \frac{T}{E} \frac{\partial E}{\partial T} \]  

(18)

where

\[ \epsilon \] is the demand elasticity. In order to simplify the application of (18), the elasticity is usually aggregated among consumers based on typical elasticity values of consumer classes (residential, industrial, commercial, etc.) [40];
\[ T \] is the electricity tariff;
\[ E \] is the consumed energy.
Based on (4), (18) can be written as:

$$
\varepsilon = \frac{T}{E} \frac{\partial \left( \frac{\partial}{\partial T} \right)}{E} \quad (19)
$$

By solving (19) and isolating the avidity:

$$
a = T \frac{1 + |\varepsilon|}{|\varepsilon|} \quad (20)
$$

Equation (4) can be used to obtain the satiety by simply isolating it:

$$
b = \frac{a - T}{E} \quad (21)
$$

The calculation of the cost parameters is thoroughly discussed / validated in [37]. The sales tax parameter is expressed as:

$$
\mu = ICMS + PIS + COFINS \quad (22)
$$

where

- ICMS are the taxes on consumption of goods and services;
- PIS is the social integration program in Brazil;
- COFINS is the contribution to social security financing in Brazil.

The first tribute is for the states, while the others are national tributes.

The operational costs parameter is calculated by:

$$
e = \frac{C_e}{E} \quad (23)
$$

where $C_e$ are the efficient operational costs.

Equation (24) is used to calculate the energy loss parameter:

$$
p = \frac{C_p B}{E^2} \quad (24)
$$

where

- $C_p$ are the energy loss costs;
- $B$ is the grid investment.

The parameters $t$, $r_w$, and $d$ are directly provided by ANEEL [39]. The parameter $k$ is obtained by (11) and $C_1$ is calculated by (15).

### 4. Analysis of the impact of COVID-19 pandemic

#### 4.1. Application of the TAROT model in the Brazilian electricity market

As previously mentioned, the market players’ surpluses obtained by the application of the TAROT model can be evaluated to verify the impact of the COVID-19 pandemic on the Brazilian electricity market. The analysis is performed based on the results of 39 Brazilian concession areas (each of them is subject to a distinct power distribution company).

In the current Brazilian regulatory model, the tariff is calculated in order to guarantee sufficient revenue for the utility to bear its costs, which are classified as manageable and unmanageable. Among the unmanageable costs, known as portion $A$, there are the expenses with the purchased energy, the sectoral funds, and the transportation costs [41]. The costs that are manageable by the distributor, are called portion $B$ and include the costs inherent to the electricity distribution activity, such as operating costs, capital yield, and depreciation. These costs can be controlled and depend on the managing and decision making practices adopted by the company [42]. Every year, ANEEL (regulatory agency) carries out the Annual Tariff Readjustment Processes, which aim to review the distributors’ portion $A$ costs and to recalculate the energy tariff fairly. Portion $B$ costs are only reviewed in the Periodic Tariff Review Processes, which occur every 4 years typically. That said, it is important to emphasize that the COVID-account (public policy to mitigate the impact of the pandemic) aims to assist the power distribution companies in honoring their contracts, focusing on the costs that comprise portion $A$, i.e. the unmanageable costs.

Among the 39 analyzed companies, 20 had access to the COVID-account proposed by the government [39]. Hence, the analysis is separated into two groups: The COVID-account group and the non-COVID-account group. Of the 19 companies that did not have access to the COVID-account in 2020, 15 companies had their Annual Tariff Readjustment Processes before July 2020, i.e. prior to the creation of this mechanism by the government. These companies may receive the loan, if necessary, and will only be included in the next readjustment made by ANEEL. Only 4 distributors did not apply for the loan (Coperlia, EFLJC, Energisa TO and Forcel), as their surpluses have not been affected by the pandemic. These four companies managed to achieve market growth, even in the face of the pandemic, since they have been at a growth rate over the past few years. Despite the pandemic having slowed the growth rate of such companies, it was still considerably positive. EFLJC presented the largest market growth with 9.85% increase in demand, followed by FORCEL (6.82%), Coperlia (2.89%) and Energisa TO (1.50%) [39]. It is also important to emphasize that these companies are relatively small and none of them are situated in the southeast region, which was the most affected region as further discussed. They are situated either on the South or North regions, which were not heavily affected.

The 39 analyzed concession areas are expected to provide a proper overview of the COVID-19 economic issue since the consumed energy ($E$) of such areas ranges from less than 1 (TWh) to more than 45 (TWh), which comprises a great variability of electricity markets.

Fig. 3 and Fig. 4 display the EVA (power distribution company’s surplus) of the 39 analyzed companies from 2018 to 2020, based on the application of (14). Since the COVID-19 pandemic was not a reality from 2018 to 2019, this period can be used as a basis for comparison. It should be noted that in the group of utilities that had access to the COVID-account (Fig. 3), the results for the year 2020 are including the loan, which will be amortized over the next 60 months.

Based on the results described in Fig. 3 (COVID-account group), it can be concluded that, from the company’s point of view, the year 2020 was worse than the year 2019 for 4 of the 20 analyzed companies, even with the loan proposed by the government. On average the EVA of the COVID-account group increased by 183 (MRS)$ from 2019 to 2020. On the other hand, Fig. 4 (non-COVID-account group) demonstrates that the year 2020 was worse than the year 2019 for 11 of the 19 analyzed companies. On average the EVA of the non-COVID-account group decreased by 60 (MRS)$ from 2019 to 2020. Therefore, the results suggest that the COVID-19 pandemic is harming Brazilian power distribution companies substantially (assuming the absence of public policies).

It is essential to check the characteristics of the most affected companies. Table 1 describes the EVA and return on investment variations from 2019 to 2020 as well as the regions of the companies, the number of consumer units and the share of commercial consumption. In order to verify if there is a considerable correlation between the EVA variation and the number of consumer units, the Spearman’s correlation coefficient can be calculated. The Spearman’s coefficient is effectively applicable when a non-linear relationship between variables is verified (it addresses monotonic relationships instead of linear relationships), the data is ordinal and there are significant outliers (the coefficient is not sensitive to outliers). Therefore, the Spearman’s coefficient ($\rho$), whose formula is represented in (25), is suitable for this analysis.

$$
\rho = 1 - \frac{6 \sum d_i^2}{n^3 - n} \quad (25)
$$

where

- $d_i$ is the difference between the two ranks of each observation;
n is the number of observations.

By applying (25), Spearman’s coefficients of 0.40 and −0.30 between the EVA variation and the number of consumer units are obtained for the COVID-account group and the non-COVID-account group, respectively. Hence, for the COVID-account group, the bigger the company the greater the upward trend of EVA from 2019 to 2020, whereas for the non-COVID-account group, the bigger the company the greater the downward trend of EVA from 2019 to 2020. This conclusion is due to the sign of the Spearman’s coefficient. However, weak correlations are verified, i.e. Spearman’s coefficients of 0.40 and −0.30 are considerably far from 1 and −1, which would be perfect correlations. Therefore, results suggest a significant number of outliers regarding the correlations between the EVA variation and the number of consumer units. Other factors such as the region of the company and the share of residential, commercial and industrial consumption (commercial and industrial classes were heavily affected) are likely to influence the EVA variation and to reduce the strength of the calculated correlations. Based on data from Table 1, the Spearman’s correlation coefficient can also be applied to verify the influence of the share of commercial consumption on the EVA variation (the commercial consumption class was chosen since it suffered the greatest demand reduction). For the COVID-account group, the Spearman’s coefficient indicated that there is an extremely weak correlation between the share of commercial consumption and the EVA variation due to the government interference in the market, thus, the analysis focuses on the non-COVID-account group. For such group, a weak correlation of −0.34 was obtained, i.e. the greater the share of commercial consumption the greater the downward trend of EVA from 2019 to 2020. As a way to obtain a stronger correlation, the concept of return on investment can be used instead of EVA, as presented in (26) (TAROT model’s context):

$$ROI = \frac{EBTIDA}{B} = \frac{R - eE - pE^2 - \mu R}{B}$$  \hspace{1cm} \text{(26)}$$

where

- ROI denotes the return on investment. The ROI variations from 2019 to 2020 are listed in Table 1;
- EBTIDA denotes the earnings before interest, taxes, depreciation and amortization;
- R is the revenue;
- eE models the operational expenses;
- pE^2/B models the energy loss costs;
- \mu R are the sales taxes;
- B is the grid investment.

The correlation is stronger when ROI is used because ROI is a percentage indicator of profit, i.e. it levels large and small companies. This approach eliminates the effect (or at least decreases the effect) that the number of consumer units has on the performance of companies. In this case, the Spearman’s correlation coefficient can be applied to verify the influence of the share of commercial consumption on the ROI variation (the commercial consumption class was chosen since it suffered the greatest demand reduction), as presented in (26) (TAROT model’s context):
case, a correlation of –0.44 is obtained between the share of commercial consumption and the ROI variation from 2019 to 2020. In conclusion, the results indicate that there is a tendency, however, the correlation is weak/moderate implying a significant number of outliers.

Based on data from Table 1, Fig. 5 presents the overall EVA variation per region. By comparing the regions, it can be verified that the Southeast market was considerably more affected by the COVID-19 pandemic. This fact occurred since the Southeast region presented the greatest consumption reduction of all regions [43]. The state of São Paulo (regarded as the Brazilian industrial/commercial center), located in the Southeast region, adopted rigorous social isolation measures (arguably the most rigorous measures of the country), which led to a drastic consumption reduction [44]. Interestingly, most distribution companies from the state of São Paulo had access to the COVID-account (AES Eletropaulo, CPFL Piratininga, EDP São Paulo and Elektro), CPFL Paulista was the only analyzed company from São Paulo that did not have access to the public policy. Hence, a fact that is counterintuitive is that São Paulo was not the main responsible for the impact in the southeast region illustrated in Fig. 5. CEMIG-D, which is the largest Brazilian power distribution company providing services for approximately 97% of consumers in the state of Minas Gerais [45], was the main responsible for the impact. Numerically, Minas Gerais accounts for 80% of the economic loss (non-COVID-account group), whereas São Paulo accounts for the remaining 20%\(^1\). In conclusion, even though social isolation measures and demand reduction are very important factors, it is essential to address other variables when analyzing the impact of the pandemic on the electricity market.

Fig. 6 presents the effect of the COVID-account on the tariffs. As verified, the COVID-account fulfills its purpose of decreasing the tariffs. It should be emphasized, however, that Fig. 6 only exhibits tariffs for 2020. Due to the 2.8% per annum interest rate to be paid in 5 years of the COVID-account, there is a tendency of tariff growth in the medium term, in addition to the normal growth trend (tariffs tend to increase even in a pandemic-free context).

Fig. 7 exhibits how the COVID-account influenced the ECA (Economic Consumer Added). Due to the tariff decrease exhibited in Fig. 6,
the public policy proposed by the government increased the ECA. The energy economic utility parameters $a$ and $b$ of each concession area are addressed as constant in the calculation of ECA so that results are more accurate (this consideration is important since the exact behavior of the demand elasticities is unknown). It should be emphasized that the results presume the effects of the pandemic on the parameters, i.e. the parameters are calculated for mid-2020 when the pandemic was already an issue. However, it is assumed that the energy economic utility parameters for two tariff conditions (with COVID-account and without COVID-account) are the same. In short, this means that the quality of life added by a specific amount of electricity consumption is the same in both cases, however, due to the tariff difference, there is a higher cost and lower ECA when the COVID-account is removed. For better visualization, this concept is qualitatively illustrated in Fig. 8 by applying equation (3).

The graphs of socioeconomic welfare are not presented here, since the data used in this work refer to the results of the annual readjustments made by ANEEL in each company in 2020. After the readjustments, the companies are in financial economical equilibrium (FEE), and according to (17) the value of the utilities’ surplus is zero or close to this value, in order to maximize socioeconomic welfare. Thus, according to (16), when a company is in FEE, after the readjustments, the consumers’ surplus represents virtually the totality of socioeconomic welfare. In conclusion, Fig. 7 can be seen as both ECA (consumers’ surplus) and EWA (socioeconomic welfare), implying that the COVID-account also increased the EWA.
4.2. Measure to mitigate the impact of the COVID-19 pandemic

As previously mentioned, one way to mitigate the impact of the COVID-19 pandemic is through the implementation of public policies. Although the public policy proposed by the Brazilian government (COVID-account) presented decent results in terms of increasing market players’ surpluses, i.e. ECA, EVA, and EWA, its interest rate is a concern (consumers have no choice whether they accept the terms of the loan or not). In this section, it is analyzed how the government / regulatory agency could reduce the sales tax (tax exemption) and modify the energy tariff in order to mitigate the impact of the pandemic. The analysis is ultimately performed based on the sales tax parameter of the TAROT model (μ) and on the tariff variable (T). It should be noted that the sales tax parameter is given by (22), thus in order to reduce μ, exemptions of ICMS, PIS, or COFINS are necessary. As a hypothesis of the proposed public policy, it is considered that the power distribution company’s surplus (EVA) must be zero (ensuring market optimization as exposed in (17)) and the consumers’ surplus (ECA) before and during the pandemic must be constant.

At first, the consumed energy (E) is unknown. However, the consumers’ surplus is known by the hypothesis of the proposed policy. Hence, from (5), E is written as:

$$E = \sqrt{\frac{2ECA}{b}}$$  \hspace{1cm} (27)

Based on the marginal utility concept equated in (4) and on the consumed energy obtained from (27), the energy tariff that maintains the consumers’ surplus constant can be obtained:

$$T = a - bE$$  \hspace{1cm} (28)

$$T = a - b\sqrt{\frac{2ECA}{b}}$$

$$T = a - \sqrt{2bECA}$$

In general, however, the tariff obtained by the application of (28) does not result in a power distribution company’s surplus equal to zero. For that to happen, it is necessary to modify the sales tax parameter of the TAROT model (it is assumed that the government grants tax exemption). As the hypothesis of the proposed public policy, the EVA must be zero. Hence, based on (14):

$$a - \mu a - c_1 + (ab - b)E = 0$$  \hspace{1cm} (29)

Isolating the sales tax parameter (μ):

$$\mu = 1 + \frac{c_1}{bE - a}$$

The consumed energy is given by (27), thus:

$$\mu = 1 + \frac{c_1}{\sqrt{2bECA} - a}$$  \hspace{1cm} (30)

Based on (31), the sales tax parameter that results in $EVA = 0$ can be obtained.

It should be emphasized that this strategy is adequate for markets that exhibited a reduction of both $ECA$ and $EVA$ from 2019 to 2020, namely: CEMIG-D, ENEL CE, ENERGISA NF, and HIDROPAN.

Fig. 9 exhibits the required tariffs to implement the proposed public policy, whereas Fig. 10 illustrates the required $\mu$ parameters.

It can be verified that some concession areas do not require significant changes to mitigate the impact of the pandemic (e.g. HIDROPAN), thus, in such cases, reasonable tax exemptions and minor tariff variations would be enough. Specifically for ENEL CE, there is no need for tax exemption, since its $EVA$ is positive even after the tariff decrease illustrated in Fig. 9. However, CEMIG-D was so severely harmed that major changes would be necessary for such a policy. In conclusion, an argument can be made that the proposed measure is reasonable depending on the concession area. It should be emphasized that the exemplified policy considered complete mitigation of the effects of the pandemic, under the established assumptions. Based on the TAROT model it is also possible to propose partial mitigations of the effects of the pandemic so that smaller modifications of the tariff and of the $\mu$ parameter would be required. In comparison to the COVID-account, the exemplified policy has the advantage of making loans unnecessary (as long as tax exemptions are possible, easy to implement and possibly with minor global effects on the economy) and also of benefiting consumers and power distribution companies in a fair manner. It is justifiable to affirm that the exemplified policy fairly benefits market agents (consumers and companies) for two main reasons: (i) by imposing $EVA = 0$, it implies that all of the power distribution companies’ costs (Illustrated in Fig. 2) can be paid, i.e. financial loss is prevented even in critical economic scenarios such as the COVID-19 pandemic (such critical scenarios would pose high risks to companies disregarding public policies and would increase defaults, which in cascade effect could lead to catastrophic consequences), and (ii) the exemplified policy ensures lower tariffs for consumers, which leads to increased electricity consumption in a context where consumption would naturally be low due to social isolation measures.
The lower tariff and higher consumption mitigate the impact of the pandemic on the consumers’ surplus (ECA) by ensuring it remains constant. Hence, the exemplified policy contemplates the interests of power distribution companies and consumers simultaneously.

In order to ensure that the proposed policy is practical and assess whether it may cause a financial burden, it is also important to evaluate how the tax exemption influences the sales taxes (Fig. 11) and if such influence is extensive in relation to the overall taxes collection from the states. Equations (2), (7), (27) and (28) were used to calculate the sales taxes for the two distinct conditions illustrated in Fig. 11 (with and without the proposed policy).

Fig. 11 demonstrates that the most considerable decrease in sales taxes is that of CEMIG-D due to two key reasons: (i) CEMIG-D was heavily harmed by the pandemic, thus, the public policy modified the $\mu$ parameter considerably to ensure $EVA = 0$, and (ii) CEMIG-D is the largest Brazilian power distribution company, hence, its revenue is substantial (the sales taxes are proportional to the revenue). The public policy would decrease CEMIG-D’s sales taxes by 2868 (MR$) or by 46%, so it may not be a feasible policy for that particular concession area. However, ENEL CE, ENERGISA NF, and HIDROPAN have not experienced massive changes in sales taxes, especially when comparing such changes to the taxes collection from the states, as exhibited in Table 2.

Table 2 highlights the taxes on consumption of goods and services (ICMS) as these are the main taxes that compose the $\mu$ parameter. It is again emphasized that ENEL CE does not require tax exemption to ensure $EVA = 0$, which justifies the negative value on Table 2. Regarding ENERGISA NF and HIDROPAN, the impact of the proposed policy on the collection of ICMS is negligible, i.e., the proposed policy would not imply financial burden. Moreover, as future work a deeper analysis would be valuable on the effective use of governmental public resources received in taxes for the well-being of population, especially in time of crises such as the COVID-19 pandemic in comparison to the usually high financial interests imposed by the financial system over the customers.

5. Conclusions

The COVID-19 pandemic, characterized as a worldwide public health and economic crisis, has massively impacted the world. This paper focused on the economic aspect, particularly on the electricity market. The Optimized Tariff Model was applied throughout the paper and proved to be a simple and efficient tool for analyzing the impact of rare occurrences such as the COVID-19 pandemic on regulated electricity markets. Based on straightforward equations, the model enables the obtention of the market players’ surpluses, which can be used to analyze the impact of the pandemic. The results suggest that the pandemic significantly impacted the Brazilian distribution electricity market, particularly the concession areas that did not have access to the COVID-account yet (public policy to mitigate the effects of the pandemic). More specifically, the study demonstrated that the surpluses of the power distribution companies (EVA) of the non-COVID-account group decreased on average by 60 (MR$) from 2019 to 2020 or by 1140 (MR$) in total.

The Optimized Tariff Model is a useful tool for analyzing proposals to mitigate the impact of the pandemic, such as the public policy presented in Section 4.2, since, unlike other models, the Optimized Tariff Model simultaneously represents the economic flows between power distribution companies, government and consumers. Thus, the outcomes of public policies based on the Optimized Tariff Model can be designed to benefit all market players.

The impact of implementing the COVID-account in this work refers to the year 2020. However, as previously mentioned, the financial loan will be amortized over a period of 60 months. Thus, the measure proposed by the Brazilian government will impact tariffs for the next 5 years. As future work, it is possible to analyze these impacts over time and assess whether this measure was really beneficial for both energy distributors and final consumers in the long run. The most likely reason why the Brazilian government opted for a loan-based public policy to mitigate the impact of the pandemic instead of another approach (e.g., tax exemption) is possibly because easily available financial institutions guarantee high interests with low risk of default from the power distribution companies, which have the Brazilian government as guarantor, transferring to final consumers the future direct burden of the loan. In summary, the results indicated that the COVID-account was beneficial, however, it presents short-term beneficial characteristics, and it was not adopted by all power distribution companies.

While it is fair to attribute a negative impact on the electricity market due to the pandemic, natural market changes might occur within one year, or one decade. It is still a challenge to numerically determine with certainty the real impact of the COVID-19 pandemic on the market, due to the inherent natural market changes mentioned. Thus, more work and
time are needed in this regard to further understand the complex economic issue related to the impact of the COVID-19 pandemic on the electricity market. It is also essential to develop several mitigation measures (public policies) since a specific measure might be unfeasible for some concession areas as discussed in Section 4.2. Moreover, the socioeconomic differences among distinct regions must be properly considered. The worldwide effort to mitigate the impact of the pandemic in several fields (e.g. public health, economics, education, environment) and the experience gained are expected to better prepare humanity for possible future crises / pandemics.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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