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Non-technical Losses in Brazil: Overview, Challenges, and Directions for Identification and Mitigation

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ABSTRACT

Non-technical losses (NTLs) directly affect the electricity distribution system's quality and create significant economic problems in developing countries. There has been an advance in Brazil's regulations to combat this kind of loss in the last 15 years. However, the electricity consumed and not billed is still high, impacting the electricity tariff and distributors' investment capacity and creating difficulties in developing public policies to mitigate the problem. Thus, this article seeks to present the panorama of NTLs in Brazil and propose legislative, regulatory, business, and academic directions. For this, 28 semi-structured interviews were carried out with specialists, resulting in identifying the main challenges for identifying and mitigating NTLs in Brazil and the factors that help overcome this problem. The results demonstrate that coordinated strategic actions among all stakeholders need to be developed to combat NTLs. The cultural change in acceptance of electricity theft needs to be one of the country's main focuses. The main contribution is to disseminate information to regulatory and legislative authorities, government, concessionaires, and researchers to develop practical actions for mitigating NTLs in Brazil.

Keywords: Electricity Theft, Electricity Distribution, Non-technical Loss, Stakeholder Perspective, Energy Policy
JEL Classifications: M10, O20, Q48, R58

1. INTRODUCTION

Quality of the electricity distribution is a crucial factor for industrial competitiveness and society's well-being (Luqman et al., 2021; Tehero et al., 2020). In developing countries, the distribution network's infrastructure tends to be more precarious and highly subsidized, creating policy and regulatory challenges associated with the payback of investments (Mori, 2021). In this scenario, one of the most significant development goals is related to reforms in the energy sector to make electricity accessible to the entire population (Dertinger and Hirth, 2020). However, distributors' investment capacity and network quality are compromised because not all electricity consumed is billed (Lewis, 2015; Smith, 2004). This electricity corresponds to non-technical losses (NTLs) caused by electricity theft, fraud, defaults, billing errors, defective meters, among others (Corton et al., 2016; Zanetti et al., 2019).

The growing electricity demand, combined with complex socioeconomic conditions in a country of continental dimensions such as Brazil, creates economic and regulatory challenges directly related to the sustainability of distribution systems and combating NTLs (Nascimento et al., 2020; Maciel et al., 2020; Simões et al., 2020). Concessionaires, policymakers, researchers, government agencies, and the Brazilian Electricity Regulatory Agency (ANEEL) make efforts to minimize the lost energy. However, NTL is caused by external factors to the distribution system (Ghasemi and Gitizadeh, 2018). Therefore, it creates challenges for identification and mitigation that can only be solved through public policies, regulations, and legislation planned with all stakeholders' collaboration.

In 2019, NTLs in Brazil totaled 35.9 TWh, which corresponds to about US$ 1.79 billion[1]. Passing on the tariff of the NTL's efficient levels is allowed in the distributors' concession contracts. There is compensation in the energy purchase costs up to the regulatory limit established by ANEEL (ANEEL, 2015, 2020a). Thus, the portion of NTL within the agency's regulatory limit is passed on by the concessionaire to the consumer's tariff. Also, there are legal mechanisms to combat NTLs in the country. Electricity theft, which corresponds to most NTLs in Brazil, is considered a crime, liable to a fine and imprisonment (Brasil, 1940). These legal measures are ongoing with those adopted by other countries. Still, their application depends on factors such as availability of police contingents, police departments specialized in electricity theft, the crime rate in the region, and accessibility of concessionaire's agents and the police to identify the flagrant.

Brazilian concessionaires have developed efficient methods of detecting NTLs through research and development (R&D) actions. The regulatory agency encourages R&D projects in partnership with academics from research centers and universities and provides advances to control the problem in the short, medium, and long terms. Nevertheless, it is noteworthy that research needs to deal with the problem globally, considering the technical, economic, social, cultural, and geographical variables specific to each concession region (Ventura et al., 2020). Analyzing the problem from a single perspective in a large country like Brazil creates less effective NTLs identification and mitigation methods. Still, strategic information about NTL needs to be researched and disclosed to help regulators, policymakers, and the government develop actions that bring benefits to business and society. Thus, this research aims to present the overview of NTLs in Brazil and propose directions for legislative, regulatory, business, and academic stakeholders. For this, the article identifies the factors that help and interfere with identifying and mitigating NTLs in the country through 28 semi-structured interviews with specialists, comprising employees and directors of concessionaires, regulators, government members, policymakers, police, and researchers.

This study expands and complements the existing literature on NTLs and energy policy by understanding the socioeconomic and political-institutional dimensions of electricity theft in a developing country, following Never (2015)'s suggestion. Furthermore, it reaffirms that the causes of NTLs in distribution are deeply rooted in social issues and the quality of governance to be resolved only in the electricity sector, in line with Dertinger and Hirth (2020). Sirin and Gonul (2016) say that new regulations should increase transparency, disseminate information, and reduce bureaucratic processes to consumers. So, this research shows that the Brazilian scenario depends on regulations based on incentives to concessionaires and considers the social, economic, cultural, and geographical differences of each country region. The results allow the formulation of regulatory, legislative, and scientific, and technological development strategies to minimize the negative impacts of NTLs on electricity distribution concessionaires and society.

1 Conversion made through the 2019 average price of the Brazilian real against the US dollar.

2. METHODS

The method is based on a qualitative exploratory approach and was organized in three main stages, as shown in Figure 1. Semi-structured interviews were carried out with 28 specialists through video calls or formularies, depending on respondents' availability. Semi-structured interviews are composed of an interview guide that includes open-ended questions, allowing respondents flexibility to spontaneously prepare their responses and creating opportunities for new ideas to be expressed (Aikenhead et al., 2015; Garlet et al., 2019). Qualitative research has already been used in studies related to NTLs, making it possible to advance the theme in the theoretical, practical, and political fields (Never, 2015; Yakubu et al., 2018).

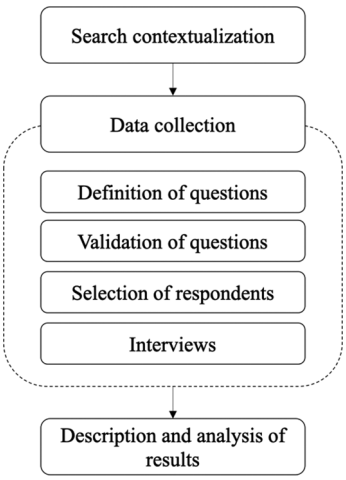
The first step included the theoretical contextualization of research related to NTLs in Brazil, identifying the leading published research and the regulations and legislation about them. After defining the dimensions to be researched, data collection involved developing questionnaires, validating the questions with specialists, selecting respondents, and conducting interviews. The results obtained were described and analyzed in the previous research methodological step. The following subsections detail these three steps.

2.1. Search Contextualization

Based on the definition of the research question and objectives, a review of the scientific literature on NTLs in Brazil was carried out in the Scopus database. The search string used was title-abstract-keywords (("non-technical loss*" OR "electricity theft") AND Brazil), without any filters, returning nine relevant articles published in conference proceedings and journals.

Canaes and Grimoni (2012) present an energy efficiency plan for a Brazilian concessionaire to reduce the region's non-payment culture. Simões et al. (2020) estimate, analyze, and predict non-technical short-term losses in Brazilian distributors considering social and economic variables. Arango et al. (2017) explore how electricity theft economically impacts distributors, consumers, and society, while Bastos et al. (2009) quantify the sources of NTLs and their regional distribution in Brazil. Corton et al. (2016) identify that the impact on the operating costs of the Brazilian electrical system is more significant when NTLs increase compared with the duration of power interruptions. Boccardo et al. (2010) bring

Figure 1: Methodological steps



the software evaluation of smart meters within a legal metrology perspective in Brazil, while De Araujo et al. (2014) analyze the relationship between behavioral variables of payment and delinquency in a Brazilian state. Hammerschmitt et al. (2020) seek to clarify how NTLs are characterized and calculated by the Brazilian regulatory agency. Leite et al. (2020) present an alternative model to ANEEL's by setting regulatory targets.

Current and proposed Brazilian regulations and laws were analyzed in addition to the search for scientific articles. In this context, in 2011, ANEEL created the Tariff Regulation Procedures (PRORET), with a normative character, and consolidated the regulation about Brazil's tariff processes (ANEEL, 2011). Sub-modules 2.2 and 2.2A (ANEEL, 2018a, 2018b), related to operating costs and sunk revenues, and sub-module 2.6 (ANEEL, 2015), associated with energy losses, regulate processes related to NTLs in Brazil. Sub-module 2.6 of the PRORET establishes the methodology to define regulatory energy losses in the Periodic Tariff Reviews of the public electricity distribution services. It has a socioeconomic complexity ranking for the concession areas and establishes non-technical regulatory loss targets defined through benchmarking between the concessionaires. Distributors can pass on NTLs within the regulatory limits to consumers through the electricity tariff (ANEEL, 2015). The improvement of regulation is periodic, and in 2020 there was a public consultation to obtain subsidies for the methodological refinement of the treatment of energy losses and irrecoverable revenues (ANEEL, 2020b).

There are Bills related to NTLs being processed in the National Congress of Brazil. Bill No. 5457/2016 provides for the exclusion of charging for the provision of clandestine connections and defaults in the calculation basis of electricity bills and proposes a 5% limitation on compensation for technical and NTLs in electricity transmission and distribution (Lopes, 2016). Bill No. 5324/2019 seeks to prohibit the inclusion of NTLs in the electricity tariffs practiced by the concessionaires and permissionaires of public electricity distribution services in Brazil (Marinho, 2019). Bill No. 1569/2019 aims to oblige concessionaires and permissionaires of public electricity distribution services to inform in the electricity bills the portion of the electricity tariff corresponding to NTLs (Ribeiro, 2019). Finally, the Brazilian Penal Code provides for a fine and imprisonment of 1–4 years for those who steal electricity, with the possibility of extending the sentence to 5 years if the theft occurs during nighttime rest (Article 155, §3, 1940).

Through the information obtained in scientific articles and regulatory and legislative documents, it was observed that there are contrasts between the objectives of the publications. Thus, to draw an overview of NTLs in Brazil, this method analyzes four dimensions: Business, from the perspective of electricity distributors; Regulatory, from the perspective of the regulatory agency and agents; Legislative, from the perspective of the development and application of laws and policies; and Knowledge, from the perspective of scientific research.

2.2. Data Collection

From the need to approach the problem in four dimensions, four questionnaires were developed, presented in Appendices A-D. The questions were developed based on the knowledge obtained through the theoretical context of the research. Then, the questionnaires were validated with specialists, who suggested possible modifications and new questions, in addition to checking if what was proposed would be sufficient to answer the research question and reach the study's objectives. From the Business perspective, the questionnaire was validated by a Master in Industrial Systems and Processes, who works as a technical assistant for an electricity distributor for over 19 years. From the Regulatory perspective, the questionnaire was validated by a Ph.D. in Electrical Engineering who is a specialist in public energy services regulation for over 15 years. In the Legislative dimension, the questionnaire was validated by a State Deputy with 2 years of experience. From the Knowledge perspective, the questionnaire was validated by two Ph.D. in Electrical Engineering, one with over 11 years of research experience at a Federal University in Brazil and another with more than 27 years of energy research experience.

A qualitative approach was used through semi-structured interviews conducted throughout formularies and video calls, considering the research's exploratory characteristics. The selection of respondents was made intentionally, seeking to include Brazilian professionals with extensive experience in NTLs. According to Never (2015), in qualitative research, the saturation point for interviews is usually reached when additional interviews do not contain new information on key subjects. Thus, the sample consisted of 28 respondents, 10 in the Business dimension, four in the Regulatory dimension, three in the Legislative dimension, and 11 in the Knowledge dimension. The respondents' profile is described in Table 1. The codes "Bi," "Ri," "Li," and "Ki" were used for respondents from the Business, Regulatory, Legislative, and Knowledge dimensions, respectively, to preserve the respondents' identity and possible conflicts of interest.

The interviews were conducted virtually between September and December 2020. It is noteworthy that all interviewees' information represents their personal, rather than institutional, opinions. The data were recorded with the respondents' consent and later transcribed and compiled using Microsoft Excel™.

2.3. Description and Analysis of Results

At this stage, the data were analyzed and separated into categories. As shown in Figure 2, the category of analysis involves an overview of NTLs in Brazil from the Business, Regulatory, Legislative, and Knowledge perspectives; the challenges for identifying and mitigating NTL; the main factors that help to combat NTL; and the future of NTLs in Brazil.

The information obtained through the sources of evidence aims to identify similar perspectives in different responses. In this way, the data fragments were used to determine the panorama of NTL in Brazil and were grouped and presented in text and tables. All the information was contrasted with the literature to deliver precise results with implications for theory and electricity distributors and provide directions for new regulations, laws, and public policies in Brazil.

Table 1: Profile of respondents

Code	Profile
B1	Master in Economics, with emphasis on regulation, has 12 years of experience in the sector. Currently, he is the Corporate Manager of Regulation of Distribution and Transmission at a large electricity distribution concessionaire which covers four states in Brazil
B2	Electrical Engineer, has 10 years of experience in non-technical losses. He is currently the Measurement and Loss Control Coordinator at an electricity distribution concessionaire in Brazil
B3	Electrical Engineer, with 1 ½ year of experience in non-technical losses. He is currently a Commercial Loss Analyst at an electricity distribution concessionaire which covers eight states in Brazil
B4	Electrical Engineer, with 12 years of experience in non-technical losses. He is currently the Measurement and Loss Control Coordinator in a large electricity distribution concessionaire which covers 10 states in Brazil
B5	Electrical Engineer, with 6 years of experience in non-technical losses. He is currently the Energy Recovery Services Manager at a concessionaire which covers two states in Brazil
B6	Electrical Engineer, with 3 months of experience in non-technical losses. He is currently Energy Recovery Coordinator at a Brazilian electricity distribution concessionaire
B7	Electrical Engineer, with 15 years of experience in non-technical losses. He is currently a Loss Analysis Engineer at a Brazilian electricity distribution concessionaire
B8	Control and Automation Engineer, he has worked for 15 years in non-technical losses control. He is currently an energy measurement technician at a Brazilian electricity distribution concessionaire
B9	Manager of commercial loss inspections at a Brazilian electricity distribution concessionaire, he has 20 years of experience in the sector
B10	Electrical Engineer, he is the Regional Manager of a Brazilian electricity distribution concessionaire. He has 13 years of experience in the sector
R1	Economist, he is a specialist in regulation and director at the Ministry of Mines and Energy for over 2 years
R2	Master in Electrical Engineering, he worked as a regulation specialist in a regulatory agency in the sector for 13 years
R3	Economist, analyst, and expert in Economics of the Federal Public Ministry
R4	Ph.D. in Energy Planning, he is a specialist in regulation in the regulatory agency. He has 23 years of experience in the sector
L1	Federal Deputy since 2011, he is a proponent of a Bill related to non-technical losses
L2	Bachelor of Law, he is a regional civil police delegate for over 5 years. He has over 21 years of experience
L3	Senator of the Republic since 2019, he is a proponent of a Bill related to non-technical losses
K1	Ph.D. in Electrical Engineering, he is a professor and researcher at a university in the United States. He has 12 years of experience in non-technical losses
K2	Ph.D. in Electrical Engineering, he is a post-doctoral researcher in an R&D laboratory in the United States
K3	Ph.D. in Computer Science, he is a post-doctoral researcher at a university in Brazil
K4	Ph.D. in Electrical Engineering, he is a professor and researcher at a federal university in Brazil. He has 15 years of experience in the sector
K5	Electrical Engineer and Master's student in Energy Systems at a federal university in Brazil. She has 7 years of experience in the sector
K6	Master in Electrical Engineering, he is a Ph.D. candidate in Energy Systems at a federal university in Brazil. He has 4 years of experience in the sector
K7	Master in Electrical Engineering, he is a researcher at a Brazilian research center
K8	Electrical Engineer, he is a researcher at a Brazilian research center. He has 4 years of experience in the sector
K9	Ph.D. in Electrical Engineering, he is a professor and researcher at a federal university in Brazil. He has 6 years of experience in the sector
K10	He is a Bachelor of Science and Technology, student of Energy Engineering, and a researcher at a federal university in Brazil. He has 2 years of experience in the sector
K11	Ph.D. in Electrical Engineering, he is a professor and researcher at a federal university in Brazil. He has 18 years of experience in the sector

3. RESULTS AND DISCUSSION

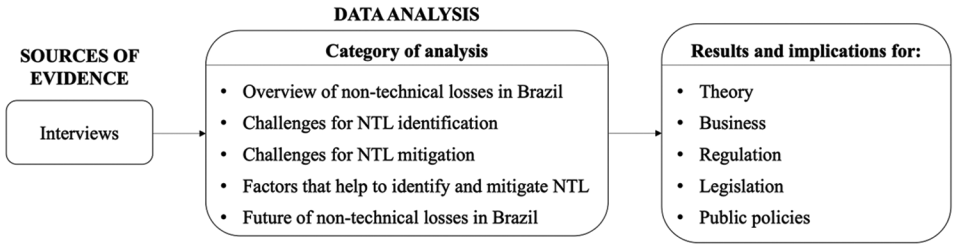
This chapter presents the results obtained through 28 interviews with 28 specialists. Initially, an overview of NTLs in Brazil is presented from the Business, Regulatory, Legislative, and Knowledge perspectives. Subsequently, the main challenges for identifying and mitigating NTLs and the factors that help combat NTL in Brazil are pointed out and discussed. Finally, future scenarios related to NTL in the country are discussed.

3.1. Overview of NTLs in Brazil

NTLs require coordinated actions by concessionaires, regulatory agents, policymakers, law enforcers, and researchers to be successfully controlled, especially in a socioeconomically complex country like Brazil. All respondents in the Business dimension point out that the concessionaires they work for invest heavily in combating NTL, one of the most significant sources of economic losses for the sector (Leite and Mantovani, 2018). B2 and B7 remind that the concessionaire they work for encourages employees' proactivity, and the company's R&D sector has already developed several devices to control the situation. B3 states that the company runs annual campaigns for consumers' conscientization about NTL. B4, B5, B6, and B9 emphasize that they invest in developing inspection methodologies and goals to maintain quality in providing services to society. B10 points out that despite the Covid-19 pandemic, which has reduced the number of employees in the *in situ* inspections, they maintain pre-pandemic NTL levels. Still, B1 points out that the company he works for is known for its high turnaround rate, in addition to investing heavily in R&D and having a robust infrastructure for identifying NTLs.

K2 highlights the importance of the partnership between researchers and concessionaires in controlling NTL. Respondents in the Knowledge dimension agree that research can help combat NTLs in Brazil by developing identification methods, better characterizing the distribution system, and improving the distributors' database. However, K9 and K10 add that it is difficult

Figure 2: Structure for data analysis



to obtain real information from utilities, as the databases contain personal data, and consumers can feel harmed if it is disclosed. All methods for NTL identification can be classified as data-oriented, network-oriented, or hybrid (Henriques et al., 2020; Messinis and Hatziargyriou, 2018). K1, K2, K3, and K10 say that there are promising data-oriented methods in the literature that can be used in Brazil, such as Support Vector Machine (Depuru et al., 2011b; Nagi et al., 2010), Optimum Path Forest (Passos Júnior et al., 2016; Ramos et al., 2011), deep learning (Bhat et al., 2017), and clustering algorithms (Dos Angelos et al., 2011). K1, K2, K4, and K6 highlight good efficiency of network-oriented techniques, such as State Estimation (Salinas and Li, 2016), Load Flow (Aranha Neto and Coelho, 2013; Tariq and Poor, 2018), Operational Impedance (Manito et al., 2019) and self-monitored supervisor current transformer (Berquó et al., 2018). K7, K9, and K11, on the other hand, say that hybrid methods (Bretas et al., 2020; Rossoni et al., 2015; Trevizan et al., 2015) are economically more viable for the Brazilian reality because they can better characterize the concession areas.

However, K1, K2, K7, and K11 highlight an excellent research opportunity in the country related to legislative, economic, and regulatory issues. They also assume that many technical solutions can only be implemented through research results encompassing all these dimensions. From the legislative perspective, L1 and L3 say that the National Congress should favor legislative proposals that result, at least, in mitigating the risk of tariff increases. L1 understands that it is necessary to deepen discussions on the subject with technical entities in the sector. However, despite the existence of Bills related to the topic in the National Congress, there is no prospect of changing the legislation in the short term, given demands associated with the covid-19 pandemic became more urgent in this period. Regarding law enforcement, L2 says that the Civil Police acts when requested due to the very high demand. Nevertheless, he believes that the institution benefits society as electricity theft is combated. Still, he adds that the penalty's size is not the solution to the problem but the population's awareness about the consequences of NTL.

R3 points out that the Federal Public Ministry acts positively by opening administrative procedures to determine and monitor distributors with a higher rate of NTLs (Brasil, 2019), helping the regulatory process. R4 states that the distributors highlight ANEEL's good performance in the fight against NTL. The agency regularly seeks to analyze stakeholder demands through public consultations, which are essential for the regulatory regime to compensate for information asymmetry in the sector (Corton et al., 2016). Besides, it maintains efforts to reduce defaults and the electricity bill, with energy efficiency and population awareness. From R2 and K7 perspectives, disclosing information on NTLs is appropriate and transparent to all sectors of society, emphasizing that reports are published annually by ANEEL and that transparency is a value within the agency. On the other hand, R1, R3, R4, K1, K2, K3, K4, K5, K6, and K11 point out that the information exists and is publicly available, but it is very technical and needs to be disseminated to the population with an awareness bias about the adverse effects of NTL on the electricity tariff.

All respondents in the Regulatory dimension highlight the advances in Brazilian regulation in combating NTLs. R3 says that the Yardstick Competition methodology (Schleifer, 1985) was adopted from the second revision cycle. A competitive environment is created between concessionaires that operate in different regions and do not compete for customers. R1 and R3 state that it is hugely relevant to consider Brazil's geographic and social characteristics for formulating regulation and observing a natural limit for reducing NTL. R4 points out that three econometric models are currently averaged to represent the best reality in each region. However, R2 says that eventually, some concessions may not have their complexity fully represented. In this sense, K7 and K9 note the importance of analyzing the correlations with standard socioeconomic variables in the most significant loss areas. It is in line with what was exposed by R4, who says that there are discussions about the proposal to consider "risk areas," whose access is limited to concessionaire agents due to high crime.

R3 agrees that the fight against energy loss is complicated and does not depend exclusively on the concessionaire. Public security, justice, and social apathy also have a share of responsibility. It is also highlighted the importance of Brazilian regulation. Before the first cycle, the distributor could transfer all NTL costs to the consumer's electricity bill. The partial transfer of NTL to consumers, provided by sub-module 2.6 of PRORET (ANEEL, 2015), represented in 2019 around US$ 1.30 billion[2], corresponding to 3% of the electricity tariff (ANEEL, 2020a). R4, K2, and K7 suggest that the ideal is that part of the NTLs would not be passed on to consumers, but it would not be feasible for the concessionaire to bear all the losses. K1 also says that this could affect the quality of the service and the distribution system, information corroborated by Fernandes et al. (2019) and Joseph (2010). R1, K5, K9, and K11 highlight the good quality of the current regulation but emphasize that its updates must always be based on regulatory incentives. All efforts made by ANEEL, concessionaires, parliament, and the State seek to reduce the average rate of NTLs in Brazil. The most up-to-date data indicate that the weighted average of NTL

in Brazil in 2019 was 15.1%, while the index of non-technical regulatory losses was 11.8% (ANEEL, 2020a). All respondents in the knowledge dimension say that the loss rate needs to be as low as possible, but K11 points out that, despite high investments, the level of losses does not fall significantly. Accordingly, K9 states an urgent need to educate the population and develop policies that encourage network modernization and energy efficiency and the focus on combat techniques. Finally, K10 and K11 highlight the importance of regionalized analysis in a country of continental dimensions such as Brazil.

3.2. Challenges for NTL Identification in Brazil

Brazil ranks 96th in the ranking of Gross Domestic Product per capita (The World Bank, 2021a) and is one of the ten countries with the world's highest inequality index (The World Bank, 2021b). L1 and K9 say that Brazil's continental size provides a scenario with regions with a high level of NTLs and others with a lower index. This can be explained because the country has very different cultural and socioeconomic characteristics between its regions (Maciel et al., 2020). R1, R4, B1, B2, B6, and B9 point to these factors as a challenge to identifying NTLs in Brazil, adding that there is a culture of acceptance of electricity theft. Still, there is a low index of specific and regional social indicators made available by the government to concessionaires, as stated by K5. Still, K1 and K11 point out that the concentration of a large part of NTLs in low voltage and the large dimensions of the distribution system hinder NTL identification.

L2 and K7 point out an excess of clandestine connections to the distribution network in places with disordered housing formations. Mimmi and Ecer (2010) corroborate this information, stating that access to electricity theft is facilitated in regions such as slums due to the proximity of regularly serviced areas. Moreover, R2 and R3 highlight the precariousness of public security policy on the peripheries. It results in great difficulty for the concessionaires and their employees accessing remote areas or with a high crime rate, as pointed out by B6, L2, K5, K8, K9, K10, and K11. According to L2 and L3, there may be coercion and threat to the distributors' employees by criminals in these regions. It ends up preventing the legal interruption of the electricity supply, as provided in articles 168 and 169 of ANEEL Normative Resolution No. 414 of September 9, 2010 (ANEEL, 2010). However, L2 mentions that many illegal connections end up being quickly redone when they are interrupted. Furthermore, B2, L2, K4, and K8 say that another factor that makes it challenging to identify NTL is the diversity and improvement of electricity theft and fraud methods, carried out under the offer of professionals with technical knowledge.

K1, K8, and K10 point out that there is a need for a high number of employees to read and maintain meters in Brazil. K2 and K4 say that the inaccuracy and lack of meters' quality are challenges to identify NTL, while K5 affirms that billing errors are a problem to be overcome. Also, B1, B3, B5, and R4 state that some of Brazil's regions have geographical characteristics unfavorable to the network's measurement and maintenance. According to B2 and B8, inspection teams need constant qualification on the part of the concessionaire to avoid reading errors, a factor that B5, B7, and K5 point out. It is corroborated by Buzau et al. (2019) as one of the significant challenges related to identifying NTLs. Still, K11 states that there may be corruption on employees, which is also mentioned by Depuru et al. (2011) e Jamil and Ahmad (2019). Reading and billing errors compromise the concessionaire's databases, creating administrative problems, pointed out by R4, and inaccuracy in the electricity bill to the consumer, suggested by B5. L1 claims that the lack of detail and inspection in calculating NTLs makes it challenging to identify.

K1 and K11 say that the constant need to update and improve the database creates technical and economic challenges for utilities. B5 and B10 suggest that the low volume of data from the distributors is a challenge, and K2 and K4 add that the data's low reliability further complicates the NTL identification process. This information is in line with Passos Júnior et al. (2016), who say that getting data sets labeled and oriented to NTL identification is generally tricky. It is necessary to evaluate unsupervised techniques to solve the problem. From a Regulatory perspective, R3 states that information asymmetry makes it difficult for the regulatory agency to act, and its decisions are subject to the information given by the utilities. According to B4, K9, and K11, these factors make it more challenging to understand fraudsters' profiles and consumption patterns. Furthermore, B4, B7, and B9 point out that changes in consumption patterns in the industrial, commercial, and residential classes further hamper the identification of NTLs. These factors are corroborated by León et al. (2011), who says that consumption patterns vary between different groups of customers, strongly related to economic activity and the contracted tariff.

Although there are several methods for identifying NTLs (Ahmad et al., 2018; Messinis and Hatziargyriou, 2018), K11 claims that many are inaccurate and have some problems, information corroborated by Zheng et al. (2019). Furthermore, B2, B6, and B8 point to the lack of modern and assertive technologies necessary to meet ANEEL's loss reduction demands (Henriques et al., 2020), and K2 states that in smaller and less organized distributors, the absence of an R&D sector can be a critical problem in the fight against NTL. B3 and B5 note the lack of large-scale smart metering to combat the problem. The widespread use of smart systems for measuring and analyzing consumption information and registering concessionaires would be a solution. However, in line with Bula et al. (2016) e Henriques and Correa (2018), R1, R4, K2, K5, K7, K9, and K11 highlight the high investment required to implement this technology.

The main challenges to identifying NTL in Brazil, discussed in this subchapter, are compiled in Table 2.

3.3. Challenges for NTLs Mitigation in Brazil

Understanding the challenges of mitigating NTLs is a fundamental process for developing Brazil's strategic medium and long-term policies. Analyzing the problem from different perspectives makes it possible to produce concrete actions to reduce the harmful impacts that this problem causes to the country, electricity distributors, and society. The culture of acceptance of electricity theft, already mentioned as a challenge to identifying NTLs, also needs to be considered to mitigate the problem. According to B2, B3, B4, B6, B10, R3, and R4, it is necessary to make society aware

Table 2: Challenges for identifying non-technical losses in Brazil

Dimension	Challenges for NTL identification
Business	Culture of acceptance of electricity theft and unfavorable socioeconomic characteristics
	Low-security conditions in areas at risk due to crime
	Diversity and improvement of electricity fraud and theft methods
	Geographic characteristics unfavorable to the measurement and maintenance of the network
	Need for the constant qualification of teams working in the field
	Human measurement failures
	Electricity bill inaccuracy
	Low volume of data from utilities
	Difficulty in identifying the profile of fraudsters
	Changes in consumption patterns in the industrial, commercial and residential classes
	Lack of modern and assertive technologies
	Lack of large-scale telemetry
Regulatory	Diversity of socioeconomic and cultural contexts in Brazil
	Precarious public security policy in the country's peripheries
	Unfavorable regional and geographical factors
	Administrative problems for utilities
	Asymmetry of information on the causes of non-technical losses
	Low use of smart systems in the measurement and analysis of consumption information and registration of concessionaires
Legislative	Disparity in the rate of non-technical losses in different regions
	Excess of clandestine connections to the distribution network
	Disorganized housing formations
	Coercion and threat to distributors' employees by criminals in socially sensitive regions
	Professional meter fraud offer
	Lack of detail and inspection in the calculation of non-technical losses
Knowledge	Regional diversity in the non-technical loss index
	Low index of specific social indicators made available by the government
	Concentration of non-technical losses in the low voltage of the distribution system
	Large distribution systems
	Clandestine connections to the distribution network
	Difficulty in accessing the concessionaire in remote areas or with a high crime rate
	Frauds carried out by professionals with technical knowledge
	High number of employees needed to verify meters *in situ*
	Inaccuracy and poor quality of meters
	Billing errors
	Reading errors
	Corruption by concessionaires' and third-party readers
	Need for constant updating and improvement of the concessionaire's database
	Low availability of utility data
	Low reliability of utility data
	Difficulty in identifying consumption patterns
	Inaccurate methods of identifying non-technical losses
	Distributors without R&D sector
	Need for investment in smart metering and communication infrastructures

of the losses caused by electricity theft to change this culture in the medium and long term. Brazil is a complex country with significant social, cultural, geographical, and economic inequality, and these differences are reflected in the concession regions for electricity distribution (Ventura et al., 2020). This scenario feeds back the culture of electricity theft according to B8, K4, K5, K7, K9, and K11. Although ANEEL bases the regulation of non-technical losses on an index of socioeconomic complexity to balance the characteristics not manageable by distributors (ANEEL, 2015; Simões et al., 2020), B5 and B9 claim that there is still room for improvement in regulatory incentives to protect the Brazilian electrical system.

Brazilian regulation allows a portion of NTL to be diluted in the tariff (ANEEL, 2015; Ventura et al., 2020). In addition to the high taxation in Brazil, the tariff pressure on consumers' electricity bills is suggested by B1, L1, L3, and K1 and corroborated by Henriques et al. (2014) as one of the main problems related to the mitigation of non-technical losses. K5 and K7 still point to an increase in consumer defaults due to tariff pressure and, consequently, to the growth in the electricity theft index, factors confirmed by Tasdoven et al. (2012). L1 and L3 affirm that a decisive role of the regulatory agency in combating non-technical losses is crucial. At the same time, K7 and K11 emphasize that ANEEL has the challenge of continually evolving its regulation. The use of regulatory incentives through benchmarking techniques defines the most efficient distributors (Xavier et al., 2015), and R2 points out the periodic review of this process as a fundamental factor for mitigating non-technical losses in Brazil. There is a need to maintain and create regulations through incentives, not by the cost of service, as stated by R1 and corroborated by Corton et al. (2016).

The control of non-technical losses in regions of difficult access and with less purchasing power is indicated by R1 as a challenge to mitigate the problem. L2 and L3 say that the State needs to meet social demands, but B5 says that Brazil's government agencies sometimes abandon irregular areas. B5, B6, R3, and R4 suggest that the absence of the State allows regions to be controlled by organized crime, making it difficult for the concessionaire to operate. Furthermore, K1 points to the political cost of large-scale disconnections. Still, Razavi and Fleury (2019) say that a possible solution is implementing preventive measures effective in these regions, such as better law enforcement and government awareness campaigns and educational programs, although electricity theft is more significant in areas with a higher crime rate.

L2 says that non-technical losses control in these regions can be intensified by consolidating partnerships between distributors and law enforcement officers. It is in line with Otuoze et al. (2020), who claim that training sessions for distributor agents with the police and local task forces are bottlenecks to mitigate electricity theft. However, B10, K7, and K8 highlight that legal impunity for fraudsters is common in Brazil. This perception of society is enhanced, as acts of "minor disturbances or crimes" practiced in public places and given to the entire population indicate no order or public security to contain them (Loureiro et al., 2017). R3 and L3 also state that there may be leniency from public safety authorities and judicial favoritism to those who steal electricity. B1, B5, B7,

and B10 complement by pointing out that Brazilian regulation is permissive and favors fraudsters. L1 and L3 highlight the need for parliament to act in the face of possible omissions by the regulatory agency and distributors. However, R2 and R4 believe there is a lack of harmony between legislators and the regulatory agency.

L3 states that the concessionaire's performance is decisive in mitigating non-technical losses, and B9 emphasizes developing intelligence actions to obtain more effective results. However, some distributors do not measure electricity accurately due to technical negligence or defective equipment (Baloch et al., 2019). B6 agrees by saying that the search for immediate results and lack of long-term planning hinders the fight against NTL. On the other hand, R4 states a cost-benefit limit for concessionaires to implement loss mitigation solutions. According to B9, K2, K4, K7, and K11, the investment in smart metering infrastructure, monitoring, and shielding of the low voltage network can bring excellent results, but its high cost can, consequently, impact the electricity tariff (Maciel et al., 2020; Ventura et al., 2020). Still, electricity theft raises concern about implementing smart grids due to large-scale investments that can, by implication, translate into huge losses (Otuoze et al., 2020). Besides, R3 says it is necessary to invest in employees and more robust technologies in the areas with the highest incidence of electricity theft, as stated by K1, K7, K8, K11. Accordingly, B9 says it is also necessary to reduce direct consumer access to electricity measurement equipment. It is assumed that malicious users have partial knowledge of the network structure and can circumvent sensors and meters (Messinis and Hatziargyriou, 2018).

Table 3 presents a compilation of the main challenges for mitigating non-technical losses in Brazil discussed in this sub-chapter.

3.4. Factors that Help to Overcome Non-technical Losses in Brazil

The fight against non-technical losses in Brazil needs to start with a cultural transformation concerning electricity theft. L2 identifies educational campaigns aimed at society as one solution that provides effective results in the medium and long term. Also, R1 defends an economic incentive to consumers who report electricity theft, in line with B3, which suggests creating or strengthening anonymous reporting channels for the population. Uganda has already proven the effectiveness of this strategy through the "United against electricity theft" campaign, launched in 2012 by Umeme, the country's largest distributor, together with Transparency International. The action intensively informed society about the benefits of greater control of the problem through radio, TV, and newspapers, promising anonymity to anyone who reported fraudsters (Never, 2015). B5 and B9 claim that distributors also need the support of their commercial agents in inspection campaigns to obtain a high assertiveness rate and the interval between measurements to be minimized, as pointed out by K2. K11 is aware of the importance of controlling employees and contractors to avoid or reduce the loss rate due to corruption. Distributors in countries like India and Lebanon have actions of combating employee corruption, such as creating specific departments related to the control of corrupt employees

Table 3: Challenges for mitigating non-technical losses in Brazil

Dimension	Challenges for NTL mitigation
Business	Society's awareness of the damage caused by electricity theft
	Socioeconomic differences between concession regions
	Lack of regulatory incentive to protect the electrical system
	Tariff pressure associated with reduced consumer income
	Existence of irregular areas abandoned by competent public organizations
	Performance in areas controlled by organized crime
	Legal impunity for fraudsters
	Permissive regulation that favors the fraudster
	Development of intelligence actions to combat non-technical losses
	Search for immediate results and lack of long-term planning
	High investment required for shielding the low voltage network
	Reduction of direct consumer access to measuring equipment
Regulatory	Cultural change in society and awareness of the harms caused by the electricity theft
	Periodic review of the regulatory agency's benchmarking process
	Creation and maintenance of regulations through incentive and not through service cost
	Control of non-technical losses in regions of difficult access and poverty
	Absence of the State in areas of high crime
	Judicial favoring bias against fraudsters to the detriment of the concessionaire
	Lack of harmony between legislators and regulatory agency
	Cost-benefit limit for implementing non-technical loss mitigation solutions
	Investment in technology and employees in the areas of most significant incidence
Legislative	Impact of non-technical losses and taxation on consumers' electricity bill
	Substantial role of the regulatory agency in combating non-technical losses
	State assistance to social demands
	Consolidation of partnerships between the distributor and law enforcement officers
	Leniency of public security authorities and the judiciary with fraudsters
	Action by parliament in the face of possible omissions by the regulatory agency and distributors
	Performance of concessionaires in combating non-technical losses
Knowledge	Brazil's social, cultural, geographical, and economic complexities
	High rate of customer default due to the pressure of non-technical losses on the electricity bill
	Need for the constant evolution of sector regulation
	Aggregation of harmonic distortions in the distribution network to non-technical losses in Brazil
	Political cost of large-scale disconnections
	Legal impunity for fraudsters
	Investment in smart meters, network monitoring, and infrastructure shielding
	Development of more robust technologies

(Sharma et al., 2016) and adopting strict measures in partnership with government regulatory agencies (Ghajar et al., 2000).

The distribution system suffers the most significant impacts from uncontrolled electricity theft (Aryanezhad, 2019). Additionally, it is challenging to control potential causes of non-technical losses in developing countries due to the network's poor infrastructure (Depuru et al., 2011b). Thus, B4 and B8 classify preventive and maintenance measures for the distribution system as crucial for mitigating non-technical losses. Furthermore, they increase the distributor's credibility with the market and society, a factor highlighted by B2 and B6 as decisive for controlling the problem. According to B10, this credibility can be built by providing the distributor with reliable information about billed and unbilled electricity. K2 and K11 state that data availability and reliability from utilities need to be high for NTL identification methodologies to be more assertive. Nevertheless, this information cannot be obtained only from inspection results, as predictions become less reliable (Glauner et al., 2017). Thus, K4 and K9 claim that complete and dynamic databases allow identifying the consumer's profile from social, economic, geographical, and financial perspectives, facilitating the development of identification methods and regulations to mitigate non-technical losses.

B1, B4, B5, B7, B9, K1, K2, K4, and K7 state that data processing standards lack the availability of technologies with constant updates and improvements, given that illegal consumers generally respond quickly to new methods and equipment implemented by concessionaires (Depuru et al., 2011a). However, the creation of these technologies is usually slower in developing countries, and therefore there is a need to encourage further research on more efficient techniques for assessing NTL (Faria et al., 2016). Brazil is acting correctly in this scenario, as R4 states that the distributors are encouraged by ANEEL to carry out R&D projects. K11 says that the best strategy involves using hybrid NTL identification methods. Bretas et al. (2020) confirm that hybrid data-oriented and network-oriented techniques have recently been presented in the literature. K2 and K7 complement by suggesting the implementation of efficient meters located outside the consumer unit.

This topic aligns with B3, K7, and K11's proposal to deploy smart meters and security devices on the network. There is a significant proliferation of smart meters in emerging distribution systems as a control measure against traditional meters' tampering (Ventura et al., 2020). However, certain groups express reluctance to deploy on a large scale due to fire risk, security, customer information privacy, and a low-cost-benefit perspective for the concessionaire (Chakraborty et al., 2021). On the other hand, the implementation of Advanced Metering Infrastructures emerges as one of the leading technologies in smart grids to mitigate and control anomalies in the network by analyzing electricity consumption trends and identifying fraudsters more easily (Jokar et al., 2016). This strategy naturally restricts problems such as adulterating physical meters, theft, diversion, exchange of meters, and billing irregularities (Otuoze et al., 2020).

However, fraudsters need to be held criminally responsible; so, identifying non-technical losses becomes effective and generates practical results, as stated by L2 and K1. Furthermore, L1 and L3 attest that there is a need for agreement between legislators, regulators, and the government through a transparent communication process, which allows the development of effective policies and legislative proposals to combat non-technical losses from all perspectives. L2 complements by defending that criminal accountability allows educating the population to live in harmony because as the State is permissive with transgressions, the culture of electricity theft is strengthened. The assumptions followed by ANEEL ideally aim at fair tariffs for consumers and electricity companies (Maciel et al., 2020). Even so, within the legislative scenario, perhaps one of the main additional actions to change this culture in the medium and long terms is the specification of the value referring to NTL in the electricity bill proposed by L1. It allows the population to be fully aware of their responsibility to pay part of the electricity not billed by the concessionaires.

In Brazil, electric power companies are required to systematically reduce energy losses in their networks to minimize losses and maintain the quality of supply within the standards and requirements established by ANEEL (Henriques et al., 2020). Accordingly, B1, B6, R1, R2, R3, and R4 highlight the importance of regulating economic incentives for efficient utilities and penalizing the least efficient in combating non-technical losses. In this scenario, Brazilian regulation is a reference in Latin America throughout its benchmarking process for clustering distributors through the socioeconomic complexity index, level of non-technical losses, and size of the concessionaire, as indicated by R1, R2, R3 and corroborate Corton et al. (2016) and Ventura et al. (2020). R1 also highlights that the publication of the companies' efficiency ranking helps in this process. R3 states that it is possible to reconcile consumers' and distributors' interests by constantly updating current regulations. Periodically, ANEEL conducts public consultations to consider stakeholders' demands in the sector's regulatory update processes. About Public Consultation 029/2020 (ANEEL, 2020b), R2 highlights that the concessionaire's possibility of creating "risk areas" was suggested. They include regions where the strong presence of organized crime limits the concessionaire's performance.

Understanding the factors that help combat non-technical losses in Brazil allows concessionaires, legislators, regulators, public policymakers, and researchers to outline objective strategies for effective results. Thus, Table 4 presents the compilation of the factors discussed in this subchapter.

3.5. Future of NTLs in Brazil

Non-technical losses in Brazil cannot be treated as a simple problem that can be solved with isolated actions by concessionaires, regulatory agencies, government, legislators, or law enforcement officers. Because it is a complex problem, which represented a cost of approximately US$ 1.79 billion[2] in 2019 in the country (ANEEL, 2020a), it requires integrated solutions built by all stakeholders. Understanding the different cultural, social, economic, and geographical realities in a country of continental size like Brazil is the starting point for developing intelligence actions to mitigate NTL in the medium and long terms. In this sense, the government, parliament, ANEEL, and concessionaires need to converge on an

Table 4: Factors that help to combat non-technical losses in Brazil

Dimension	Factors that help to combat NTL
Business	Anonymous reporting
	Support of commercial agents in inspection campaigns with a high rate of assertiveness
	Preventive and maintenance measures for the electricity distribution system
	Credibility of the distributor towards market and society
	Reliable information provided by the distributor about billed and unbilled electricity
	Technological evolution of software and improvement of techniques for data processing
	Use of telemetry to measure electricity consumption
	Regulatory incentive for distributors to achieve efficiency goals
Regulatory	Economic incentive for consumers who report electricity theft
	Encouraging concessionaires to carry out R&D projects aimed at reducing electricity theft
	Regulatory process with economic incentives for more efficient utilities and penalties for less efficient ones
	Benchmarking for clustering of distributors through the socioeconomic complexity index, level of non-technical losses, and size of the concessionaire
	Publication of companies' efficiency ranking
	Conciliation of consumer and concessionaire interests
	Possibility of considering "risk areas" by the concessionaire
Legislative	Educational campaigns for cultural change concerning electricity theft
	Criminal liability for electricity theft
	Public policies and legislative proposals to combat non-technical losses
	Specification of the amount referring to non-technical losses in the electricity bill
Knowledge	Short interval between measurements
	Total control of employees and contractors
	High availability of data from utilities
	High reliability of data from utilities
	Identification of the consumer profile from social, economic, geographical, and financial perspectives
	Availability of technologies for processing utility data patterns
	Use of hybrid identification methods
	Efficient meters located outside the consumer unit
	Deployment of smart meters and security devices
	Enforcement of laws to face non-technical losses

educational strategy at the national level to change the acceptance of electricity theft, widely known by the term "gato" in the country. Campaigns need to be developed and disseminated massively in traditional media and social networks and leveraged in regions with a greater focus on NTL. In this sense, the importance of Bill No. 1569/2019 (Ribeiro, 2019) is highlighted, which aims to compel distributors to inform the portion of the electricity tariff corresponding to non-technical losses in the invoices. Most of the population has no science that pays for NTL and therefore does not repress when close people steal electricity. Furthermore, it is suggested that exclusive channels be opened for anonymous reports of fraud in the electricity grid in this educational strategy, with financial incentives for complaints converted into shutdown.

Still, under a macro analysis of the problem, the importance of the regulation used by ANEEL concerning energy losses is highlighted. The agency's availability to listen to stakeholder demands through public consultations aligns with the solutions proposed by the experts who contributed to this research. It is suggested that ANEEL continues to invest in regulatory incentives for concessionaires that can adopt measures to control non-technical losses and improve the protection and quality of the distribution network. The benchmarking method through socioeconomic complexity ranking and the econometric models that allow this analysis need to be continuously improved to portray each concession area's realities. Besides, stimulating R&D projects that involve socioeconomic, regulatory, and legislative variables to mitigate NTL is an opportunity in Brazil. The creation of "risk areas" in the concession regions, allowing compensation to concessionaires that are prevented from acting due to the strong presence of organized crime, needs to be carefully studied not to harm the current model The solution involves regulatory compensation and strengthening public security, educational and social policies in these regions. Brazilian institutions need a coordinated fight against corruption, organized crime, and the militias that control these regions and directly impact non-technical losses.

In this scenario, it is clear that the transfer of part of the financial damage caused by non-technical losses to the population is not ideal. Nevertheless, it is not feasible for the concessionaire to bear all the damage. Two Bills are passing through the National Congress aiming to prevent this transfer in the electricity tariff. However, it should be noted that this would directly affect the quality of the electricity distribution network and service in the country, further harming consumers. ANEEL is continually looking for solutions to make this problem more adherent to reality. Still, it is essential to highlight that it is necessary to harmonize legislators' and regulators' actions to reduce the rate of non-technical losses in Brazil. In addition to the importance of nationally coordinated solutions, it is essential to analyze the problem from a regional perspective. The State must concentrate efforts on making available a greater variety of regionalized socioeconomic indicators to facilitate the development of methods to combat non-technical losses in the short term. In addition to the constant improvement of fraud techniques, the concession regions do not have homogeneous socioeconomic, geographic, and cultural characteristics. It is crucial to encourage exchanges of experiences between concessionaires from different areas but with similar micro-level problems. It needs to go beyond benchmarking comparison, reaching a collaboration level with mutual benefit between the distributors. Finally, it should be noted that through these integrated measures among all stakeholders in the sector, there is a good perspective that in the future, the impact of non-technical losses in Brazil is minimized, generating significant benefits for the entire Brazilian society.

4. CONCLUSION AND POLICY IMPLICATIONS

Non-technical losses are responsible for a significant economic imbalance in Brazil. The high levels of unbilled electricity impact

the tariff and influence the concessionaires' investment capacity in the service and distribution network. All sectors of society are affected, as the tariff pressure and the low quality of the distribution system reduces the industrial sector's competitiveness (Zanardo et al., 2018), generating an increase in default and electricity theft rates. This cycle creates a ripple effect and undermines national development, inclusion, energy, and regulatory policies. In this scenario, policymakers, regulators, distributors, and researchers must agree to identify and mitigate the problem.

In a socioeconomically complex country with significant regional differences, the ANEEL's positive performance in formulating incentive-based regulations for concessionaires to reduce their rates of non-technical losses stands out. Electricity distributors in Brazil are encouraged to invest in R&D. In this scenario, the importance of partnerships with universities and research centers is highlighted to develop effective methods to combat non-technical losses. The regulatory agency must also seek greater harmony with legislators, demonstrating that eventual demands from the population and parliament prohibiting the transfer of part of the electricity not billed in the tariff could make the good quality of electricity distribution unfeasible to the Brazilian population.

The primary strategy suggested to mitigate non-technical losses in the medium and long terms in Brazil is formulating educational policies with coordinated actions among all stakeholders to make the population aware of the negative impacts of non-technical losses. In this process of cultural change of Brazilian society concerning the theme, the relevance of information campaigns and the proposed Bill on the effects of unvoiced electricity on the tariff (Ribeiro, 2019), together with the creation of anonymous channels, stands out for denunciation and the strengthening of police action and the judiciary against impunity in the crime of electricity theft. Furthermore, the State must make available a greater variety of regionalized socioeconomic indicators to facilitate the concessionaires and researchers' planning and performance in the sector.

Policymakers, regulators, and the government still need to address the indirect causes of the high level of non-technical losses in Brazil. Although the ANEEL has information and transparency tools on the electricity bill, a consensus is needed to reduce the high rate of taxation on electricity tariffs in Brazil, where different charges and taxes are levied at the municipal, state, and federal levels. Additionally, strengthening the fight against corruption and crime is fundamental and benefits the population beyond identifying and mitigating non-technical losses. Public policies for inclusion and job creation strengthen the population's purchasing power, making it possible to reduce the default rate.

Solutions related to the implantation of smart meters are proven effective in the literature to face non-technical losses. However, these meters' cost is very high, making large-scale installation impossible in the short term in Brazil. Additionally, there is a need for a good telecommunication structure, which requires even more investments. Still, it is considered that regulations and public policies that would provide greater dynamism in the electricity tariff would be necessary for smart grids to bring more benefits to consumers and concessionaires in addition to reducing non-technical losses. It also highlights the existence of several methods used to defraud smart meters, further affecting the return on investment within the current Brazilian reality if the most significant benefits were related to the control of non-technical losses. Therefore, the need to collect information from specialists from several perspectives is emphasized. Sometimes, technical solutions can show significant results, but when implemented separately, they become less efficient. Given this, medium and long-term solutions must also consider the social, economic, regulatory, legislative, and cultural characteristics of the region or country to maximize their results.

The results presented in this article serve as a basis for future research in the area. They will be useful for academics, regulators, policymakers, and concessionaires to develop practical actions to combat non-technical losses. It is possible to understand the main challenges of identification and mitigation and the factors that help tackle non-technical losses in Brazil from several specialists with extensive experience in the sector. Although this article addresses the Brazilian scenario, the results presented can support new studies related to the theme in other regions and countries with socioeconomic, cultural, and geographical characteristics similar to Brazil's. Still, the possibility of studies that address the relationship between the distributed generation of photovoltaic energy and the rate of non-technical losses and the regulatory challenges related to the theme is highlighted, considering that photovoltaic systems can reduce losses in transmission and distribution (Garlet et al., 2020). Finally, it is suggested that further research use the factors presented in this article through quantitative methods to propose solutions to concessionaires and policymakers, regulators, political analysts, and the government. Also, they can use the results of this study to create public policies to mitigate non-technical losses in the country.

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APPENDICES

Appendix A: Questionnaire for professionals from Business Perspective (English version)

1. Overview of non-technical losses in Brazil
   - 1.1. What are the main challenges related to non-technical losses identification in Brazil?
   - 1.2. What are the main challenges related to non-technical losses mitigation in Brazil?
   - 1.3. What factors help to combat non-technical losses from the Business perspective?
   - 1.4. How do you consider the role of [concessionaire name] in combating non-technical losses?
   - 1.5. Does [concessionaire name] use specific methods to identify non-technical losses?
   - 1.6. Does the [concessionaire name] invest in research and development (R&D) to increase assertiveness in identifying non-technical losses?
   - 1.7. Does the company/organization you work for have specific planning for identifying and mitigating non-technical losses?

2. Identification
   - 2.1. Name
   - 2.2. Respondent's role in the organization
   - 2.3. How long have you been working in the sector?

Appendix B: Questionnaire for professionals from Regulatory Perspective (English version)

1. Overview of non-technical losses in Brazil
   - 1.1. What are the main challenges related to non-technical losses identification in Brazil?
   - 1.2. What are the main challenges related to non-technical losses mitigation in Brazil?
   - 1.3. What factors help to combat non-technical losses from the Regulatory perspective?
   - 1.4. How do you consider the [institution name] performance in combating non-technical losses?
   - 1.5. Are the existing regulations in Brazil efficient in combating non-technical losses?
   - 1.6. Do you consider that the information/dissemination of information about non-technical losses is adequate and transparent to all sectors in society?
   - 1.7. Do you consider that the regulation limiting the value of NTL to be passed on to the consumer is adequate?
   - 1.8. Do you think that the regulation that provides for regulatory values of non-technical losses differentiated by the concessionaires is adequate?

2. Identification
   - 2.1. Name
   - 2.2. Respondent's role in the organization
   - 2.3. How long have you been working in the sector?

Appendix C: Questionnaire for professionals from Legislative Perspective (English version)

1. Overview of non-technical losses in Brazil
   - 1.1. What are the main challenges related to non-technical losses identification in Brazil?
   - 1.2. What are the main challenges related to non-technical losses mitigation in Brazil?
   - 1.3. What factors help to combat non-technical losses from the Legislative perspective?
   - 1.4. How do you consider the [institution name] performance in combating non-technical losses?
   - 1.5. Is there any prospect of changes in existing legislation to combat non-technical losses?

2. Identification
   - 2.1. Name
   - 2.2. Respondent's role in the organization
   - 2.3. How long have you been working in the sector?

Appendix D: Questionnaire for professionals from Knowledge Perspective (English version)

1. Overview of non-technical losses in Brazil
   - 1.1. What are the main challenges related to non-technical losses identification in Brazil?
   - 1.2. What are the main challenges related to non-technical losses mitigation in Brazil?
   - 1.3. What factors help to combat non-technical losses from the Knowledge perspective?
   - 1.4. How do you think research can help to combat non-technical losses in Brazil?

1.5. What is the direction of research on non-technical losses in the country?
1.6. Which methods for identifying non-technical losses have the most significant potential for assertiveness?
1.7. Do you consider that the information/dissemination of information about non-technical losses is adequate and transparent to all sectors in society?
1.8. Do you consider that the regulation limiting the value of NTL to be passed on to the consumer is adequate?
1.9. Do you think that the regulation that provides for regulatory values of non-technical losses differentiated by the concessionaires is adequate?
1.10. In your opinion, what would be an acceptable rate of non-technical losses in Brazil?

2. Identification
2.1. Name
2.2. Respondent's role in the organization
2.3. How long have you been working in the sector?