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RESEARCH ARTICLE

SERVICE QUALITY IN FRONTIER-BASED BENCHMARKING MODELS: A PROPOSAL FOR BRAZILIAN TRANSMISSION SERVICE OPERATORS BY LITERATURE REVIEW

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Abstract

This study investigates the incorporation of service quality into frontier-based benchmarking models, focusing on Brazilian Transmission Service Operators (TSOs). Service quality is a critical variable in the regulatory context, as it directly reflects operational efficiency and consumer impacts. However, benchmarking models adopted in the Brazilian electric transmission sector, particularly those proposed by ANEEL for the 2017-2022 tariff review cycle, still exhibit gaps in the effective inclusion of quality proxies. The research is grounded in a systematic literature review conducted across the Web of Science and SciELO databases, covering studies published between 2000 and 2023. Articles discussing the integration of quality into benchmarking models were analyzed, with emphasis on methodologies such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). Data analysis included 32 Decision Making Units (DMUs) from Brazilian TSOs, covering the period from 2013 to 2016, based on ANEEL’s Technical Notes 160/2017 and 164/2017. Results indicate that service quality, when represented as a monetary variable, is most effective when incorporated as an input to adjust operational costs. The research highlights that ANEEL's proposed model for the 2017 tariff review still lacks a consistent methodology for fully integrating service quality into benchmarking processes. The study concludes that adopting more robust proxies, such as the Parcel Variable (PV), could enhance the accuracy of efficiency assessments and ensure that TSOs meet appropriate performance standards, aligning with international best practices. This research contributes theoretically and practically to the ongoing debate on the optimal integration of service quality in regulated industries’ benchmarking models.

Introduction:-

This study provides a comprehensive literature review on the use of service quality proxies in the electric transmission sector, focusing specifically on the Brazilian context. The transmission segment is managed by Transmission System Operators (TSOs) under the supervision of regulatory agencies. Globally, regulatory agencies and society are increasingly focused on optimizing the operational performance of the energy transmission sector. Operators face constant challenges from regulation, customers, and the market as they strive to maintain and enhance system reliability. Improvements in operational performance impact energy availability, ancillary services, and service processes, ultimately influencing service quality levels (Lovelock, 2011).

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From the perspective of agents, service quality is perceived as adequate when the quality experienced meets customer expectations. When expectations are not met, the perceived quality diminishes, even if the actual service level aligns with operational benchmarks. The overall perceived quality is determined by the gap between expected and experienced service levels (Grönroos, 1990).

In monopolistic markets, such as the electric transmission sector, regulation can induce competition by fostering operational efficiency through direct intervention by regulatory agencies (Beesley & Littlechild, 1989). In Brazil, the National Agency of Electric Energy (ANEEL) was established to minimize the externalities associated with monopolies and ensure social welfare by guaranteeing access to electricity. ANEEL's primary role is to promote satisfactory service conditions for Brazilian consumers. Similar regulatory frameworks exist in other South American countries, such as Argentina, Uruguay, and Chile, where agencies oversee concession processes (Spiller & Martorell, 1996).

Modeling efficiency in a regulated monopoly, as in the transmission sector, presents unique challenges, particularly when incorporating service quality into performance evaluations. The optimal quality level may differ from that in competitive markets, and regulators often struggle with the trade-off between pricing and quality standards (Spence, 1975; Vogelsang, 2006). Energy regulators tend to view quality improvements as a cost driver, requiring significant capital investment to enhance service levels. As a result, firms typically invest only enough to meet the minimum quality standards set by regulators (Gabszewicz & Wauthy, 2002; Langset & Tore, 2002).

Customer satisfaction with service quality is a constant concern, as consumers often demand higher service levels, even if they are not willing to pay proportionately for these improvements (Yu et al., 2009). In the electric sector, customers generally have no choice but to pay for higher service levels associated with improved quality. However, the complexity and high costs of service provision mean that total costs are shared among consumers. This should not, however, lead to a situation where customers receive suboptimal service if they are unwilling to pay for higher levels of quality (Ajodhia & Hakvoort, 2005). Moreover, consumers are often unaware of the full scope of transmission services they pay for, such as operational performance, voltage support, load management, and power system security (Steiner, 2000).

In Brazil, the measurement of service quality in the electricity sector began with the now-defunct National Department of Waters and Electric Energy (DNAEE) under Law 46/1978. Later, quality performance goals were established for DEC and FEC indices. However, it was only with Technical Notes 48/2010 and 021/2011 that service quality was integrated into efficiency measurement for Brazilian TSOs (Bernardo, 2013; Cyrillo, 2011). A proxy for quality was first introduced in 2012 (TN 383/2012) as an ad hoc adjustment to the DEA efficiency score. Lopes and Lanzer (2015) criticized these adjustments, citing inefficiencies in the way ANEEL applied them. For example, the TSO ELETROSUL initially had a DEA efficiency score of 46%, but, after receiving a 49% adjustment for service quality, its score increased to 95%. Similarly, CTEEP's efficiency score reached 135% after quality adjustments.

During the next tariff review cycle in 2017, ANEEL revised its approach and proposed incorporating a quality measure directly into the DEA model (TN 160/2017 and TN 164/2017). Despite this improvement, several issues persisted, including criticisms of the metrics used and inconsistencies in the calculation of operational costs for system outages of varying transmission capacities. Additionally, agents like ISA CTEEP raised concerns about the averaging of quality values, which masked volatility. Furthermore, ANEEL initially treated service quality as a desirable output in the DEA model, but this was later corrected. Finally, nearly half of the TSOs did not have a quality variable contributing to their efficiency score, resulting in zero weights for this variable.

Given the importance of service quality in efficiency analyses and the unresolved issues in Brazil's transmission benchmarking model, **this study aims to review the relevant literature on energy regulation worldwide and propose a model tailored to Brazilian transmission operators**. The study will explore quality proxies and methods for integrating them into a DEA model for regulatory purposes.

This research focuses exclusively on the electric transmission segment. It will analyze variables proposed by national and international literature and experts in the field. Moreover, the study contributes to the literature by surveying service quality variables used in the regulation of electric power transmission companies. It offers a discussion on the relevance of incorporating service quality metrics in performance analyses, as highlighted by key authors. The review also identifies appropriate quality proxies for modeling and application in frontier-based benchmarking. Ultimately, this research proposes a theoretical recommendation for improving the Brazilian TSO performance model by incorporating a more robust DEA-based quality measurement.

To address the study's general and specific objectives, this work is organized into five chapters. The second chapter provides a theoretical review of the key concepts and methods supporting this study. Chapter three outlines the research methodology and techniques employed. The results and contributions are presented in chapter four, followed by the conclusion in chapter five.

Literature Review:-

Brazilianissues on regulation

Due to the scale and complexity of the Brazilian electric sector, this research focuses specifically on the transmission segment, which serves as the intermediary between energy generation and distribution. The transmission system, characterized by extensive networks of cables supported by transmission towers, operates across various voltage levels, from 69 kV to 750 kV (ANEEL, 2009). The National Electric System Operator (ONS) oversees the system, managing energy flow to ensure continuous supply throughout the country (ANEEL, 2015).

The transmission system's primary role is to transport electricity from generating facilities to distribution networks. According to Sato (2013), the Brazilian National Interconnected System (SIN) manages 98% of the country's energy flow, mitigating operational risks, especially during periods of low rainfall when energy availability from hydroelectric sources is reduced. ONS coordinates this complex system, ensuring efficient use of the network at minimal cost to consumers, and is responsible for both strategic planning and operational management.

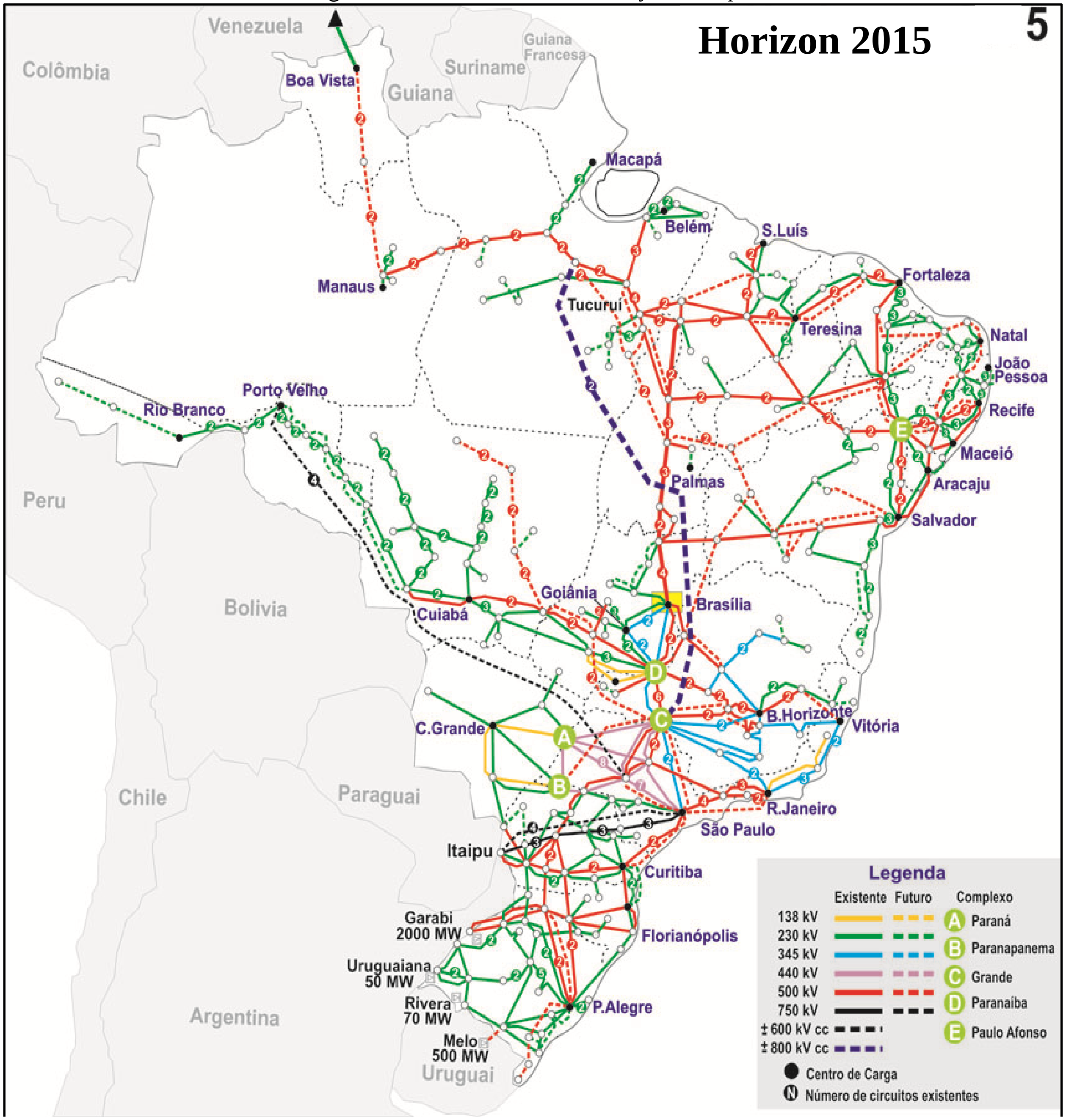
The monopolistic characteristics of the transmission segment create a natural monopoly, where a single provider services multiple consumers over a given region. This monopoly feature necessitates regulation to prevent inefficiencies and to protect consumers from potential price abuses. Araujo (2005) argues that regulation is essential in such industries to reduce negative externalities and ensure that companies operate within legal frameworks designed to maximize social welfare. Through regulation, entities like ANEEL ensure that Transmission Service Operators (TSOs) provide quality services at fair prices while maintaining the economic balance necessary for their operations. The regulatory framework in Brazil also includes tariff reviews (CTR), which are intended to share the benefits of operational efficiency with consumers, thereby reducing the cost of energy transmission (Mello, 2008; Assunção et al., 2015).

Economic theory supports regulatory intervention in monopolistic markets to mitigate market failures, especially when monopolistic providers can exert excessive pricing power or deliver suboptimal service. According to Mueller (2013), regulation is justified to protect the public interest from inefficiencies that arise in the absence of competition. Rubinfeld and Pindyck (2002) further argue that such regulation reduces the negative externalities associated with monopolistic market conditions, promoting social welfare by encouraging more efficient resource allocation and pricing.

Transmission systems, like other parts of the energy sector, require significant capital investment due to the infrastructure's scale and the specialized nature of its assets. These high fixed costs and low marginal costs create a natural monopoly that intensifies under concession regimes, where TSOs operate under strict regulatory oversight. The absence of competition in these regions requires regulatory mechanisms that promote efficiency while maintaining the service quality demanded by society (Bogetoft & Otto, 2012). Regulatory intervention in this context includes incentive-based mechanisms that encourage TSOs to optimize their operations and reduce costs without sacrificing service reliability (Saintive & Chacur, 2006).

However, even within a regulated market, challenges such as informational asymmetry persist. TSOs possess detailed knowledge about their operations, costs, and demand patterns that are not always fully shared with regulators, creating potential inefficiencies in the regulatory process (Berg & Tschirhart, 1988). To address this, comparative techniques like benchmarking can be employed, allowing regulators to assess relative performance and encourage cost reduction among TSOs. Jamasb and Pollitt (2000) argue that such techniques can foster greater transparency and competition, even in a monopolistic setting.

Figure 1:- Brazilian Transmission System Map.



Source: Electrical System National Operator.

One of the primary regulatory models employed by ANEEL is Yardstick Competition, outlined in Technical Note TN 064/2006. This model allows regulators to simulate a competitive market by comparing the performance of different TSOs, dismissing geographical and operational differences to establish standard benchmarks. Originally proposed by Shleifer (1985), Yardstick Competition induces cost reduction by promoting competition through benchmarking, encouraging TSOs to align their performance with that of a virtual standard firm. This model plays a crucial role in ensuring that the benefits of cost reductions are passed on to consumers, thereby enhancing overall system efficiency (Agrell & Bogetoft, 2016, 2017).

Even under regulation, however, the potential for inefficiencies remains. Melo and Neto (2007) point out that regulation can safeguard against market concentration abuses, while Souza (2008), Miranda (2015), and Rubinfeld and Pindyck (2002) highlight that tariff regulations can minimize negative externalities by promoting economic incentives that align with social welfare goals. These subsidies are designed to reduce operational costs and promote investment in infrastructure improvements, ensuring that TSOs meet the regulatory expectations for service quality and reliability.

Brazil's regulatory process for the transmission segment began in earnest in 2006, following the concession contracts that introduced formal provisions for tariff adjustments and periodic revisions. Before this, many contracts lacked such clauses, making it difficult to guarantee fair pricing for consumers. To address this, the CTR process was introduced, ensuring that efficiency gains realized by TSOs could be shared with consumers (Mello, 2008). This process not only adjusts TSO reimbursements but also sets the framework for revising the Annual Permitted Revenue (RAP), a key component in determining the maximum revenue that TSOs are allowed to earn (Lopes & Lanzer, 2015).

The RAP is composed of several factors, including the Annual Cost of Electrical Assets (CAAE), Sector Charges (ENC), Parcel Adjustment (PA), and Administration, Operation, and Maintenance Costs (CAOM). The CAOM component, in particular, is adjusted based on the Efficiency Coefficient (CE), which is derived from benchmarking techniques such as DEA. TSOs with higher efficiency scores receive higher reimbursement rates, creating a direct incentive for cost-effective and high-quality service delivery (Agrell et al., 2005).

Costs beyond the control of Transmission System Operators (TSOs) are passed through as subsidies during the tariff review cycle. In the Brazilian transmission segment, a variant of the price cap system is adopted, known as a revenue cap or maximum allowed revenue. The regulatory agency, ANEEL, allows TSOs to have a capped revenue based on performance efficiency, applying the yardstick competition method for benchmarking. From 2007 to 2012, ANEEL reimbursed Brazilian TSOs according to the following equation, where the Annual Permitted Revenue (RAP) is composed of the Annual Cost of Electrical Assets (CAAE), Sector Charges (ENC), Parcel Adjustment (PA), and Administration, Operation, and Maintenance Costs (CAOM).

$$RAP=CAAE+ENC+PA+CAOM \quad (1)$$

The CAAE (Annual Cost of Electrical Assets) includes expenses related to fixed assets associated with the transmission concession, which are evaluated and depreciated according to ANEEL's criteria. These costs also cover warehouse operations, approved assets, and special obligations. The ENC (Sector Charges) encompasses taxes such as PIS (Social Integration Program), COFINS (Contribution to Social Security Financing), RGR (Global Reversion Reserve), TFSEE (Inspection Fee for Electric Energy Services), and R&D (Research and Development). The PA (Parcel Adjustment) results from annual contractual adjustments. Finally, CAOM (Administration, Operation, and Maintenance Costs) is composed of the following components:

$$CAOM=CA+CAIM+COM \quad (2)$$

CAOM (Administration, Operation, and Maintenance Costs) is determined by Administrative Costs (CA), which include expenses related to personnel, materials, and services exclusively associated with the administrative sector, including insurance and taxes. The Annual Cost of Mobile Facilities and Properties (CAIM) refers to the infrastructure necessary to support transmission services, such as office buildings, transportation, furniture, equipment, computer systems, and maintenance vehicles. Of particular importance in this context, COM refers to operating and maintenance costs, which include personnel, materials, and services directly linked to operational and maintenance activities. These operating and maintenance costs are adjusted by an Efficiency Coefficient (CE). In the Brazilian regulatory model, this CE is determined using DEA (Data Envelopment Analysis) benchmarking, which calculates a relative efficiency score among the evaluated units. Thus, the formula for operating and maintenance costs is defined as:

$$COM=COM\times CE \quad (3)$$

constant costs. The higher the Efficiency Coefficient (CE), the more COM (operating and maintenance costs) the TSOs will receive. The financial equilibrium guaranteed by the tariff review must also cover regulatory obligations, such as investments in infrastructure, projects, and compliance with regulatory requirements and procedures. Consequently, the length of the network, as well as the management, operations, and maintenance procedures, must be adequately scaled by TSOs to ensure the continuous provision of essential services. This includes maintaining the physical availability of processes and activities required to support a constant supply of energy. If processes fail to meet operational standards, low efficiency will result in reduced cost reimbursement, leading to revenue losses (TN 371/2008). It is important to note that, in the Brazilian transmission service, revenue (RAP) is not directly tied to productivity or the volume of energy transmitted, but rather to the operational and maintenance availability required to meet demand (TN 257/2007).

Quality in the Brazilian DEA model

In 2006, ANEEL, through Technical Note 064/2006, proposed the adoption of Stochastic Frontier Analysis (SFA) as a model to estimate the efficiency scores of TSOs. SFA relies on deterministic and parametric frontier assumptions to measure an average efficiency score. However, concerns were raised regarding the econometric assumptions of insignificant deviations among TSOs and the requirement for a predefined functional form for costs. These assumptions posed the risk of bias in efficiency scores and potential heterogeneity due to omitted variables. These concerns were addressed during the 2007 public hearing. Consequently, as noted in ANEEL's Technical Note 06/2006, the SFA method was never implemented for performance measurement. Instead, ANEEL selected Data Envelopment Analysis (DEA) due to its specific advantages. DEA was first applied during the initial tariff review cycle (1CTR) in 2007, as detailed in Technical Note 182/2007, to assess operational cost efficiency for the period from 2005 to 2008. At that time, quality factors were not yet integrated into the DEA model for measuring operational cost efficiency.

Second Cycle of Tariff Review – 2CTR

The second cycle of periodic tariff review (2CTR) took place in 2009, focusing on operational analysis from 2009 to 2012, following the chronological sequence established after the first cycle (1CTR). To increase the number of Decision Making Units (DMUs) under analysis, ANEEL used panel data covering 55 DMUs from 2002 to 2008, representing major TSOs such as CEEE, CEMIG, CHESF, COPEL, CTEEP, ELETRONORTE, ELETROSUL, and FURNAS. Notably, data from COPEL in 2008 were excluded due to a corporate financial split, as outlined in Technical Notes 274/2009 and 396/2009.

For the efficiency analysis, ANEEL employed a two-stage procedure. In the first stage, the DEA model was applied under the assumption of Non-Decreasing Returns to Scale (NDRS). This assumption was justified by the idea that large TSOs cannot be scaled down for comparison with smaller TSOs, while smaller ones can be compared to larger ones. Additionally, weight restrictions were used to ensure data homogeneity. In the second stage, a Tobit regression was employed to adjust the DEA efficiency scores by accounting for environmental variables that indirectly affect operational efficiency. Notably, the 2CTR also marked the introduction of quality measurements as an indirect factor influencing operational efficiency in the energy transmission sector.

In the first stage of the DEA model, operational and maintenance expenses (OPEX) were used as the input variable. OPEX includes personnel, materials, third-party services, insurance, taxes, and other financial costs associated with operation and maintenance. For output variables, the model used indicators representing transmission operational services, including Network Length, Modular Units, and Equipment Modules. The Modular Units variable comprised the number of Inputs Line (EL), Transformer Connections (CT), and Interconnection Busbars (IB), while the Equipment Modules variable represented the number of transformers and power capacity in megavolt-amperes (MVA). In the second stage, environmental variables, quality of service, and transformation capacity were the key variables. Environmental variables included factors such as the average salary by operational region, network dispersion, and the geographic area covered. The quality of service was measured using DEC.

The introduction of quality measurement in the transmission sector began in the 2CTR. ANEEL incorporated a proxy for quality based on DEC, which measures the total hours (duration) of system outages. This proxy captures interruptions and disconnections affecting the availability of the transmission system. For this purpose, ANEEL requested information from the TSOs through letter 234/2009 - SER/ANEEL (Technical Note 274/2009). To refine the quality assessment, ANEEL classified interruptions into manageable and unmanageable events. The DEA quality proxy specifically considered DEC values based on outages classified as manageable by the TSOs, representing those that could have been avoided.

Concessions renewal in 2012

On September 11, 2012, the Brazilian government passed legislation that introduced new arrangements for the renewal of public service concessions in the energy sector, encompassing electricity generation, transmission, and distribution. Published as MP 576/2012, this law established new guidelines for tariff affordability and charge rates, enforced through revised contractual policies. The 2012 renewal was an anticipation of public service concession contracts set to expire in 2015.

The tariff review for this period covered 2012 to 2016, aligning with the timeline following the conclusion of the 2CTR. A panel data approach was used, analyzing 40 DMUs over the period from 2007 to 2011. These DMUs included major TSOs such as CEEE, CEMIG, CHESF, COPEL, CTEEP, ELETRONORTE, ELETROSUL, FURNAS, and CELG. It is worth noting that CELG was excluded from the efficiency analysis due to its small operational size, which was considered an outlier. The relevant data and methodology are outlined in Technical Note 383/2012.

For efficiency modeling, ANEEL employed a two-step process. First, the DEA model was measured using both Non-Decreasing Returns to Scale (NDRS) and Constant Returns to Scale (CRS). Weight restrictions were applied to ensure homogeneity among variables. Unlike in previous cycles where Tobit regression was used, ANEEL adopted a mean normalization approach to adjust the DEA efficiency scores, resulting in a more standardized set of efficiency scores across TSOs.

In terms of inputs, the same OPEX proxy used in the 2CTR was retained. However, there were some changes in the output variables, particularly with Network Length, which was now segmented by power capacity ranges, including 69-88 kV, 138 kV, 230 kV, 345 kV, 440-525 kV, and 600-765 kV. No significant changes were made to Modular Units or Equipment Modules. However, it is important to take a closer look at how quality was treated in this cycle.

As part of the DEA measurement process, quality was integrated into the efficiency score normalization. ANEEL revised the quality measurement methods used in the 2CTR, introducing a ratio of a Parcel Variable (PV) divided by RAP (Annual Revenue Allowance). The Parcel Variable represents the financial impact of outages and system unavailability in transmission operations, as outlined in Technical Note 729/2016:

$$\mathrm{PV} = \frac{\mathrm{PB}}{24 \times 60 \times \mathrm{D}} \times \left(\sum_{\mathrm{i}=1}^{\mathrm{NRL}} (\mathrm{ROL} \times \mathrm{DROL}) + \sum_{\mathrm{c}=1}^{\mathrm{NRC}} (\mathrm{ROC} \times \mathrm{DROC}) \right)$$

The Parcel Variable (PV) formula incorporates several key factors that influence the financial impact of outages in transmission operations. PB represents the transmission payment, which forms the basis of the financial penalty for unavailability. NRL denotes the number of long restrictions, while ROL refers to the proportional reduction in operational capacity due to long interruptions, with DROL capturing the duration of these long system outages. For shorter disruptions, NRC indicates the number of short restrictions, and ROC measures the proportional reduction in operational capacity from short interruptions, with DROC representing the duration of these short outages. Finally, D refers to the total number of days during which outages occurred. Together, these variables determine the financial penalties applied to transmission service operators based on system unavailability.

The Parcel Variable represents the number of hours of service interruption multiplied by the financial cost associated with system outages. This value is subtracted from the RAP as a penalty for the unavailability of transmission services. Brazilian TSOs are reimbursed based on system availability, requiring them to maintain power capacity and infrastructure consistently available to meet the demands of the National System Operator (ONS). The PV proxy was calculated using outage data from the years 2009/2010, 2010/2011, and 2011/2012, and an average PV ratio was determined.

The efficiency scores calculated using DEA-CRS and DEA-NDRS were then normalized based on the average PV group, with the highest-quality group receiving the maximum quality adjustment. The first group, considered to provide the best quality service, received the highest quality score, while the remaining groups saw a 10% decrease in adjustment per group. The final adjustment value was based on the geometric mean of the DEA-CRS and DEA-NDRS scores. It is important to note that these adjustments were applied unevenly among TSOs, with some (e.g., ELETROSUL and CTEEP) receiving adjustments under DEA-NDRS, while others were adjusted using DEA-CRS. ANEEL justified this by suggesting that ELETROSUL and CTEEP did not benefit from economies of scope in their operations across both generation and transmission.

The quality adjustment process allowed TSOs to approach the efficiency frontier. For instance, ELETROSUL achieved 95.9% efficiency, and CEMIG reached 90.5%, despite initial DEA scores of 46.9% and 61.5%, respectively. CTEEP, in particular, was over-rewarded for its quality performance, reaching 135% efficiency.

Methodology:-

In this section, the scientific method used to achieve the goals of this research will be presented. The focus is on identifying the appropriate technique for incorporating quality variables into frontier-based benchmarking models by literature review. This study examines the concerns raised in both national and international literature regarding the inclusion of service quality in the benchmarking model of TSOs, aligning the findings with theoretical and empirical suggestions from these studies.

Research Characteristics

This study adopts a qualitative and exploratory approach, which is particularly well-suited for understanding complex phenomena where existing knowledge may be limited or fragmented (Creswell, 2014). Qualitative research focuses on exploring issues in depth, allowing for a more nuanced understanding of the underlying mechanisms that influence specific topics. This is crucial in fields like energy transmission regulation, where the dynamics between service quality and benchmarking models are not fully established.

The exploratory design used in this study allows for flexibility in investigating areas with limited prior knowledge (Yin, 2011). Exploratory research is commonly employed when the goal is to gain insights into new or evolving phenomena, making it an appropriate choice for the study of service quality incorporation in benchmarking models. This design provides the researcher with the ability to adapt and refine the research focus as new patterns and themes emerge during the study (Stebbins, 2001).

Given the evolving nature of quality measurement in frontier-based benchmarking models and the specific regulatory context in Brazil, this approach enables a thorough investigation of relevant themes and practices. The qualitative and exploratory framework is essential for capturing the nuances of how service quality is integrated into performance evaluation, particularly in the energy transmission sector, where the topic has not been extensively explored (Flick, 2018).

Systematic literature review

The systematic literature review was conducted using the Web of Science and SciELO databases, following the principles outlined by authors such as Tranfield, Denyer, and Smart (2003). These authors emphasize the importance of a rigorous and structured approach to identifying, evaluating, and synthesizing existing literature in a transparent manner. To ensure comprehensive coverage of the topic, the searches included keywords such as "benchmarking models," "service quality," "energy transmission," "DEA," "SFA," and "Brazil." The search covered the period from 2000 to 2023. The use of these databases ensured access to a wide range of high-quality studies of international relevance, as well as regional literature important for the Brazilian context. This reflects the recommendations of Kitchenham and Charters (2007), who stress the necessity of including multiple databases for a more complete and robust review. The studies selection can be seen at Table 1.

Inclusion and exclusion criteria were applied following the guidelines proposed by Booth, Sutton, and Papaioannou (2016). These criteria were used to ensure that only the most relevant studies were selected for analysis. Articles were prioritized if they addressed the integration of quality variables in regulatory benchmarking models or focused on empirical studies related to the energy transmission sector. This selection process was essential in narrowing down the vast array of literature to the studies most relevant to the research questions.

The focus of the review was on studies offering both theoretical and practical contributions, with particular attention to the regulatory and performance contexts of transmission operators in Brazil. This approach enabled the mapping of best practices, as well as the identification of significant gaps in the literature regarding the use of quality proxies in benchmarking models. The systematic review thus provided a structured foundation for understanding how quality measures have been incorporated into performance benchmarking models both in Brazil and internationally.

Table 1:- List of selected studies from systematic literature review.

N	Author	Title

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1	Korhonen et al (2003)	Evaluation of Cost Efficiency in Finnish Electricity Distribution
2	Ajodhia et al (2004)	Economic Benchmarking and its Applications
3	Giannakis et al (2005)	Benchmarking and incentive regulation of quality of service: an application to the UK electricity distribution networks
4	Tanure et al (2006)	Establishing quality performance of distribution companies based on yardstick regulation
5	Yu et al (2007)	Incorporating the Price of Quality in Efficiency Analysis: The Case of Electricity Distribution Regulation in the UK
6	Arocena (2008)	Cost and quality gains from diversification and vertical integration in the electricity industry: A DEA approach
7	Coelli et al (2008)	Incorporating quality of service in a benchmarking model: an application to French electricity distribution operator
8	Cadena et al (2009)	Efficiency analysis in electricity transmission utilities
9	Yu et al (2009)	Does weather explain cost and quality performance? An analysis of UK electricity distribution companies
10	Yu et al (2009)	Quality of Service: An Application to Efficiency Analysis of the UK Electricity Distribution Utilities
11	Growitsch et al (2009)	Social cost-efficient service quality - integrating customers valuation in incentive regulation: evidence from the case of Norway
12	Growitsch et al (2010)	Efficiency Effects of Quality of Service and Environmental Factors: Experience from Norwegian Electricity Distribution
13	Martirosyan et al (2010)	Incentive regulation, service quality, and standards in U.S. electricity distribution
14	Azadeh et al (2010)	An integrated multivariate approach for performance assessment and optimization of electricity transmission systems
15	Jamasb et al (2012)	Estimating the marginal cost of quality improvements: The case of the UK electricity distribution companies
16	Miguéis et al (2012)	Productivity change and innovation in Norwegian electricity distribution companies
17	Coelli et al (2013)	Estimating the cost of improving quality in electricity distribution: A parametric distance function approach
18	Cambini et al (2013)	Output-based incentive regulation in electricity distribution: evidence from Italy
19	Xavier et al (2015)	How Efficient are the Brazilian Electricity Distribution Companies?
20	Silva (2015)	What affects the efficiency of the operating costs of electrical energy distributors in brazil? Na analysis using stochastic frontier
21	Altoe et al (2017)	Technical efficiency and financial performance in the Brazilian distribution service operators
22	Goerlich et al (2017)	Quality and Efficiency — A DEA Based Analysis of the Austrian Electricity Distribution Sector
23	Zaja et al (2017)	Efficiency Gains in Croatia's Electricity Distribution Centers Following Industry Structure Changes

Source: made by autors

Results:-

Quality review

The trade-off between quality and cost should be analyzed separately. Quality incentive regimes are based on cost expenditures. Cost performance can provide faster improvements in quality levels than capital cost incentive regimes. However, operational cost reimbursements based on performance in the short term may not support quality improvements. This disincentive occurs because high levels of quality service are capital-intensive and deteriorate over time. In the short term, firms are not fully reimbursed for all incurred costs, which can decrease long-term investments in quality-related operational services. To maintain or improve quality service, financial resources and new projects are managed and executed in the medium to long term. This directly conflicts with regulatory incentive policies that focus on cost reduction without altering performance in the long term (Joskow, 2014). Quality service investments exhibit diminishing marginal returns, meaning each additional dollar spent on improvements does not proportionally increase the quality level (Llorca et al., 2016).

To reduce diminishing marginal effects, regulators make TSOs' reimbursements annually to avoid monetary losses related to quality improvements. Heggset et al. (2001) suggested that regulators should constantly monitor the quality of service being provided. This can prevent TSOs from increasing unnecessary costs, which might impact operational cost performance. For quality performance measurement, the quality proxy should incorporate undirected costs from the operational environment. These costs may be influenced by regional geography, operational conditions stemming from concession legislation, or infrastructure requirements. In addition to environmental concerns, the quality proxy should reflect improvements beyond the desirable level, supporting financial incentives for higher performance (Langset et al., 2001; Langset & Tore, 2002).

Various metrics and methodologies have been discussed in the literature for incorporating quality into performance measurement in the energy transmission and distribution sector. The quality proxy has different interpretations, attempting to accurately capture the level of service provided by TSOs. However, different understandings and effects of quality service are perceived by consumers in tangible or intangible ways. To make it tangible, quality perception can relate to price levels through flexibility and convenience, where legislative policy must align with intangible customer expectations (Chase & Hayes, 1991; Lovelock et al., 1971). It is also difficult to measure quality perception for both customers and regulators, as the service is provided at the same time it is consumed (Grönroos & Ojasalo, 2004).

The trade-off between cost reduction and quality depends on TSOs' choices, where they may provide an undesirable level of service in an unregulated monopoly regime (Giannakis, Jamasb, & Pollitt, 2005). Regulators must implement legislation that aligns with social criteria for quality service levels. Additionally, oversight of TSO operations is necessary to adjust, control, and manage the provision of public services (Robert, 2001). In the energy sector, Langset et al. (2001) initiated a discussion on incorporating quality service into performance analysis, suggesting a proxy for system outages or interruptions.

Langset et al. (2001) recommended using power supply outages as a quality service proxy in the energy sector. This interruption proxy could be employed in SFA and DEA benchmarking models. DEC and FEC are typically recorded by companies and regulators to assess operational system performance. The literature identifies FEC as a variable in studies by Altoé et al. (2017) and Silva (2015), while DEC is more frequently used in research on operational energy efficiency (Ajodhia & Hakvoort, 2005; Coelli et al., 2013; Korhonen & Syrjanen, 2003; Yu et al., 2009a, 2009b). Research by Banker et al. (2017) and Ter-Martirosyan and Kwoka (2010) also employs both DEC and FEC to represent quality levels, with DEC often fitting better in benchmarking models. Other studies have used proxies adjusted by the number of consumers affected in outage areas to improve model accuracy (Coelli et al., 2008; Giannakis et al., 2005).

Most academic contributions on quality performance measurement in benchmarking models related to energy policy were published after 2009, as noted by Emrouznejad et al. (2008). Lampe and Hilgers (2015) conducted a bibliometric analysis of benchmarking models in DEA and SFA, identifying the development of energy performance models. In addition to advancing benchmarking theory, Mesquita (2017), Agrell and Bogetoft (2016), Haney and Pollitt (2009), and Jamasb and Pollitt (2000) examined how variables and models have been used by regulators in Brazil, Colombia, Finland, France, Germany, the Netherlands, Italy, Norway, Spain, England, the United States, and Iran.

Given the methodology employed, reviewing how quality has been implemented in benchmarking models is relevant. Some academic studies found that quality measurement does not significantly contribute to performance measurement, based on statistical significance in SFA (Coelli et al., 2008; Growitsch et al., 2009; Ter-Martirosyan & Kwoka, 2010) and DEA (Cambini et al., 2014; Coelli et al., 2008; Giannakis et al., 2005; Growitsch et al., 2010; Yu et al., 2009a, 2009b). However, the lack of statistical significance does not rule out the effect of quality on efficiency, either positively or negatively, as it can either reduce (Goerlich & Ruehrnoessl, 2017; Growitsch et al., 2009; Korhonen & Syrjänen, 2003) or increase efficiency (Ajodhia et al., 2004; Giannakis et al., 2005). Despite varying statistical significance in benchmarking models, authors agree on the relevance of including quality in performance measurement (Goerlich & Ruehrnoessl, 2017; Žaja et al., 2017; Altoé et al., 2017; Azadeh & Movaghar, 2010; Cambini et al., 2014; Coelli et al., 2013; Jamasb et al., 2012; Ter-Martirosyan & Kwoka, 2010; Xavier et al., 2015).

The trade-off between cost and quality becomes evident when TSOs make minimal investments to improve quality beyond the desired level because they won't be reimbursed. Some authors agree that there are benefits to incorporating the quality variable into performance benchmarking models, not only for adjusting efficiency (Altoé et al., 2017; Giannakis et al., 2005) but also to capture marginal gains from consumers who desire high quality levels (Keyaerts & Meeus, 2017) but are not willing to pay for them (Growitsch et al., 2012). Even when looking at efficient DMUs (100% efficiency), DMUs with low-quality levels can still reach the efficiency frontier, as found by Giannakis et al. (2005), Growitsch et al. (2010), Xavier et al. (2015), and Yu et al. (2009a, 2009b, 2007).

Quality in benchmarking can be modeled as an output, where higher values are desirable (Ajodhia et al., 2004; Azadeh & Movaghar, 2010; Banker et al., 2017; Cadena et al., 2009; Growitsch et al., 2012; Korhonen & Syrjanen, 2003; Silva, 2015; Tanure et al., 2006; Ter-Martirosyan & Kwoka, 2010). However, quality measurement based on system outages, particularly using DEC and FEC, often treats quality as an undesirable variable, contradicting this assumption. These variables should minimize undesirable system interruptions. Azadeh and Movaghar (2010) and Tanure et al. (2006) addressed this concern by developing a technique to transform quality metrics (DEC and FEC) into desirable variables. However, in DEA literature, Bogetoft and Otto (2012), Forsund (2015), and Thanassoulis (2000) caution that variable transformations can alter the numerical properties of data, leading to inaccurate efficiency results. Other authors have implemented alternative techniques for better-fitting SFA models by adjusting costs to reflect quality effects (Cadena et al., 2009; Jamasb et al., 2012; Silva, 2015).

To build a quality proxy, researchers have used different units for DEC and FEC, such as adjusting these metrics by the number of inhabitants in outage areas (Coelli et al., 2008; Coelli et al., 2013; Giannakis et al., 2005; Growitsch et al., 2009; Growitsch et al., 2010; Yu et al., 2009a, 2007). After 2009, some researchers introduced a financial value to reflect system outages. This monetary value measures the opportunity cost for consumers deprived of energy supply. Service unavailability is measured by estimating DEC in hours multiplied by the average hourly service cost, capturing the financial impact of quality levels on efficiency analysis (Amundsveen et al., 2016). The assumption of quality as a financial variable to be minimized reinforces that TSOs should avoid system outages (Altoé et al., 2017; Cambini et al., 2014; Growitsch et al., 2010; Miguéis et al., 2012; Yu et al., 2009b).

Table 2:- Incorporation of quality by regulators.

REGULATOR	METHODOLOGY	QUALITY INTO BENCHMARK
GERMANY	DEA NDRS and SFA CRS	DEA – DOES NOT USE QUALITY MEASUREMENT SFA – QUALITY IS A DEPENDENT VARIABLE
AUSTRIA	DEA NDRS, MOLS and CRS	DEA – QUALITY ADDED TO TOTEX E sTOTEX MOLS - QUALITY IS A DEPENDENT VARIABLE
DENMARK*	AVERAGE COST	EXTERNAL PROCESS, SUBTRACTED FROM ALLOWED REVENUE
FINLAND	StoNED CRS	DEA - DOES NOT USE QUALITY MEASUREMENT SFA - QUALITY IS A DEPENDENT VARIABLE
HOLLAND*	AVERAGE COST	EXTERNAL PROCESS, SUBTRACTED FROM ALLOWED REVENUE
NORWAY	DEA CRS	QUALITY ADDED TO TOTEX
SWEDEN	DEA and SFA	EXTERNAL PROCESS, SUBTRACTED FROM ALLOWED REVENUE
CHILE	AVERAGE COST	QUALITY ADDED TO TOTEX
COLOMBIA	AVERAGE COST	QUALITY ADDED TO TOTEX
MEXICO*	DEA	DEA - QUALITY ADDED TO COST
PANAMA	DEA VRS	DEA - QUALITY ADDED TO COST
PERU	AVERAGE COST	QUALITY ADDED TO TOTEX

* OPEX countries

Source: adapted from Mesquita (2017)

Despite the use of a quality proxy, a modeling issue still requires close attention. This extends to how this variable has been implemented or incorporated into benchmarking models. Monetary values as a proxy for poor quality have been used in two ways: either as a separate variable in the model, treated as an undesirable output or input, or by incorporating these values directly into the other variables. Both techniques are commonly used in benchmarking models. Goerlich et al. (2017), Growitsch et al. (2010), and Yu et al. (2009a) proposed using the financial value of the quality variable as an input, where the desirable objective is to reduce this value. Additionally, other researchers, such as Goerlich et al. (2017), Altoé et al. (2017), Cambini et al. (2014), Growitsch et al. (2010a, b), and Miguéis et al. (2012), incorporated quality into operational costs by adjusting the financial value for quality service. This adjustment adds the monetary value associated with quality service to the operational cost variable. The effect of this can either positively or negatively impact performance by decreasing or increasing operational costs, respectively.

It is important to highlight that regulators from countries such as Germany, Austria, Denmark, Finland, the Netherlands, Norway, Sweden, Chile, Colombia, Mexico, Panama, and Peru also use quality in some form to evaluate performance, as analyzed by Goerlich et al. (2017), Altoé et al. (2017), Silva (2015), Xavier et al. (2015), Cambini et al. (2014), Miguéis et al. (2012), Growitsch et al. (2009), and Yu et al. (2009a, b). Table 2 summarizes Mesquita's (2017) research and review on how regulators incorporate quality into performance evaluations.

Implications and a contribution for the 3rd cycle of tariff review – 3CTR

The latest model proposed by ANEEL for the tariff review is from 2017, and it will be applied to the 3CTR. This tariff review covers the period from 2017 to 2022, following the timeline set by the Concessions Renewal. The data spans from 2013 to 2016, using a panel approach, and includes 97 DMUs. This increase in the number of DMUs reflects ANEEL's assumptions regarding the corporate composition of TSOs and the inclusion of bidding TSOs. ANEEL now interprets that operational and maintenance costs from concession TSOs should be shared with costs from the controlling holding company. In addition to CEEE, CEMIG, CHESF, COPEL, CTEEP, ELETRONORTE, ELETROSUL, FURNAS, and CELG, the group of controllers and bidding firms were included. CELG was no longer considered an outlier due to its operational size.

For the proposed 3CTR model, ANEEL used a two-step procedure for efficiency measurement. First, the DEA model was measured assuming Non-Decreasing Returns to Scale (NDRS). Weight restrictions were also applied to the variable relationships to ensure data homogeneity. Second, a third percentile for normalization was used. This tariff composition had been in place until the 2012 Concessions Renewal (MP 579/2012, later transformed into Law 12.783/2013), which introduced a different interpretation. These assumptions remained valid for the 3CTR proposed in 2017, which will use data from 2013 to 2016. The proposed model for the 3CTR requires further attention. The only significant change was in the Equipment Modules, where three-phase equipment was transformed into single-phase by dividing the three-phase by three.

In the latest proposed model for the 3CTR (TN 160/2017 and TN 164/2017), ANEEL suggests a quality proxy for transmission service based on DEC, different from what was used in the 2CTR and the 2012 Concession Renewal. For the 3CTR, the proposed quality proxy will be constructed using the sum of Interruptions in Power Capacity (IPC). This new metric is composed of the total outage hours at each transmission power capacity level. To reduce volatility in annual service outages, the model uses an average IPC over the analysis period from 2013 to 2016. Additionally, ANEEL made an error in initially inserting the quality's negative effect as positive in TN 160/2017, later correcting it to a negative impact in TN 164/2017. If the mistake had persisted, quality would have been interpreted as a positive effect, meaning that a maximization of quality interruptions in transmission service would have been desirable, contradicting the variable's purpose in performance evaluation.

Finally, ANEEL employed weight restriction techniques to ensure a homogeneous analysis of performance variables among TSOs. In the 2CTR, network length was segmented by power capacity with a ratio based on 230kV, as all TSOs had some network length operating at this level under equal regulatory conditions. The DEA model assigned weights to input and output variables to adjust the network length, ensuring that no TSOs could achieve 100% efficiency by only operating at one power capacity length. In the 2017 proposed 3CTR model, the regulator applied weighting across other variables, such as the sum of lengths greater than 230kV divided by OPEX, the sum of lengths lower than 230kV divided by lengths greater than 230kV, Power Capacity divided by OPEX, Modular Voltage Network divided by OPEX, and Modular Voltage Network divided by Equipment Modules.

Conclusion:-

This research provides both an academic and technical framework for understanding the incorporation of service quality into a frontier-based benchmarking model for the electric transmission segment. By conducting a comprehensive review of service quality concerns in the electrical energy sector, this study contributes to the literature with an analysis of quality proxies and their application in frontier-based benchmarking models. The findings indicate that treating quality as a monetary value is most effective when used as an input, allowing for the adjustment of operational costs.

The Brazilian transmission regulatory model, as applied in the 2007, 2009, 2012, and the most recent 2017 proposed tariff reviews, was analyzed and found to diverge from best practices recommended in the literature and adopted by leading global energy regulators, particularly in terms of incorporating quality measures into benchmarking models. This research compared different frontier-based benchmarking methods for integrating the quality variable into Brazilian Transmission System Operators (TSOs) and identified key concerns from the literature, such as the global adoption of quality measures, the composition of proxies, and their impact on performance. Additionally, this study evaluated the efficiency of Brazilian TSOs based on international regulatory practices and academic recommendations, offering critical insights into the current approach.

The proposed Brazilian model for the 2017 tariff review, developed by ANEEL, should consider adopting the Parcel Variable (PV) as a proxy for quality. The PV reflects the costs associated with transmission service outages, a factor that has not been incorporated into the previous tariff review cycles of 2007, 2009, or 2012, nor is it currently included in the 2017 proposal. Furthermore, in terms of modeling techniques, quality should be treated as an input that adjusts the operational costs for Transmission System Operators (TSOs). This approach would align the Brazilian model with international standards and improve the accuracy of efficiency evaluations.

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