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CONTEXTUALIZATION AND ASSUMPTIONS OF NON-TECHNICAL LOSSES IN THE BRAZILIAN ELECTRICAL SYSTEM

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Abstract: Energy losses in electrical power systems are caused by the processes inherent to the conduction and transformation of energy, and to causes caused by the theft or fraud of electrical energy. These causes are called Non-Technical Losses (NTP), and are caused by human action for their occurrence. PNTs are a common problem in all electrical systems, with a main focus on electrical energy distribution systems, mainly in developing countries. In this context, the Brazilian electrical system is situated, where PNT corresponded to 7.3% of the energy injected into the grid for the year 2020. Thus, this study aims to contextualize energy losses in the Brazilian electrical system. In this work, the definitions and premises related to the PNTs are reported, highlighting the paradigms intrinsic to the Brazilian electrical system and its complexity. This way, the main considerations involving the regulation of PNTs in Brazil are exposed. In conclusion, PNTs must be mitigated and actions to reduce this problem must be encouraged.
Keywords: Non-technical losses; regulation of non-technical losses; energy losses; Brazilian electrical system.

INTRODUCTION

The National Interconnected System (SIN) is a hydro-thermal-wind-solar generation system, which comprises the generation and transmission of electric energy, with preeminence of generation from a hydro source, and interconnects the Brazilian electric grid from north to south and east to west of the country. It is noteworthy that Brazil is a country of continental dimensions, and that there is great complexity in the management and operation of a system of this size.

Non-Technical Losses (NTP) is an adversity in the transmission and distribution of electricity and a problem faced by the electrical energy sector in all nations of the world. PNTs become more aggravating in countries with emerging economies, where the highest rates of PNTs are identified, examples being Brazil and India. Worldwide, it is estimated that NTPs are responsible for losses in the order of 100 billion dollars (GLAUNER et al., 2018). In Brazil, in 2020, PNTs represented 8.6 billion reais.

Losses in electrical power systems are divided into two categories, Technical Losses (PT) and PNT. The first one happens due to the thermal effect caused by the electric current that passes through conductors and equipment of the system. According to the National Electric Energy Agency (ANEEL), PNTs, on the other hand, can be caused by installation errors, measurement errors, theft (clandestine connection, direct deviation from the network) and fraud (tampering the meter or deviations) of energy (ANEEL , 2021).

PNTs represent a serious problem for the electrical system, as they cause financial losses for distributors and consumers. In addition, they make system operation difficult, causing several consequences such as a drop in stability and reliability, steady-state voltage variation, system voltage unbalance, which can result in unbalanced load, losses due to overload and harmonic distortions (GLAUNER et al. ., 2017; P.J. NAVANI, 2009).

Pursuant to tariff regulation and revisions, and as an immediate measure, a tariff pass-through of efficient levels of losses to consumers' tariffs is carried out up to a limit stipulated by ANEEL, to compensate for the revenue that was not invoiced due to PNTs, in order to financially balance the agents of the sector. As a result of this tariff increase, there is a decrease in the surplus consumed by billed consumers with correct conduct, and violating consumers consume a greater amount of energy than regular consumers, and do not pay financially for it. In other words, PNTs generate a social imbalance and a great sense of injustice that must be fought by agents, the regulatory body and society in general (ARANGO, 2019).

The Medium-Term Electrical Planning of the National Interconnected System published by the National System Operator (ONS) aims to evaluate the performance of the SIN over a 5-year horizon. According to the planning perspectives, a growth of around 17.3% in the maximum load of the system is expected by 2024. In addition, the estimate of necessary investments according to the Expansion and Reinforcement Plan for the execution of works, is given in the order of 6.2 billion reais in the 2020-2024 cycle (ONS, 2020).

With budgets in the billions, it is evident the importance of projects to mitigate losses in the electrical system, with the objective of optimizing the use of energy. In addition to directly reducing the damage caused by PNTs, it is still possible to reduce the future investment needed to meet the growth in electricity demand in Brazil.

In this scenario, the electricity distribution systems are where PNTs mostly occur. Thus, this work aims to contextualize energy losses in the Brazilian electrical system, with evidence in the PNT and its premises, regarding the definitions and regulations in the national scenario. The rest of the work is divided by chapter 2, with the contextualization of energy losses. In chapter 3, the definitions of PNTs are discussed in detail, where the regulation and premises for obtaining regulatory PNTs are presented. And in chapter 4, the final considerations of this work are presented.

ENERGY LOSSES AND THE BRAZILIAN ELECTRICAL SYSTEM

The Brazilian Electric System is heavily discussed and regulated by institutions and agencies linked to the sector. It is regulated by ANEEL, linked to the Ministry of Mines and Energy (MME), and has great responsibility with regard to the electricity sector, taking into account economic and financial aspects in Brazil's electrical and energy planning. Some other institutions work in the sector, such as the National Energy Policy Council (CNPE), the Electricity Sector Monitoring Committee (CMSE), the Energy Research Company (EPE), the ONS, the Electric Energy Commercialization Chamber (CCEE) and your agents. The hierarchy and institutional iterations are shown in Figure 1.

Within this scenario, the EPE is responsible for Brazilian energy planning, which is published annually by the report of the National Energy Balance (BEN), in order to support decisions in the sector. The report provides information on energy use of energy sources, and in which sector of the economy it was used in Brazil. For example, Figure 2 shows the flow of sources of hydraulic energy, oil and biomass, in parallel with their use, such as industrial, transport, residential. It is emphasized that the losses are inherent to the most varied processes of energy use, and it is noteworthy that the losses in the transformation together with other losses added up in the year 2020 to a value of 11.5% of all energy used in the country. According to the EPE, this value includes losses in gas pipelines, oil pipelines, electricity transmission lines, electrical distribution networks (EPE, 2021).

The electric power distribution system is the last arm of the electric power system and mainly involves medium and low voltage, it is also responsible for distributing energy and delivering it individually to large, medium and small consumers. Also, it must lower the voltage to levels suitable for its use. Finally, this is where a large portion of the PNTs are identified. In this scenario of electrical energy losses, those that occur in electricity distribution networks, are an important part of energy losses. The evolution of electrical energy losses injected into the Brazilian electrical system can be seen in Figure 3.

As seen in Figure 3, the losses in the distribution systems are composed of two parts, the PT and the PNT, with the total losses being the result of the sum of the two. It can be seen that in recent years there has been a positive slope of the total loss curve. Additionally, it must be noted that the increase has a majority contribution from the PNTs, which have been developing an upward curve in recent years, moving from 6.2% in 2017 to 7.3% in 2020.

PNTs are thefts and frauds in the consumption of electricity, and can be carried out in multiple and sometimes ingenious ways by fraudulent users. In this sense, the most common and easily practiced deviation occurs when the consumer performs a by-pass of the meter clock, also called a jumper, thus forging or not counting the energy consumed in the Consumer Unit (CU). In addition, other methods are used by human action to defraud or steal electricity, as in CHANDEL (2016), where it was described that meter violations are a major cause of PNT. The author also reports several methods used by fraudsters, such as tampering with voltage or current measurement, external tampering with the measurement with the application of a magnetic field or high frequency waves, and hacking or manipulation of meter data (CHANDEL; THAKUR). ; SAWALE, 2016). Figure 4 shows some PNT records.

So, in order to reduce the losses caused by PNTs, the issue of fraud and energy theft is widely discussed in the Brazilian electrical system. It can be said that it is practically inherent to the electrical energy distribution process. Also, it is a topic discussed in distribution processes of the most different service models, for example, water distribution in Al-Radaideh and Al-Zoubi (2018), and in telecommunications services in Tarmazakov

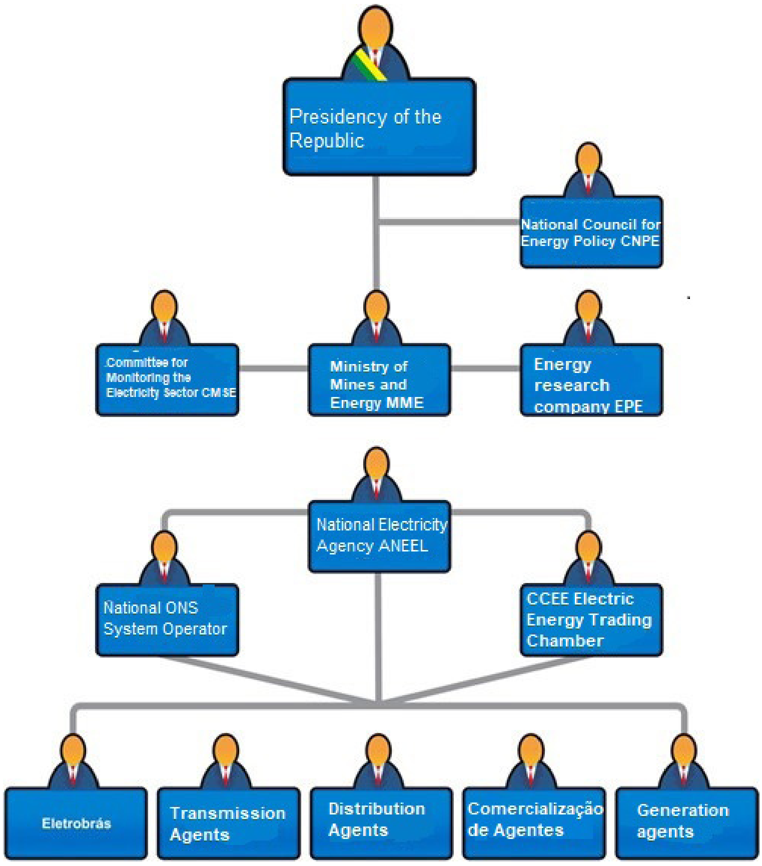

Figure 1- Structure of the Brazilian Electric System

Source: (ABRADEE, [s.d.])

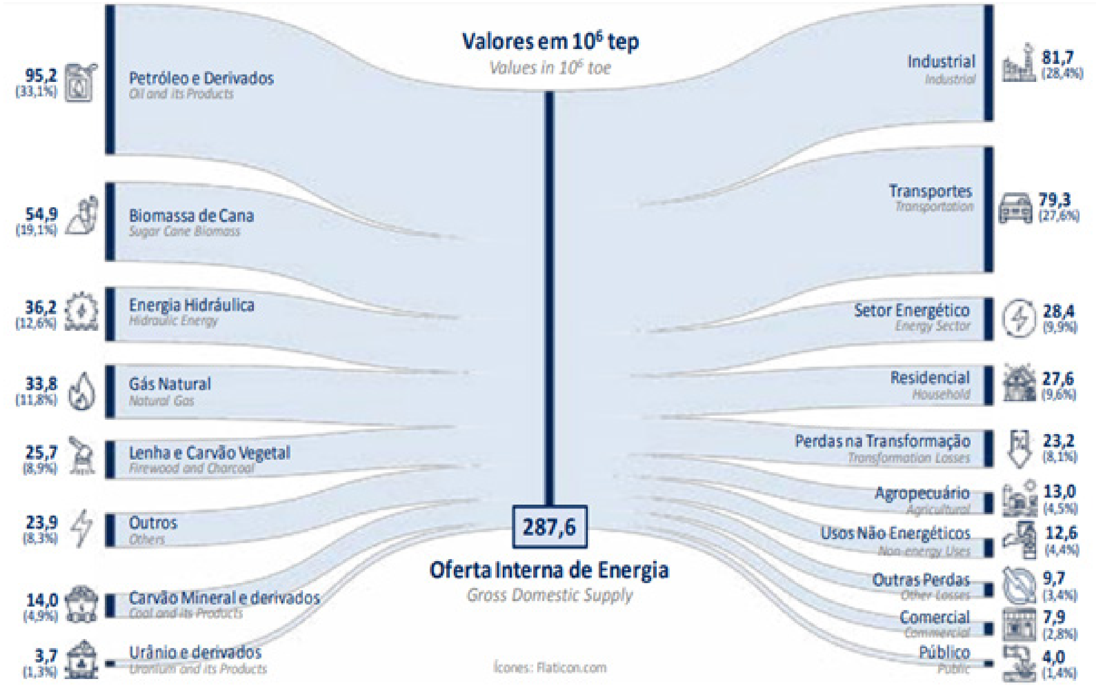

Figure 2 - BEN Energy Flow

Source: (EPE, 2021)

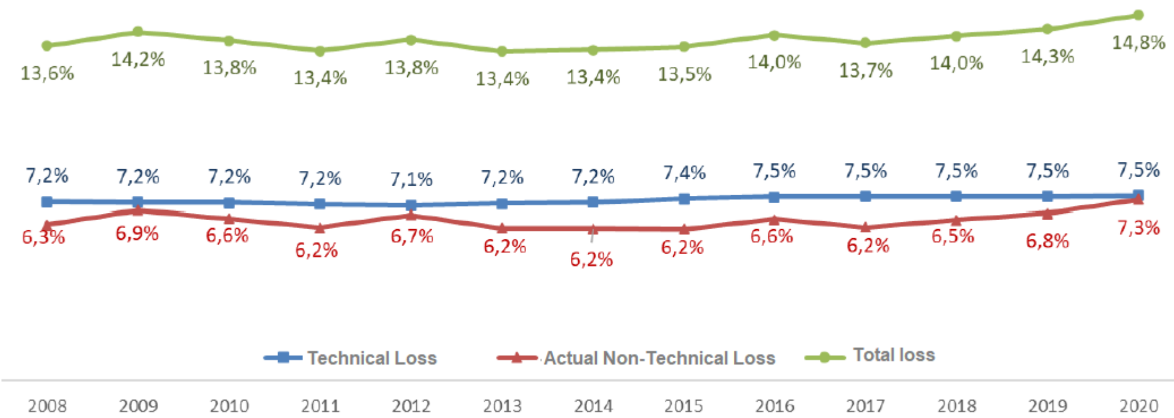

Figure 3 - Losses on Injected Energy

Source: (ANEEL, 2020)

Energy Deviation   Meter tampering   Damaged Meter

Figure 4 - PNT of Electric Energy

Source: Author

and Silnov (2018) (AL-RADAIDEH ; AL-ZOUBI, 2018; TARMAZAKOV; SILNOV, 2018).

Next, the impacts of fraud and theft of electricity in Brazil will be described, that is, the PNTs, and how they are addressed by the Brazilian electricity system. It will also report which regulations apply for this category of energy loss.

NON-TECHNICAL LOSSES IN BRAZIL

The captive electricity market is commonly composed of smaller consumers, which had an electricity supply revenue of R$147 billion in 2018 (ANEEL, 2019). The PNT corresponded in the year 2020 to about 37.9 TWh, 7.6% of the energy injected into the systems in the same year. Using the average price of energy in the tariff processes, without considering taxes, the PNTs represented a cost of R$ 8.6 billion, an amount that represents about 2.9% of the electricity tariff.

The electricity tariff of the concessionaires is regulated by ANEEL, being divided between portion A and portion B. Portion A consists of the purchase of energy, transmission and sector charges. Portion B is composed of costs directly manageable by energy distributors, with PNTs representing a portion of operating costs and sunk revenues within portion B. According to ANEEL, portion B represents 17% of the total electricity tariff, and it can also be noted that the PNTs in 2020 represented 9.8% of the B portion of the tariff (ANEEL, 2020).

According to ANEEL, PNTs in 2020 represented 13.2% of the billed low voltage market (ANEEL, 2021), illustrated in Figure 5.

REGULATION OF NON-TECHNICAL LOSSES

Losses are regulated by Module 7 of the Electricity Distribution Procedures in the National Electric System (PRODIST). Therefore, according to Module 7 of PRODIST, the losses are obtained by the difference between the energy measured at the feeder output, and the energy measured in the CUs, belonging to the medium and low voltage distribution system, plus the energy losses downstream. from the feeder. Thus, energy losses are calculated using the power flow method, and it is noteworthy that they consider PT due to the presence of PNT. Therefore, to perform this calculation, ANEEL uses a recursive algorithm (ANEEL, 2018).

In Brazil, PNTs are divided into two types, which are the real PNT and the regulatory PNT. The differences between the two are highlighted, which are calculated using different models. The real PNT is estimated with the aid of power flow methods and quantities of energy actually delivered to consumers. However, the regulatory PNT is the price that is actually charged to consumers, diluted through the energy tariff. Complexity models are applied to calculate the regulatory PNT, the models being applied by ANEEL, which aims to encourage concessionaires to seek adequate levels of PNT, and consequently, not be able to pass on the entire real PNT index to the market.

ANEEL applies specific models for each energy distribution and transmission segment, using simplified information from existing networks and equipment, in which elements such as transformer power, conductor length and gauge, and energy supplied to the UCs are used. Based on this information, ANEEL estimates the percentage of efficient PTs, proportional to the energy injected into the grid. This way, the actual PNTs are calculated by the difference between the total losses, reported by the distributors, and the regulatory PTs, calculated by ANEEL (ANEEL, 2019b).

However, regulatory PNTs, as they are more

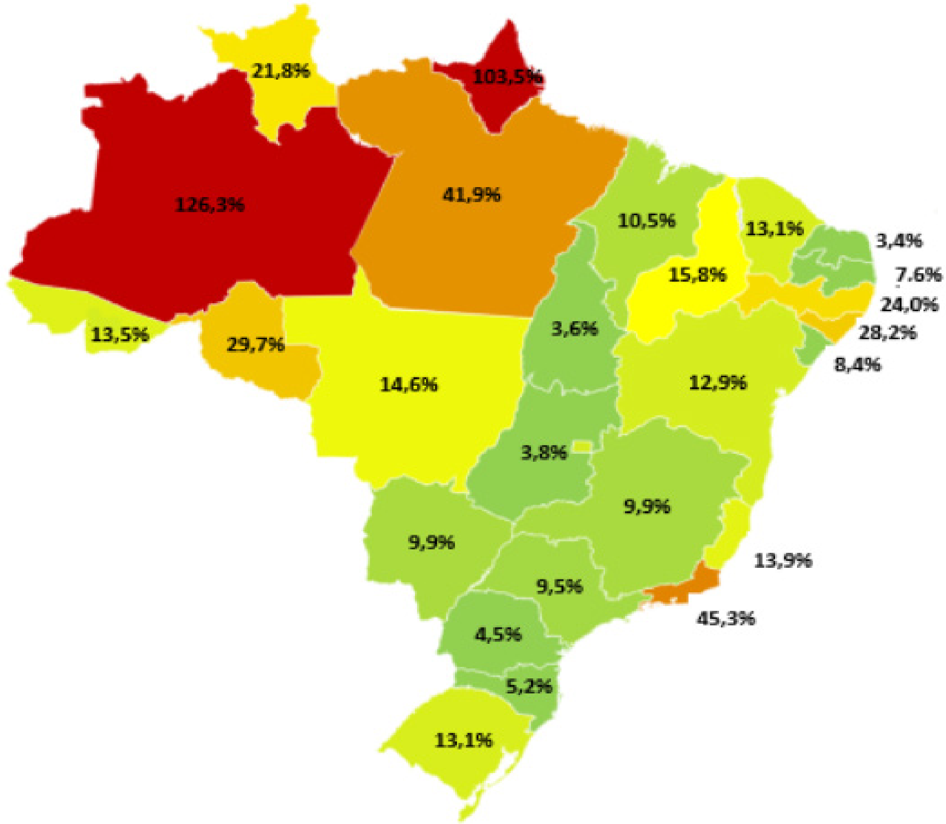

Figure 5- Real Non-Technical Losses on Invoiced Low Voltage - Brazil Map (2020)

Source: (ANEEL, 2021)

Tariff Review Period	**1ª RTP (2003 a 2006)**	**2ª RTP (2007 a 2010)**	**3ª RTP (2011 a 2014)**	**4ª RTP (2015 a 2018)**
ANEEL Technical Note	NT No. 30 of 2003	NT No. 342 of 2008	NT No. 298 of 2011	NT No. 106 of 2015
Model	Historical Data Analysis	- Complexity Model - Panel with random effects - *Benchmarking* - 1 model with 5 variables	- Complexity Model - Panel with random effects - *Benchmarking* - 3 models with 5 variables each	- Complexity Model - Panel with random effects - *Benchmarking* - 2 models with 5 variables each and 1 with 4 variables
Goals	Concessionaire's Historical Average	Weighted average between the benchmark and the company's history	Average between the goals of the 3 models (C, G, K)	Average between the goals of the 3 models (C, G, K)
Departure Points	Historical Average (Total Loss)	Minimum Previous Cycle History	With some exceptions, the minimum between the target of the previous cycle and the minimum of the previous 4 years is calculated	Rule considering company size
Reduction Speed	X	Linear, decreasing or fixed trajectory, without reduction limiter	Creation of 5 *clusters* with different trajectories	Specific rules according to the size of the company

Table 1 – Main characteristics of the Tariff Review Cycles

Source: Adapted of (TAVARES et al., 2019) complex to calculate, are reviewed annually and established in the periodic tariff review processes that take place every 3, 4 or 5 years. The summary characteristics of the methods used in the review processes by ANEEL can be seen in Table 1.

It is possible to verify that ANEEL has been improving its complexity model over the years through tariff reviews, and with that, evolving in the use of only historical data from the concessionaires to the average among the 3 models developed. The evolution of econometric models (C, G, K) has also introduced new variables to the models (precariousness, per capita income, garbage collection, among others), which demonstrates the agency's concern with having reliable regulatory PNT indices to what actually takes place in the market. A review of the regulatory evolution of non-technical losses in the four regulatory cycles was carried out by Tavares et al. (2019), observed in Table 1 (TAVARES et al., 2019).

The region's socioeconomic performance has an important influence on PNT rates, and distribution concessionaires operate in concession areas with socioeconomic differences. Therefore, with the objective of a fairer evaluation of the distributors that operate in places with different challenges, ANEEL developed a ranking of socioeconomic complexity, allowing the comparison of the performance in the management of the PNT of the distributors. ANEEL identifies the existence of a reference distributor, which is normally located in an area with more precarious socioeconomic indices, but which has lower losses.

Based on these parameters, ANEEL establishes regulations for distribution concessionaires, and determines the transfer of the regulatory PNT index to energy consumers. As a result, regardless of the level of regulatory losses established and passed on in the tariff, ANEEL expects that distributors will be encouraged and must always act to reduce PNTs, whether to reduce losses or obtain gains. It is noteworthy that it is possible to earn gains if the regulatory PNT value is greater than the actual PNT (ANEEL, 2019b).

ANEEL provides annual reports with findings related to the development of PNTs in the Brazilian market. Investigating the simple average graph on the low voltage market in recent years presented in Figure 6, it is verified that the regulatory value develops a fall and the real PNT values a high, thus representing 12.3% in 2017 and reaching to 13.2% in 2020. This movement is due to several factors, and must be a cause for concern for agents in a market that moves billions of reais. In general, any high PNT index is worrying for agents, but they are even more critical when the gap between the two values is greater, and represents energy generated/distributed, but not billed by energy concessionaires.

CONCLUSION

Energy losses in electrical power systems are a common factor in all energy systems in the world. Therefore, these losses are even greater in developing countries, where socioeconomic issues and social inequality are complex. One of these energy losses is characterized by the theft or fraud of electric energy, also called by the PNT.

The PNTs generate billions in losses to electric energy distribution concessionaires, and to consumers. In Brazil, real electricity losses corresponded to 14.8% of the total energy injected into the grid, with 7.3% related to PNTs. This portion of the PNT is partially borne by the energy concessionaire and regular consumers. However, due to the complexity of the PNTs and difficult verification, what is actually passed on to consumers are the regulatory PNTs, which are obtained by ANEEL through the complexity

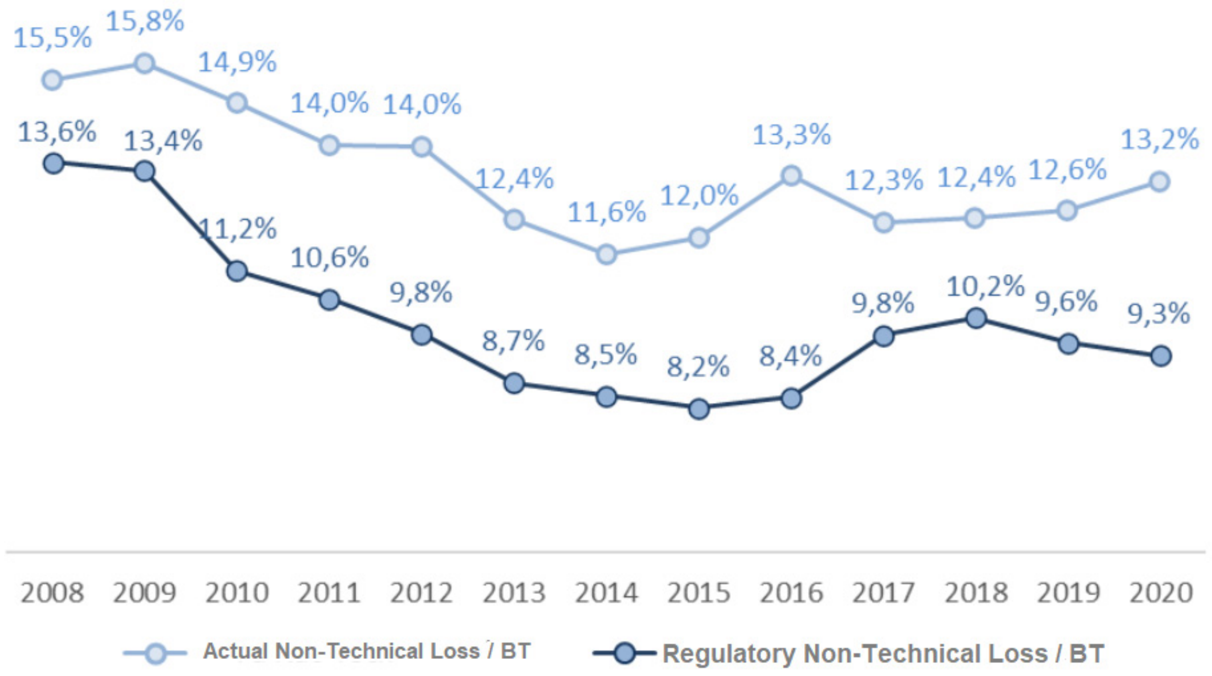

Figure 6 - Real Non-Technical and Regulatory Losses on Low Voltage Billed (simple average)

Source: (ANEEL, 2021)

model of the distributor's concession region, with annual and four-year periodic review.

Thus, as a way of recovering the losses intrinsic to the PNTs, energy distribution concessionaires are able to dilute part or all of the costs of energy consumed by consumers who commit fraud or theft of energy. It must be noted that energy concessionaires are responsible for promoting actions to reduce energy losses, a fact that allows them to deduct their losses in the tariff pass-through. In conclusion, PNTs are a problem that must be mitigated, and this results in the proper functioning of the energy system in technical and financial matters.

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