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Incorporating quality into frontier-based benchmarking in the context of Brazilian transmission service operators

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Incorporating quality into frontier-based benchmarking in the context of Brazilian transmission service operators

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ATA DA DEFESA DE DISSERTAÇÃO DE MESTRADO EM ADMINISTRAÇÃO da Senhora **RICARDO AUGUSTO OLIVEIRA SANTOS**, REGISTRO Nº 632/2018. No dia 09 de fevereiro de 2018, às 10:00 horas, reuniu-se na Faculdade de Ciências Econômicas da Universidade Federal de Minas Gerais - UFMG, a Comissão Examinadora de Dissertação, indicada pelo Colegiado do Centro de Pós-Graduação e Pesquisas em Administração do CEPEAD, em 17 de janeiro de 2018, para julgar o trabalho final intitulado **"Incorporating quality into frontier-based benchmarking in the context of Brazilian transmission service operators"**, requisito para a obtenção do **Grau de Mestre em Administração**, linha de pesquisa: **Gestão de Operações e Logística.** Abrindo a sessão, a Senhora Presidente da Comissão, Profa. Dr. Ana Lúcia Miranda Lopes, após dar conhecimento aos presentes o teor das Normas Regulamentares do Trabalho Final, passou a palavra à candidata para apresentação de seu trabalho. Seguiu-se a arguição pelos examinadores com a respectiva defesa da candidata. Logo após, a Comissão se reuniu sem a presença da candidata e do público, para julgamento e expedição do seguinte resultado final:

(X)APROVAÇÃO;

( )APROVAÇÃO CONDICIONADA A SATISFAÇÃO DAS EXIGÊNCIAS CONSTANTES NO VERSO DESTA FOLHA, NO PRAZO FIXADO PELA BANCA EXAMINADORA (NÃO SUPERIOR A 90 NOVENTA DIAS);

( )REPROVAÇÃO.

O resultado final foi comunicado publicamente à candidata pela Senhora Presidente da Comissão. Nada mais havendo a tratar, a Senhora Presidente encerrou a reunião e lavrou a presente ATA, que será assinada por todos os membros participantes da Comissão Examinadora. Belo Horizonte, 09 de fevereiro de 2018.

NOMES ASSINATURAS

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If you torture the data long enough, it will confess to anything.

DARREL HUFF´S (1954)

ABSTRACT

This study uses an academic and technical structure to clarify relevant issues of incorporating service quality level into a frontier-based benchmarking model in the electric transmission segment. The goal of this research is to contribute to the literature with a survey on service quality in the electrical energy sector and with a review of quality proxies and modeling applications into frontier-based benchmarking models. The Brazilian transmission regulatory model and the efficiency process adopted in 2007, 2009, 2012 and the latest proposed model in 2017 are presented and analyzed. The benchmarking model proposed in 2017 by the Brazilian regulator, Agência Nacional de Energia Elétrica (ANEEL) has limitations in evaluating quality proxies and in understanding how to incorporate this information into benchmarking efficiency analyses. Results showed that it is more effective to incorporate quality into the efficiency analysis when it is assumed as an input by adjusting operational expenses (OPEX) through a monetary value. When the monetary value of quality was added to the OPEX, the average score presented less standard error deviation, consistent with predicted results. This research used the Parcel Variable (PV), a monetary value for non-disposability in electric transmission service, as a proxy for quality. Based on the 2017 ANEEL proposal, this research recommends the adoption of PV as a quality proxy, inserted as an input to adjust OPEX. This new approach will lead to a government saving of R$ 2 billion reals on cost reimbursement based on benchmarking efficiency measurement at Brazilian transmission segment.

Key words: Benchmarking Models, Quality at Electricity, Operational Efficiency, Monetary Quality Variable

SUMMARY

LIST OF ACRONYMS

ANEEL – National Agency of Electrical Energy
CRS – Constant Return of Scale
CTR – Cycle of Tariff Review
DEA – Data Envelopment Analyses
DEC - Equivalent Duration of Interruption
DMU – Decision Making Unit
EPE - Energy Research Company's
FEC - Equivalent Frequency of Interruption
IPC – Interruption in Power Capacity
MVA – Mega Volt Ampere
NDRS – Non-decreasing Returns of Scale
OPEX – Operational Expenses
ONS - Electric System Operator
PV – Parcel Variable
RAP – Permitted Annual Revenue
SFA – Stochastic Frontier Analyzes
SIN – National Interconnected System
StoNED - Stochastic Nonparametric Envelopment Data
TN – Technical Note
TOTEX – Total Operational Expenses
TSO – Transmission Service Operator
VRS – Variable Return of Scale

1 INTRODUCTION

This research study will seek to clarify the concerns of quality service measurement at the electric transmission segment, contextualize to Brazil. The segment is managed by Transmission Services Operators – TSOs in supervision by regulatory agencies. Worldwide regulatory agencies and society are always looking for the best operational performance at the transmission energy sector. Constant challenges are set up by regulation, costumers and market when comes to operate the transmission system. Improvements impact operational energy disposability, supplementary services, processes in which reflects at quality service levels (LOVELOCK, 2011). From the agent's perspectives, good quality is perceived when quality experienced meets costumer expectations. If expectations are not met, the total quality perceived will be lower, even if the quality experienced reheated costumer's expectation. The total level of perceived quality is determined by the gap between expectation and experienced quality (GRÖNROOS, 1990).

Investments in infrastructure are necessary to support growth at the electric sector ensuring economic development. The additional demand for electric energy in Brazil grew 12% between 2011 to 2015, allowing electricity access for 8.5 million people. Consumption growth at residential and rural class was 17% and 23% with an industrial decreased of 8% according to the Energy Research Company's – EPE 2015 report. The Ten-Year Energy Expansion Plan until 2023 foresees an expansion of more than 182 thousand kilometers of power lines. The growth at energy transmission is a reflection of investments in energy generation, which already presented growth of 9%. Investments were made at North and Northeast on generation by new renewable sources from water and wind (INSTITUTO ACENDE BRASIL, 2015). Hence, energy consumption has grown 21% in North and 24% at Midwest. Achão and Schaeffer (2009) pointed out a need for investments to maintain and support infrastructure and a constant expansion of Brazilian electric sector.

The Brazilian electric sector is composed by concessionaries – companies that offers public services in different productive segments as generation, transmission, distribution and commercialization. Accordingly ANEEL (2015) the power generation system is concentrated in hydroelectric (64%), thermoelectric (28%) and nuclear plants (1%) and wind energy (5%). In order to provide energy access and transport to different regions and market consumers, the energy transmission lines extend over 116 thousand kilometers (NATIONAL OPERATOR, 2015). Once transported at high voltage lines, energy will arrive at transformation substations, where it is converted into a low voltage and then, distributed to the consumer. At distribution segment, 38 companies permitted to operate, where the 10 largest distribute 58% of Brazilian energy market (ANEEL, 2015).

Not only in Brazil, the electric sector has strong impact in the economy, in which, under natural monopoly configuration (where we have a single service provider for many market demanders), needs regulation to minimize externalities. In order to provide public services, the State allows the supply to be operationally conducted by a concession regime, by means of bidding and auctioning instruments. This process of operation and delivery of public services can be provided by public and private companies. These concession is a formal permission to operate and manage auction segments. Then, under a monopolistic market condition caused by auctions segments, an introduction of regulation on public services is required to minimize monopoly effects. In this way, service providers are encouraged to seek the lowest (efficient) cost with the highest desirable quality by the regulatory legislation.

Under monopolistic characteristics, regulation may induce competition as a competitive market through direct intervention by an regulatory agency (BEESLEY and LITTLECHILD, 1989). In Brazil, National Agency of Electric Energy - ANEEL was established as in charge to minimize externalities effect from monopoly and guarantee the social welfare by assuring access to electricity. In terms of incentives and restrictions to TSOs, the main purpose of agency is to enable and ensure satisfactory conditions of service that are provided to Brazilian consumers. Not only in Brazil, but in other countries of South America such as Argentina, Uruguay and Chile, the regulatory agencies control and make concessions process (SPILLER and MARTORELL, 1996).

In order to implement regulatory policies, the tariff regime adopted by ANEEL for TSOs regulation is a derivation of the price cap, known as revenue-cap or maximum revenue, in which the regulator determines the maximum permitted revenue allowed – RAP through parameters of efficiency (TN 068/2006). As a part of the RAP, ANEEL reimburse TSOs from operational costs incurred over time, which can be composed by infrastructure investments, equipment depreciation, costs of third-party capital and capital structure until 2012 (DE ANDRADE and

SANTANNA, 2011; SERRATO, 2009), as well as, operating and maintenance costs, taxes and charges.

TSOs reimbursement are attached to operational efficiency scores. The regulator has been adopting benchmarking methodologies to compare efficiency performance between TSOs. It is through operational comparison of inputs as operational expenses and outputs as network length, modules, equipment and quality service level that ANEEL evaluate the transmission performance service operation. Since the first time implemented in 2007, ANEEL has changed variables and modeling specification over Cycle of Tariff Review – CTR from 2007, 2009, 2012 and the newest proposed for 2017. These changes impact the revenue of the companies as well as the consumer´s charges on the energy bill.

All proposed models by ANEEL for CTR uses the benchmarking methodology called Data Envelopment Analysis – DEA. DEA is a methodology for measuring the relative efficiency of Decision Making Units - DMUs through linear programming, developed by Charnes, Cooper and Rhodes (1978) and improved by Banker; Charnes; Cooper, (1984). The most commonly methodologies for benchmarking approach in energy regulation are Stochastic Frontier Analyzes - SFA, DEA or the newest Stochastic Nonparametric Envelopment Data - StoNED developed in 2010. Each methodology has specific modeling characteristics as SFA require parametric definition while DEA is non-parametric and StoNED is a mix between SFA and DEA (BJØRNDAL *et al.,* 2010; KUOSMANEN *et al.,* 2013; CHARNES *et al.,* 2013).

Mesquita (2017), Agrell and Bogeroft (2016), Haney and Pollitt (2009) and Jamasb and Pollitt (2000) investigated different quantitative methodologies and regulation efficiency models at electric distribution and transmission energy segment. At transmission segment Agrell and Bogeroft (2016) research pointed to Belgium, Denmark, Germany, Netherlands, Norway and Portugal using DEA. Others, as Mexico and Portugal use SFA in distribution and StoNED method is used in Finland distribution. Also, some countries like Germany use a mix of DEA and SFA.

Modeling efficiency analysis has been a challenge when comes to quality at monopolistic regimes, as occurs at the electric transmission segment, where optimal level may not be the same as in market conditions. Regulation turns to be difficult when price and quality levels are to be decided. Usually regulators are found in a tight position, with a tradeoff between setting prices and the level of quality desirable for market and consumers (SPENCE, 1975; VOGELSANG, 2006). Energy Regulators commonly consider quality as a cost, in which, an upgrade at the service level requires amounts of capital investments. As an non-desirable effect from regulation, firms only make investments to reach the optimal level of quality required by regulatory agencies (GABSZEWICZ and WAUTHY, 2002; LANGSET and TORE, 2002).

Satisfaction on quality supply can be highly desirable, where customers always demand a higher service even if they aren´t proportionately willing to pay for more improvements (MORRI, 1999; YU *et al* 2009). Quality is capital-intensive, demanding higher levels of investments to an optimum level, in which firms and costumer aren´t willing to pay. At electric sector, usually, consumers don´t have a choice of not paying for a higher price associated with a higher quality service. Due to the high capital amounts and operational complexity for cost allocation, the total cost is proportionally shared between costumers. But, this should not imply to receive lower levels of quality of service when they aren´t willing to pay for higher service levels (AJODHIA and HAKVOORT, 2005). Consumers also don´t see the whole process for electric transmission service in which they pay for operational performance, capacity, voltage support, off-peak load, spinning reserve, load following capacity, black start capacity, dual fuel capacity and local load Steiner (2000), besides disposability and security of uninterrupted power supply.

Regulators wants to adjust TSO annual operational costs for reimbursement in a way of reduction does not reflect in offering lower levels of quality service. Some regulators implemented metrics to evaluate goals for a minimum quality level provision. This require process for performance measurement, which regulator must analyze and assure the minimum level of quality (HEGGSET *et al.*, 2001). It´s necessary to represent a quality proxy by a variable that considers structural differences between companies. These proxies must reflect positive and negative effect from service level. In addition, regulatory policy should incentive improvements by awarding quality service above consumers expectation (LANGSET *et al.*, 2001; LANGSET and TORE, 2002). Quality incorporated to performance analyzes as reward can incentives firms to structure service by balancing internal costs towards an economic optimum with higher quality level service (LANGSET and TORE, 2002).

Worldwide regulators had implement quality service measurements successfully, incentivizing a cost reduction, operational process improvements, and minimizing energy losses maintaining desirable levels of quality (JAMASB and POLLITT, 2007). This can be seen even under challenges of different types of consumers at urban zones and rural zones, mentioned in Cadena *et al.* (2009). Academic studies analyze the adoption of quality variables for performance measurement at energy distribution and transmission segment. Different approaches for performance benchmarking models have been adopted in country's as Netherlands, Norway, Ireland, Sweden, United Kingdom, Germany, Finland, Spain, France, Italy, Iran, United States, Brazil, Colombia, Austria, Croatia (AJODHIA *et al.*, 2004; ALTOÉ *et al.*, 2017; AROCENA, 2008; AZADEH and MOVAGHAR, 2010; CADENA *et al.*, 2009; CAMBINI *et al.*, 2014; COELLI *et al.*, 2008; DE QUEIROZ, 2012; GIANNAKIS *et al.*, 2005; GOERLICH and RUEHRNOESSL, 2017; GROWITSCH *et al*,. 2009; KLOP, 2009; KORHONEN and SYRJÄNEN, 2003; TER-MARTIROSYAN; and KWOKA, 2010; ŽAJA *et al.*, 2017)

Not a single model but different metrics and methodologies have been developed and analyzed to insert quality service into benchmarking models. Recent research study's Korhonen et al (2003), Ajodhia et al (2004), Giannakis et al (2005), Tanure et al (2006), Yu et al (2007), Arocena (2008), Coelli et al (2008), Cadena et al (2009), Yu et al (2009), Yu et al (2009), Growitsch et al (2009), Growitsch et al (2010), Martirosyan et al (2010), Azadeh et al (2010), Jamasb et al (2012), Miguéis et al (2012), Coelli et al (2013), Cambini et al (2013), Xavier et al (2015), Silva (2015), Altoe et al (2017), Goerlich et al (2017), Zaja et al (2017) contributed for discussing some concerns about how to capture the quality effect on performance analyzes. As a proxy for quality of the service provided, the variable Equivalent Duration of Interruption – DEC represents the duration in time dimension for the system energy outages. Also, the frequency of outages over a time dimension, known by Equivalent Frequency of Interruption – FEC, has been used to measure quality. These two metrics are the most frequently used at literature as proxies to represent quality.

Quality measurement was introduced in Brazil by state-owned electric power companies, by law 46/1978 from the extinct National Department of Waters and Electric Energy - DNAEE. Later on, goals for quality service operation were set for DEC and FEC. However, only in TN 48/2010 and TN 021/2011 quality was introduced as a variable in efficiency measurement for Brazilian TSO cost performance (BERNARDO, 2013; CYRILLO, 2011). A proxy for quality was implemented for the first time in 2012 (TN 383/2012). Actually, at this time, quality was used as an ad hoc adjustment to the DEA efficiency score. Lopes and Lanzer, (2015) criticized the ad hoc adjustments made by ANEEL that made to ELETROSUL, a TSO company from the south of Brazil, which reached a DEA score of 46% showing a big inefficiency, but received more 49% for the quality of the service, reaching a total of 95% efficiency. Another TSO, CTEEP, reached 135% of efficiency score after the adjustment.

During the next cycle of tariff review in 2017 discussions ANEEL changed its approach and proposed, through the technical notes 160/2017 and 164/2017 the introduction of a measure of quality in the DEA model. However, this approach also has its pitfalls and received several critics from the agents. One of them, is at the metric, where ANEEL assumes same operational cost for system outage in different transmission power capacity, where in a year, 6 minutes or 0,1 hours at 6000MW is equal to 10 hours of 60MVA, leading to a 600 MVA/H power interruption (AEA, 2017). Second, agents as ISA CTEEP criticize the values measured, an average mean was used to reduce high volatility over the years. Third, ANEEL in TN 160/2017 implemented quality as an output, assuming that quality service from transmission outages was desirable. This was later corrected at TN 164/2017. At last, almost half of the TSOs do not have quality variable to contribute to the efficiency score, presenting zero weights for the quality variable.

Given the quality service relevance for the efficiency analyses and the unsolved quality concerns at the Brazilian transmission benchmarking model, a literature review will be required on world energy regulators. It is necessary to search for quality proxies and the way to implement this measure in a DEA model for regulation of energy transmission companies. This research uses an academic and technical structure to clarify relevant issues concerning cost regulation of Brazilian TSOs, following the research question:

How should the quality of energy transmission service be introduced into the Brazilian benchmarking cost regulation?

1.1 Goals

1.1.1 Main goal

Build a proposal that incorporates quality of service into the Brazilian transmission service operator costs regulation.

1.1.2 Specific goal

- Provide an overview of quality variables suggested in the literature for regulation of energy companies;
- measuring the TSOs' efficiency by DEA with and without quality variables;
- interpreting the results of the different models in the context of Brazilian TSOs.

1.2 Study structure

In order to prioritize and fulfill the general and specific objective of this study, the work was divided into 5 chapters, including this introduction. In the second chapter, we present a theoretical review about the main concepts and methods that support this study. The third one presents the methodology procedures of research as well as the techniques that were used. Chapter 4 will be presented the results and discussions and 5th one the conclusion.

1.3 Research limitations and contribution

This research will focus only on the electric transmission segment. Regarding the object of research, we will analyze variables suggested by the national and international literature and experts in this area. Hence, the model proposed in this research may use unique variables for incorporating quality in the DEA model. In addition, discussions and theoretical implications of the composition of the variables of operating costs, maintenance costs, and compensation of the assets will not be approached in detail.

This research contributes to the literature with a survey of service quality variables used in regulation of electric power transmission companies. It will seek to provide a discussion of what the main authors justify as relevant in incorporating service quality measurements in performance analysis. Regarding the literature, a review of quality proxies that represent properly electrical operational service is offered as a way of modeling and application in frontier-based benchmarking. A review of what has been done so far from ANEEL for cost reimbursement at 2007, 2009, 2012 and the latest proposed model in 2017 will be presented. This research will offer a recommendation to the Brazilian TSO performance model to adopt the proper modeling considering DEA measurement.

2 LITERATURE REVIEW

2.1 Quality for electrical transmission energy

The tradeoff between quality and cost should be analyze separately. Quality regimes of incentives is based on costs expenses. Cost performance can provide faster improvements at quality level than capital costs incentives regimes. However, the operational costs reimbursement based on performance, in the short term may not support quality improvements. This disincentive occurs because of high levels of quality service are capital intensive and deteriorates over time, where in short term, firms aren´t been reimbursed in all incurred costs. This can decrease quality investments on long term operational services. To maintain or to improve quality service, financial resources and new projects are manageable and executed in medium to long term. This conflicts direct to regulation incentives policy for cost reduction without altering performance in long term (JOSKOW, 2014). Quality service investments has a marginal decreasing effect, in which, for each additional dollar spent on improvements does not improve proportionally quality level (LLORCA *et al.*, 2016).

To reduce decreasing marginal effects, regulators make TSOs reimbursements annually to avoid monetary losses at quality improvements. Heggset *et al.*, (2001) suggested that regulator should check constantly for quality service level that are been provided. This can mitigate TSOs from increasing unnecessary costs, in which might impact operational cost performance. For quality performance measurement, the quality proxy should be able incorporate undirected cost from the operational environment. This can be regional geography, operational conditions from a concession legislation or even through infrastructure requirements. Not only environment concerns, but also a reflection of quality improvements higher than the desirable level, supporting financial incentivizes for higher performance (LANGSET *et al.*, 2001; LANGSET and TORE, 2002).

Metrics and methodologies have been discussed at literature for quality into performance measurement at energy transmission and distribution segment. Quality proxy has different interpretations attempting to capture properly the level of service provided by TSOs. However, different understandings and effects of quality service are perceptible to consumers in a tangible or intangible way. To make it tangible, quality perception can be price level by flexibility and convenience, in which the legislator and his policy must be adjusted to the intangible costumer expectation (CHASE and HAYES, 1991; LOVELOCK *et al.*, 1971). It´s also difficult to measure quality perception for costumer and for the regulator, because service can be provided in the same time as it is consumed (GRÖNROOS and OJASALO, 2004).

The tradeoff between costs reduction and quality relays on TSOs choice, where it can provide service in an undesirable at a non-regulated monopoly regime (GIANNAKIS; JAMASB; POLLITT, 2005). Regulators must implement legislations in accordance of social criteria for quality service levels. Also a supervision at TSO operations should be seen to adjust, control and manage the provide public service (ROBERT, 2001). At energy sector Langset *et al* (2001) started and introduced a discussion of adding a quality service into performance analyzes, in which, suggested a proxy for system outages or system interruptions.

Langset *et al* (2001) recommended a proxy for quality service at the energy sector as outages in power supply. This interruption proxy could be used in SFA and DEA benchmarking models. DEC and FEC is usually registered by companies and regulator to analyze operational system performance. Literature points the use of FEC as a variable in Altoé *et al.*, (2017) and Silva (2015) and DEC more frequently used in operational energy efficiency research studies Ajodhia and Hakvoort (2005), Coelli *et al.* (2013), Korhonen and Syrjanen (2003), Yu *et al.* (2009a, b). Nevertheless, the research of Banker *et al.*, (2017) and Ter-Martirosyan and Kwoka (2010) also use DEC and FEC concomitantly to represent quality level provision. Indeed, they found DEC has fitted better for benchmarking performance models. Others, had used other proxy for a better adherence as ratio for DEC and FEC adjusted by the number of consumers affected at the outage area (COELLI *et al.*, 2008; GIANNAKIS *et al.*, 2005).

Most academic contributions for quality performance measurement at benchmarking models related to energy policy were published after 2009, in accordance of results found by Emrouznejad et al. (2008). Lampe and Hilgers (2015) had made a bibliometric analysis of benchmarking models at DEA and SFA, identifying developers of energy performance models. Not only focusing on benchmarking theory development, Mesquita (2017), Agrell and Bogetoft (2016), Haney and Pollitt (2009) and Jamasb and Pollitt (2000) had verify 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.

In view of the used methodology, a review on how quality has been implemented at benchmarking models is relevant. Some academic studies verified quality measurement does not promote relevant contribution for performance measurement, based on statistical significance at SFA methodology (COELLI *et al.*, 2008; GROWITSCH *et al.*, 2009; TER-MARTIROSYAN and KWOKA, 2010) and also in DEA (CAMBINI *et al.*, 2014; COELLI *et al.*, 2008; GIANNAKIS *et al* 2005; GROWITSCH *et al.*, 2010; YU *et al.*, 2009a, b). Although, the low or statistical absence of significance does not rule out the quality effect to affect efficiency positively or negatively, in which reducing (GOERLICH; and RUEHRNOESSL, 2017; GROWITSCH *et al.*, 2009; KORHONEN and SYRJÄNEN, 2003) or increasing it (AJODHIA *et al.*, 2004; GIANNAKIS *et al.*, 2005). Besides statistical significance at benchmarking models, the authors converge to the relevance and the use of quality into performance measurement (GOERLICH and RUEHRNOESSL, 2017; ŽAJA *et al.*, 2017; ALTOÉ *et al.*, 2017; AZADEH and MOVAGHAR, 2010; CAMBINI *et al.*, 2014; COELLI *et al.*, 2013; JAMASB *et al.*, 2012; TER-MARTIROSYAN and KWOKA, 2010; XAVIER *et al.*, 2015).

The trade-off between cost and quality materialize, where TSOs make few investments to improve quality above desired level because they won't be reimbursed. Some authors agree that there are some benefits when quality variable is incorporated into performance benchmarking models, not only for adjusting efficiency (ALTOÉ *et al.*, 2017; GIANNAKIS *et al.*, 2005) but to capture marginal gains from consumers, where they desire high quality levels (KEYAERTS and MEEUS, 2017) without willing-to-pay for them (GROWITSCH *et al.*, 2012). Nevertheless, when we look for efficient DMUs, 100% efficiency, even DMUs with low levels of quality would still able to reach the frontier, as found at Giannakis *et al* (2005); Growitsch *et at* (2010); Xavier *et al.* (2015); Yu *et al* (2009a, b, 2007).

Quality in benchmarking can be modelled as an output, where higher values is desirable (AJODHIA *et al.*, 2004; AZADEH and MOVAGHAR, 2010; BANKER *et al.*, 2017; CADENA et al., 2009; GROWITSCH *et al.*, 2012; KORHONEN and SYRJÄNEN, 2003; SILVA, 2015; TANURE *et al.*, 2006; TER-MARTIROSYAN and KWOKA, 2010). Although, quality measurement is based on system outages, relays on DEC and FEC, as an undesirable variable contradicting the presuppose. These assumption must conduct to a minimization effect of undesirable system interruption. Azadeh and Movarghar (2010) and Tanure *et al.*, (2006) solved this concern by developing a technique to transform quality - DEC and FEC - into desirable variables. However, in DEA literature, Bogetoft and Otto (2012); Forsund (2015) and Thanassoulis (2000) highlighted that variable transformations can modify the numerical property of the data, leading to inaccurate and erroneous results of efficiency scores. Other authors implemented other techniques to a better fit at SFA by adjusting costs by quality effect (CADENA *et al.*, 2009; JAMASB *et al.*, 2012; SILVA, 2015).

To build a proxy for quality researchers have been using also different units for DEC and FEC, like adjusting it by number of inhabitants present at the outage area (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 implemented a financial value that reflect system outages. This monetary value measures the opportunity cost for consumers from been deprived from supply energy service. This service unavailability is measured by estimating DEC in hours multiplied by an average hour cost service. This assumption captures the financial impact of the level of quality service on efficiency analyzes (AMUNDSVEEN *et al.*, 2016). The negative assumption of quality as a financial value assumes an objective to be minimized where must be avoided by the TSOs (ALTOÉ *et al.*, 2017; CAMBINI *et al.*, 2014; GROWITSCH *et al.*, 2010; MIGUÉIS *et al.*, 2012; YU *et al.*, 2009b).

Despite of quality proxy, a modeling issue still need a close attention. This extends to how this variable has been implemented or incorporated in benchmarking models. Monetary values as a proxy to bad quality has been used in two ways, as a separate variable used in the model as an undesirable output or as an input, or as been added to them. Both techniques are used inside the benchmarking models. Goerlich *et al* (2017), Growitsch *et al* (2010) and Yu (2009a) proposed to use the fanacial value for quality variable as an input, in which the desirable objective is the reduction. Additionally, other researchers Goerlich *et al* (2017), Altoé *et al.* (2017), Cambini *et al.* (*2*014), Growitsch *et al* (2010 a,b) and Miguéis *et al.* (2012) used at inputs, they adjusted quality into operational costs. Technically, this adjustment occurs by adding the financial value for quality service at the operational cost variable. This effect can have a positive or negative impact by decreasing or increasing the operational cost, respectively. A summary of quality into benchmarking efficiency models can be further seen at ANNEX 1.

It is important to highlight, points out that regulators from Germany, Austria, Denmark, Finland, Holland, Norway, Sweden, Chile, Colombia, Mexico, Panama and Peru also use the quality in some way to evaluate performance as analyzed by Goerlich et al (2017), Altoé et al (2017), Silva (2015), Xavier et al (2015), Cambini et al (2013), Miguéis et al. (2012), Growitsch et al (2009) and Yu et al (2009 a, b). TABLE 1 summarize Mesquita (2017) research and review on performance made by regulators, when quality is incorporated.

TABLE 1- 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

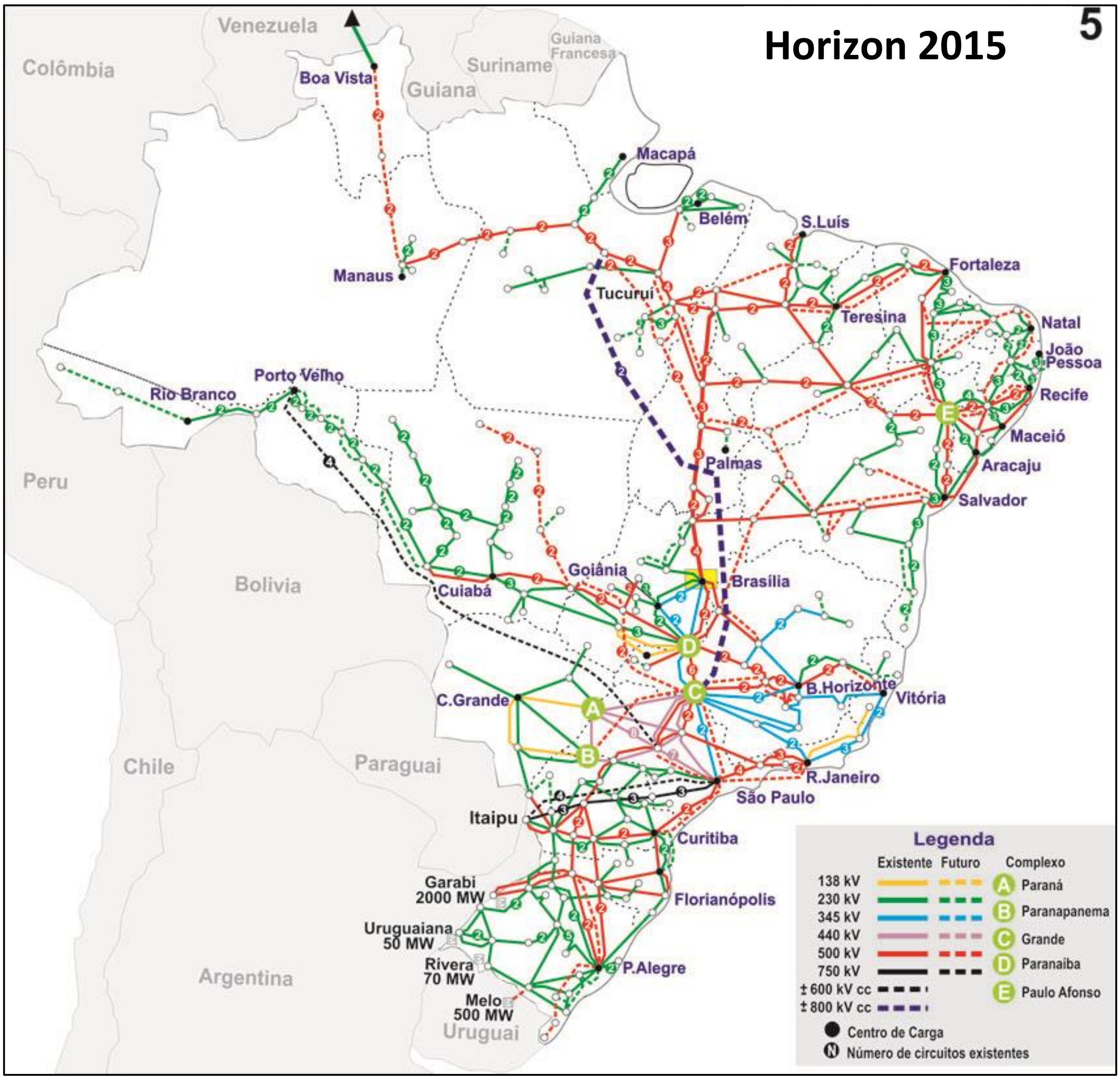
Source: adapted from Mesquita (2017)

Given this quality review, a close look to the Brazilian DEA model is necessary. ANEEL model still not present the appropriate treatment for performance measurement when quality service is incorporated over the cycles of tariff review, even to the proposition for 2017. The next section review what have been done at the Brazilian energy transmission performance modeling.

2.2 Brazilian issues on regulation

Due the dimensions of the Brazilian electric sector, this research will focus only at transmission, which is located between energy generation and distribution. This system can be recognized by network cables supported by transmission towers. In Brazil, the basic transmission network has different voltages levels that can be grouped as 69 to 88 kV, 138 kV, 230 kV, 345 kV, 440 kV to 525 kV, 600 kV to 750 kV (TN 274/2009). The system is operated and coordinated by the National Electric System Operator - ONS which develops studies and actions for managing electric energy stock in order to guarantee the continuous supply throughout national territory (ANEEL 2015).

FIGURE 1 – Brazilian Transmission System Map



Source: Electrical System National Operator

The transmission system is in charge to transport energy from generating to distribution. According to Sato (2013) the Brazilian National Interconnected System (SIN) is responsible for managing and operate the system, in which 98% of the energy supply is transported to consumer centers. what is left is dismissed by geographical conditions and no system interconnection. Among SIN main functions one is to guarantee energy strategic supply for hydroelectric plants operation in order to minimize operational risks. At periods of less rain SIN needs to manage energy flow at adequate levels throughout country, use efficiently the whole electric network for a lower cost to consumers and carry out strategic and operational programming for power generation by its demands. The transmission system operation is supervised by ONS, which is responsible for the execution and management transportation through control of performance, analyzing and evaluating the short and long-term energy demand. FIGURE 1 shows the Brazilian transmission system map where can be seen different network voltage levels. These transmission networks are operated by different TSOs under concessions permission, regulated by ANEEL. Network segment operation bring up features of monopoly, where we have a single provider for many demanders.

De Araújo (2005) justifies a need of regulation by an economic and social market features to reducing negative externalities from natural monopolies, requiring some interventions. Companies, under a regulatory regime are submitted to tariff rules in accordance with costumer’s expectation. This process occurs by stablishing legal regulations and a clarified process where social benefit is pursued. Therefore, regulators have the power to decide how energy market should behavior and proceed. Companies must follow rules and accept the new challenges for costs expenses to be reimbursed (LIZARDO, 2001). ANEEL holds periodic meetings to discuss and debate issues related to regulation, covering cycles of tariff revisions – CTR in order to assure TSOs to have economic balance. In order to formalize meetings, the summary is published through Technical Notes - TN, available physically and electronically for public consultancy.

The economic theory that justifies regulatory intervention is based on market failures, generated by monopoly segments. Based on public interest against losses of welfare or abuse of power through excessive prices, caused by unfair competition among companies, government are able to justify interventions to minimize externalities (MUELLER, 2013). The negative externality arises when individuals carry out consumption of public goods and services in their own benefits. This, excludes others from consuming the same publics goods, by eliminating social marginal consumption benefits from others (RUBINFELD and PINDYCK, 2002).

Generation, transmission, and distribution share some common feature, among market and investments. Energy segment require high amounts capital for investments in infrastructure, which has low marginal productive cost. In addition to monopolistic characteristics, a natural monopoly is set and intensified by the regime of operation concessions, bidding or permission which allow specific region or segment length. Thus, there are a few or no substitutes in market to provide the same scale service at competitive prices due to operation and environment conditions (BOGETOFT and OTTO, 2012). Rubinfeld and Pindyck (2002) believe on the adoption of regulatory policy to reduce or eliminate market inefficiencies generated by monopoly conditions. Regulation by rules and tariffs forces monopolies to approximate to a competitive market, allocating resources in a distributive and productive way that benefits consumers and society (SAINTIVE and CHACUR, 2006).

Even under regulation, uncertainties and informational asymmetry are constantly present where regulators must define how regulatory incentives will stimulate quality improvements by minimizing operational costs. According to Berg and Tschirhart (1988) companies have self-information and details of operation for supply and demand, in which is not fully disposable and shared with the regulator. Companies consider information as strategic to be at market. Jamasb and Pollitt (2000) have shown that tariff regulation, by comparative efficiency techniques can produce effects to encourage companies to cost reduction. Comparative techniques between units or benchmarks allows a relative performance comparison of efficient units. Agrell *et al,.* (2005) assure that the implementation of regulatory models will minimize market failure. These seeks to encourage market competition by efficient process and cost reduction, whose benefits will be passed over to society. The main regulatory models are Cost Recovery, Fixed Price, Franchise Auction and Yardstick Competition (AGRELL and BOGETOFT 2016, 2017; JAMISON *et al.*, 2004).

The Yardstick Competition model, adopted by ANEEL TN 064/2006, allows a simulation comparison in levels, establishing standards assumptions among TSOs. This model allows regulation by comparing and simulating a competitive market dismissing the geography condition and economic welfares. This method induces costs reduction by analyzing performance between firms under the same conditions. Proposed by Shleifer (1985) this method allows companies to compete in different geography location at same virtual market, even under information asymmetry and monopoly regime. The regulator establishes a virtual standard firm and the desirable of performance.

Melo and Neto (2007) also affirm that a tariff regulation method can also secure abuses caused by market concentration at monopoly conditions. Souza (2008); Miranda (2015); Rubinfeld and Pindyck (2002) agree with an application of tariff as an operating subsidy cost reduce negative externality by providing greater economic incentives and social results. A subsidy is conditioned to generate social benefit since entails to support indirect costs reduction and producer direct price system intervention.

The regulation process at Brazilian transmission segment began in 2006 after the public concession contracts. Until then, previous contracts had no clauses regarding readjustment and periodic revision for energy tariffs under concession or bidding regimes. To guarantee the principle of reasonability, the process does allow to transfer part of TSOs efficiency gains to consumers (MELLO, 2008; ASSUNCAO *et al.*, 2015). The tariff review process consists on transferring to society part of benefits from performance improvements, as a consequence of efficiency and quality service. ANEEL through regulatory instruments, transfers part of the past efficiency gains to the society.

Therefore, it is not by only adjusting TSOs reimbursement, but also the allowed revenue. Tariff review process allows a repositioning of monetary adjustment at the Annual Permitted Revenue - RAP. However, by determination of the Court of Auditors of the Federal Government - TCU in 2001 and accepted by ANEEL lately 2007, new contracts must have a periodic tariff revision process to transfer cost efficiency gains to costumer. Every 5 years ANEEL review the efficiency model for cost reimbursement by productivity performance, implemented before 2009 CTR. Although, not only the short come of CTR for cost reimbursement expenses might be sufficient to cover all operating costs, in level of the capital invested (LOPES; LANZER, 2015).

Costs are beyond control of TSOs and are passed as a subsid in a time cycle tariff review. At Brazilian transmission segment is adopted a variant of the price cap system, known as revenue cap or maximum revenue allowed. The regulatory agency allows TSOs to have a maximum revenue, supported by as performance efficiency structure under the yardstick competition method for benchmarking. From 2007 to 2012, ANEEL reimbursed the Brazilian TSOs accordingly the Equation where the Annual Revenue Allowance (RAP) is composed by Annual Cost of Electrical Assets (CAAE), Sector Charges (ENC), Parcel Adjustment (PA) and Administration, Operation and Maintenance Costs (CAOM).

$$\mathrm{RAP} = \mathrm{CAAE} + \mathrm{ENC} + \mathrm{PA} + \mathrm{CAOM} \qquad (1)$$

The CAAE includes costs related to fixed assets of service related to the concession from the transmission, evaluated and depreciated as established by ANEEL criteria, warehouse operations, approved assets as well as special obligations. ENC is composed by taxes duly collected as PIS - Social Integration Program, COFINS - Contribution to Social Security Financing, RGR - Global Revision Reserve, TFSEE - Inspection Fee for Electric Energy Services, R & D - Research and Development. PA results from the application of the adjustment provided for in the contract, used annually. CAOM is the sum of the following components:

$$\mathrm{CAOM} = \mathrm{CA} + \mathrm{CAIM} + \mathrm{COM} \qquad (2)$$

CAOM is determined by Administrative Costs (CA) composed of personnel costs, materials, and services associated only to the administrative area, including insurance and tax expenses. Annual Cost of Mobile Facilities and Properties (CAIM) contain the infrastructure of offices and transport necessary to support transmission services such properties, furniture and equipment, computer systems and transport (as vehicles of maintenance). Regarding the focus of this work, COM covers the sum of operating and maintenance costs, added to personnel costs, materials and services associated with processes, operational and maintenance activities. Specifically, the cost of operation and maintenance is adjusted by an introduction of the Efficiency Coefficient (CE). At the Brazilian model, this CE is determined by DEA measurement, which, through benchmarking, provides relative efficiency score between analyzed units. Hence, operating cost and maintenance formula is formed from:

$$\mathrm{COM} = \mathrm{COM} * \mathrm{CE} \qquad (3)$$

TSOs who obtain the highest productive efficiency score will receive high values of reimbursement, while keeping costs constant, higher is CE more COM TSOs will receive. The financial equilibrium supported by a tariff review also should cover legislation tasks imposed by the regulator, where is expected implement investments on infrastructure, projects, requirements and procedures. Therefore, network length, management, operation and maintenance procedures to support the main services must be adequately sized by TSO. This should include physical availability of process and activities, maintain physical operational capacity available anytime to support constant energy supply. When processes do not meet operational requirements, low efficiency will punish cost reimbursement, causing revenue losses (TN 371/2008). Is important to highlight that in Brazilian transmission service is associated by disposability of physical facilities at power capacity. The RAP is not conditioned directly to productivity as a volume or flow of energy at transmission, but to the operational and maintenance availability to support the demand (TN 257/2007).

2.3 Quality at the Brazilian DEA model

ANEEL in 2006, through TN 064/2006, proposed an adoption of a Stochastic Frontier Analysis - SFA as a model to estimate TSOs efficiency scores. The model requires deterministic and parametric frontier assumptions to measure an efficiency average score. Some concerns on this measure approach are the econometric assumptions of non-significant deviation among TSOs and a definition of a functional form for costs. Also, this can conduct to present bias at efficiency scores and a possibility of heterogeneity from omitted variables. These concerns were analyzed on the public hearing of 2007. Thus, published by ANEEL in NT 06/2006, the SFA method has never been used to measure performance, in which, Data Envelopment Analysis - DEA was the method chosen because of it features. The DEA measurement approach begun at the first cycle of tariff review – 1CTR in 2007, published through technical note no. 182/2007 to analyze operational cost efficiency over 2005 to 2008. At time, quality was not a concern to be inserted at DEA model for operational cost efficiency measurement.

2.3.1 – Second Cycle of Tariff Review – 2CTR

The second cycle of periodic tariff review – 2CTR succeeded in 2009. Tariff review took over an operational analyzes of 2009 to 2012, following a chronological order after 1CRT. Data were used in panel to increases the number of units at analysis, supporting 55 decision making units – DMUs over 2002 to 2008. The DMUS described the TSOs CEEE, CEMIG, CHESF, COPEL, CTEEP, ELETRONORTE, ELETROSUL, FURNAS operations. At time, ANEEL didn’t used COPEL data from 2008 because of a corporative financial split. Data can be found at the Technical Note - TN of 274/2009 and 396/2009.

For modeling the efficiency approach, ANEEL used a two stages procedure. At first stage, DEA model was measured assuming Non-Decreasing Returns of Scale – NDRS. They justify by assuming that large TSOs can´t be reduced to be compared to small TSOs, but small TSOs can be compared to large TSOs. In addition, weight restriction is used to set a brand for variables to make data more homogeneous. At second stage, a Tobit Regression was used to adjust DEA score efficiency by environmental variables that effect indirectly the operational efficiency. At the 2CTR, quality measurement was introduced as an operational indirect effect at energy transmission segment.

At first stage procedures, DEA Brazilian model used as input a variable of operational and maintenance expenses - OPEX. The proxy OPEX is composed by the sum of financial costs of Personnel, Materials, Third Party Services, Insurance, Taxes and Others assigned to operation and maintenance cost. For outputs, the variables that portray transmission operational services were Network Length, Modules Units and Equipment Modules. Modular Units is composed by the sum of Inputs Line - EL, Connection of Transformers - CT and Interconnection Busbar - IB. Modules of Equipment consists of the number of Transformers and Power Capacity in MVA (mega/volt/ampere). At second stage, environmental variables, quality service and transformation capacity were the main variables. Environment Variable is composed by an Average Salary by operational region, Network dispersion and covered area. Quality service was measure by DEC.

Quality measurement at transmission segment was first introduced in the 2CTR. ANEEL inserted a proxy based on DEC which stand for the sum of hours – duration - of system outages. This proxy captures interruptions and disconnection of transmission system viability. This information was first requested to TSOs by letter 234/2009 - SER/ANEEL (TN 274/2009). An addition information for quality assumptions, ANEEL had classified interruptions on manageable events and unmanageable events. DEA Quality proxy assumed only DEC based on outages classified from events that were manageable by TSOs that could be avoided.

2.3.2 – Concessions renewal of 2012

On September 11 of 2012 Brazilian Government published a law permitted new arrangements for renewal of public concessions services at energy segment, composed by generation, transmission and distribution of electricity. Published at MP 576/2012, the law allowed new sets for tariff affordability and charges rates by enforcing new policy by new contract. The renewal in 2012 is an anticipation on concessions contract for public services that would expired in 2015.

Tariff review analyzed the period of 2012 to 2016, following the time line set by the end of 2CTR. Data were also used in panel approach, supporting 40 DMUs over 2007 to 2011. The DMUS described the TSOs CEEE, CEMIG, CHESF, COPEL, CTEEP, ELETRONORTE, ELETROSUL, FURNAS and CELG operations. An attention is need to CELG, in which, ANEEL excluded from efficiency analysis by considering the small operational size as an outlier. This data and approach can also be verified at TN 383/2012.

For modeling, ANEEL used a two procedure. First, DEA model was measured assuming Non-Decreasing Returns of Scale – NDRS and Constant Returns of Scale - CRS. Weight restriction was also used to set a brand at variables relation to make data more homogeneous. Second, instead of a Tobit Regression, ANEEL adopted an average mean approach to adjust the score efficiency measured by DEA. This procedure normalized the score efficiency, conducting TSOs to have a score homogeneity, in which, scores were level up.

Do to the variables, ANEEL used the same OPEX proxy assumptions as an input in 2CTR. For outputs, the model presented some changes for Network Length. Beside a unique value, Network Length was segmented in the sum of power capacity ranges from 69 to 88 kV, 138 kV, 230 kV, 345 kV, 440 kV to 525 kV, 600 kV to 765 kV. The model used did not presented any change for Modules Units and Equipment Modules. Although, for quality procedures a closer view should be check.

As a secondary process of DEA measurement, quality was used in a way of normalize efficiency score. ANEEL changed metric and method assumption used at 2CTR, adopting a ratio of a Parcel Variable divided by RAP. Parcel Variable - PV stands for an outage price of non-system disposability for transmission operational service measure by formula presented at Technical Note 729/2016:

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

PB - stand for payments at transmission, NRL – Number of operation long restrictions, ROL – Proportional reduction of long interruption at operational capacity, DROL – Long Duration system outage, NRC - Number of operation short restrictions, ROC - Proportional reduction of short interruption at operational capacity, DROC - short Duration system outage and D – number of day of outages.

Parcel Variable - PV is comprehended by number of hours of service interruption multiplied by the payments at transmission segment, a financial value for system outages. This is a monetary value stand for losses of efficiency and is subtracted from RAP as a punishment for transmission service facilities unavailability. Brazilian TSOs are reimbursed based on system disposability, where they must maintains transmission power capacity and facilities always disposable for ONS demand. To PV proxy, the ratio was built by information of outages from each year and divided as follow 2009/2010, 2010/2011 and 2011/2012. Then an average mean over years for PV ratios were divided into 5 groups with similarly values– see TABLE 2.

The efficiency score measured at DEA-CRS and DEA-NDRS were normalize in accordance with PV average group, where the highest quality average would receive the maximum of quality adjustment. The first group received a maximum quality value, been considered as best quality service provider. To others, quality adjustment was scaled decreasing by 10% from the highest score given to the first group. The value of adjustment was the geometric mean of DEA-CRS and DEA-NDRS to add to the score efficiency. Although, this adjustment had been equally done to all TSOs, as ELETROSUL and CTEEP had the adjustment at DEA-NDRS and other to DEA-CRS. ANEEL assumed that ELETROSUL and CTEEP didn’t have economy of scope by operating at generation and transmission.

Quality adjustment process after DEA score measurement allowed TSOs to almost reach the efficiency frontier as ELETROSUL 95.9% and CEMIG 90.5% presenting DEA score of 46.9%

and 61.5%. Also, CTEEP had an over gratification for quality service, reaching 135% of efficiency.

2.3.3 – Propositions for Third Cycle of tariff review – 3CTR

The latest proposed model by ANEEL for tariff review is in 2017, in which will be for the 3CTR. Tariff review cover period of 2017 to 2022, following the time line set by Concessions Renewal. Data is overdo 2013 to 2016 set in panel approach, supporting 97 DMUs. This amount of DMUs takes place on ANEEL assumptions on corporative composition on TSOs and biddings TSOs. Now, ANEEL interprets that operational and maintenance costs from concessions TSOs are to be shared with costs from the controller holding company. Addicted to CEEE, CEMIG, CHESF, COPEL, CTEEP, ELETRONORTE, ELETROSUL, FURNAS, CELG an inclusion of the controllers group and biddings firms as ALUPAR_h, CEEE_h, CELEO_h, CEMIG-GT_h, CHESF_h, COPEL-GT_h, CTEEP_h, ELETRONORTE_h, ELETROSUL_h, FURNAS_h, STATE GRID_h, TAESA_h where consider. Also, CELG didn´t have been consider as an outlier because of the operational size.

To the 3CTR proposed model, ANEEL used a two procedure for efficiency measurement. First, DEA model was measured assuming Non-Decreasing Returns of Scale – NDRS. Weight restriction was also used to set a brand at variables relation to make data more homogeneous. Second, a third percentile for normalization was used,

This tariff composition was used until the renewal of concessions in 2012 (MP 579/2012, transformed in law 12.783/2013) was published with a different interpretation. So far, these assumptions still valid to the last proposed CTR in 2017- third cycle review – 3CTR that will use data from 2013/2016.

The proposed model for 3CTR must be checked with a further attention. Only Modules of Equipment had been changed in 3CTR, where the tree-phase equipment had been transformed in single-phase, dividing tree-phases by tree.

The latest proposed model to 3CTR at TN 160/2017 and TN 164/2017, ANEEL suggest a quality proxy for transmission service, based on DEC different from what was in 2CTR and

2012 Concession Renewal. Although, to 3CTR proposed quality proxy will be constructed by the sum of interruptions in power capacity - IPC. This new metric is composed by sum of outages hours in each transmission level of power capacity. To reduce volatility over service outages annually, the model had received an average mean of IPC during period of analyzes from 2013 to 2016. Also, ANEEL had made a mistake on inserting quality negative effect as positive on TN 160/2017, where later had corrected to negative impact at TN 164/2017. If the mistake purse, quality would be inserted and interpreted as a positive effect, where a maximization of quality interruptions at transmission service would be desirable, contradicting the variable purpose and concerns for performance evaluation.

At last, but not less important, ANEEL used weight restriction techniques to seek a homogeneous analysis between TSOS at performance variables. At 2CTR, network length was segmented by power capacity to a ratio related to 230kv. 230kv power capacity was chosen because all TSO had some kilometers length to operate in equal regulatory conditions. DEA model received weights between variables of inputs and outputs to adjust network length, where none of TSOs would be 100% efficiency by only operating one power capacity length. Regarding this technique at the proposed model of 2017 3CTR, the regulator weighted through other variables, as sum of higher length then 230kV divided by OPEX, sum of lower length then 230kV divided by higher length then 230kV, Power Capacity divided by OPEX, Modular of Voltage Network divided by OPEX and Modular of Voltage Network divided by Module of equipment’s. At 1CTR and the Concession Renewal none of weighting treatment were used. ANEEL transmission models of 1CTR, 2CTR, 2012 Concession Renewal and 3CTR are summarized in ANNEX 2 and weight restriction index can be seen in ANNEX 3.

TABLE 2 – 2012 Renewal of concession – Quality incorporation process by ANEEL

	DEA Score		Loss of Revenue by it Unavailability / Total Revenue							Operational Costs for TSOs at 2012		
Company	IRS	CRS	2009-2010	2010-2011	2011-2012	Mean	Group	Quality Adjustment	Final Efficiency'	Operational Costs (R$)	Participation of Listed Assets***	Adjusted Operational Costs (R$)"
ELETROSUL	47,0%	46,9%	0,14%	0,01%	0,01%	0,05%	1	49%	95,9%**	395.932.791	4,25%	379.114.265
CTEEP	96,0%	96,0%	-0,11%	-0,21%	0,09%	-0,08%	2	39%	135%**	342.706.037	0,20%	342.013.504
COPEL	83,0%	45,5%	-0,14%	-0,09%	-0,12%	-0,11%	2	39%	84,5%*	126.133.420	2,48%	123.006.211
CEMIG	96,0%	61,5%	-0,24%	-0,18%	-0,55%	-0,32%	3	29%	90,5%*	149.644.956	1,77%	146.993.313
CEEE	76,0%	58,3%	-0,65%	-0,23%	-0,72%	-0,53%	4	19%	77,3%*	206.309.759	0,60%	205.072.746
ELETRONORTE	33,0%	26,7%	-1,04%	-0,40%	-0,50%	-0,65%	4	19%	45,7%*	556.729.100	2,78%	541.276.679
CHESF	37,0%	36,7%	-0,46%	-0,61%	-1,26%	-0,78%	4	19%	55,7%*	840.718.572	0,95%	832.733.546
FURNAS	39,0%	39,3%	-1,41%	-1,15%	-1,35%	-1,31%	5	10%	49,3%*	1.166.195.863	1,86%	1.144.478.739
Geometric mean	58,1%	49,0%										

'Final Efficiency = DEA Score + Quality Ajustment

"Adjusted Operational Costs = (1 - Participation of Listed Assets) * Operational Cost

* CRSscore + Quality Ajustment

** IRSscore + Quality Ajustment

***Participation of Listed Assets = Not Listed Assets Costs / Operational Costs

Source: ANEEL TN 383/2012

2.4 DEA Benchmark methodology

Data Envelopment Analysis – DEA was developed by Edward Rhodes under the supervision of William Cooper in a research of performance comparison at U.S. publics schools' during Rhodes dissertation. The research challenge was to measure relative technical efficiency by adding multiple inputs and outputs without inserting price information. This task was solved and published by Charnes; Cooper; Rhodes, (1978) common known as Constant Return of Scale model – CRS - CCR. CCR is based on mathematical programing by generalizing Farrel (1957) technical-efficiency method of single input/output (CHARNES et al., 2013). These first standard models assume free disposability and convexity for any production form of inputs and outputs (BOGETOFT, 2012).

After developing CCR model in 1978, Banker; Charnes; Cooper (1984) - BCC expanded the method to not only analyze constant return to Variable Returns to Scale - VRS. This new process allows assumptions for increasing inputs in different rates of producing outputs. Not only, at CCR or at BCC, input or output orientation must be chosen as a technology scale assumption process to set the model optimization emphasizes (BOGETOFT, 2012; CHARNES *et al.,* 2013). Technology assumption can assume different productive forms from constant, increasing and decreasing returns of scale according to an economic theory behind. A negligence on the technology theoretical modeling for scale or productivity return by the orientation method can lead to imprecise performance results, data noise and outlier observation (SAASTAMOINEN *et al.,* 2017).

The concept of efficiency developed by Farrel (1957) deduced a ratio coefficient between 0 and 1 or 0% and 100% by comparing a single output and input. A score value next or equal 0 present low efficiency and close or equal to 1 indicates the maximum efficiency (RAY *et al.,* 2015). The ratio measure relative efficiency by Decision Making Units – DMU thorough the comparison of virtual transformation at multiple outputs/inputs. The technical efficiency is set by Pareto assumptions, in which, the ratio is formed by a weighted sum of outputs divided by a weighted sum of inputs, where both weight multiplies outputs and inputs respectively (CHARNES *et al.,* 2013).

According to Charnes *et al.*, (2013) both models CRS and VRS reflects the best possible practices for a benchmarking frontier by individual DMU optimization analyzes. Compared to parametric models and others, DEA is set as non-parametric which has further advantages as,

a) Focus on the observed individual comparing with the population;

b) Measurement of each DMU assigning a ratio for inputs and outputs;

c) It simultaneously uses multiple inputs and multiple products;

d) Can be adjusted for exogenous variables;

e) Can incorporate categorical Dummy variables;

f) Doesn't require specifications or a priori knowledge of weights or prices for inputs and outputs;

g) it´s not necessary to determine the functional form or production function;

h) Adjustments can be made if necessary;

i) Produces specific estimative for input and output changes for DMU projected at the lower level of the efficiency frontier;

j) It´s a Pareto Efficiency

k) Reveals the best practice on the efficiency frontier than mean statistical methods

l) Meets fair criteria for each DMU individually

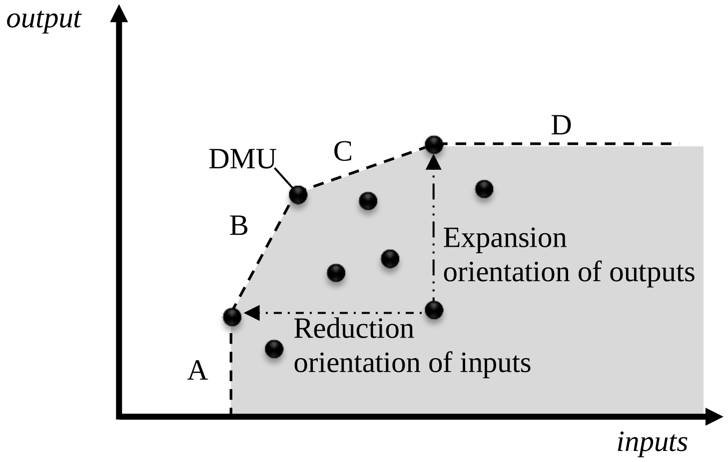
DEA in both models, CRS or VRS assumes that there are *n* DMUs to be evaluated. Each DMU consumes different quantities of inputs to produce different quantity of outputs given a set of technology process. It consumes different $X_j = \{x_{ij}\}$ of inputs (i = 1, ... , m) and produces $Y_j = \{y_{rj}\}$ of outputs (r = 1, ... , m). For each constant x_{ij} and y_{rj} we assume they are greater than zero. To measure performance index, production in a manner of optimization - maximization or minimization, specific weights v_i e u_r are inserted to input i and output r. The score coefficients still at interval of 0 and 1. The efficiency is measured by each DMU under analyze in a function R_0 that must be optimize, subject to constraints. Efficiency will be measured by a radial projection from the DMU to the frontier. As an example, VRS model assumes an input orientation and is written as EQUATION 4.

Therefore, always, at least one DMU will be efficient, with 100% efficiency in best capacity of transformation input into outputs. The frontier is built with at least a DMUs of 100% efficiency Ray et al (2015) and can be represented in a geometric space as seen in FIGURE 2 (PESSANHA *et al.*, 2010).

EQUATIONS 4: VRS input oriented

Formulation of **Multipliers**	Formulation of **Envelopment**
$\Phi = \text{Max} \sum_{i=1}^{m} u_i\, y_{j0} + u_0$ Subject to, $-\sum_{i=1}^{s} v_i\, x_{i,j0} + \sum_{i=1}^{m} u_i\, y_{i,j0} + u_0 \le 0$ $\sum_{i=1}^{s} v_i\, x_{i,j0} = 1$ $u_i \ge 0 \quad \forall_i = 1, m$ $v_i \ge 0 \quad \forall_i = 1, s$	$\theta^* = \text{Min}\ \theta$ Subject to, $\sum_{j=1}^{n} \lambda_j X_{ij} \le \theta X_{i0} \quad i = 1, 2, \dots, m$ $\sum_{j=1}^{n} \lambda_j Y_{rj} \ge Y_{r0} \quad r = 1, 2, \dots, s$ $\sum_{j=1}^{n} \lambda_j = 1$ $\lambda_j \ge 0 \quad \forall_j = 1, \dots, n$
m+s restrictions n+1 variables	m+s restrictions n+1 variables

FIGURE 2 – DEA-VRS: Efficient Frontier with Model Orientation



Source: adapted from Bogetoft; Otto, (2012) e Charnes *et al.*, (2013)

VRS model consider variable returns of scale by a convex combination of inputs and output, where in FIGURE 2 is presented in gray. Variable returns are a property of convex combination of boundaries, which can present different sets for technology, seen at FIGURE 2 by segments at the frontier by the change of angles at A, B, C, and D. The frontier boundaries can present constant, increasing and decreasing returns of scale (BOGETOFT and OTTO, 2012; RAY *et al.*, 2015). Although, an attention is need for some impossible convex combination under some technology assumptions. This implies of not any weighted combination of inputs and outputs can be produced by the technology process and can be represented in production plan.

Efficiency definition used by DEA is based on concept of the total engineering productivity factor, which uses the sum of weighted ratio from outputs divided by the sum of weights at inputs. Linear programming allocates weighted factor value in other to maximizes or minimize the performance index for each analyzed DMU (ALLEN *et al.*, 1997). The incorporation of weights limits procedures can limit a variable boundary in inputs or outputs. At literature this technique is known as weight restriction procedures (PODINOVSKI, V V, 1999). In CRS model, weights allow greater flexibility, whose allocation is done by linear programming. In the VRS model, besides the possibility self-weight allocation, it is possible to limit variables boundaries according to an analyst's choice (CHARNES *et al.*, 1978). This weight incorporation can be classified into three categories: Assurance regions of type I, Assurance regions of type II, Absolute weights restrictions (ALLEN *et al.*, 1997; THOMPSON *et al.*, 1990).

Assurance region type I, limits boundary variation to a certain region by a cone ratio method, where present values related to transformation of inputs and outputs. In Assurance region type II, the impact ratio between inputs and outputs is estimated by an average mean of a combination rather than individual analysis of boundary variables. Similarly, in both, type I and type II depends on scale that are been assumed. Absolute weights restrictions are introduced to prevent input and output variables from being ignored or too important for performance analyzes. In type I the restriction value must be based on economic concept from substitution marginal rates structured in price and cost. However, type II weight restriction does not have much attention in the literature, but market issues have been used to define restrictive limits (ALLEN *et al.*, 1997; THOMPSON *et al.*, 1990).

At this point, after a literature review on Quality Variables, Brazilian Regulation, Brazilian Model and DEA Method, next chapter will present the research methodology process. The methodology will follow academic base according to the literature review appointments.

3 METHODOLOGY

In this section, it will be presented the scientific method to accomplish goals of this research study. Intended to clarify which is the appropriate technique for inserting quality variables at benchmarking frontier-based models. To reach this purpose will be analyzed the Brazilian Transmission Service Operators, in which have their operational cost reimbursement decided by the efficiency score measured by a DEA model. This study verified concerns that surround theory and literature suggestions from national and international studies around the inclusion of quality of service in the TSOs benchmarking model.

3.1 Research Characteristics

This is a quantitative and exploratory research to verify how quality variables have been adopted at benchmark frontier models. This process permeates a quantitative analysis based on secondary data collected directly from the Brazilian electricity sector regulator, ANEEL. The TSO inform data to ANEEL annually, for annual cost reimbursement adjustment trough the electric tariff review. Even under information asymmetry, the regulator believes that data is reliable and concise. Thus, data was collected from ANEEL website published at TN 164/2017 during the 3CTR. Data did not have any change or adjustment by this research study.

Bono and Mcnamara (2011) state that quantitative studies are valuable because of the strong theoretical constructs and quantifiable object for analysis. These models are constructed and specified for simulation and control, measuring the impact and behavior separately between models through independent and dependent variables. By this process, is possible to portray a reality analyze and comprehend the effects. Although is emphasizes that only theory and quantitative models are not enough affirm empirically the reality of logical facts. Yin (1994) augmented case of studies is an adequate strategy to answer the proposed question.

Voss; Tsikriktsis; Frohlich (2002) define how to conduct and procedure an exploratory study in management, by setting literature and methodology. This are the base for constructs and research objective. These processes are presented and discussed in accordance of the literature review.

3.2 Data collection

Zhang and Shaw (2012) address a need to report in detail the collection of data for complete, credible and clear work. Data are available and were collected on the ANEEL website http://www.aneel.gov.br through TN 164/2017. This is an official data document from the regulatory agency that describes the proposed model for the 2018-2022 cycle of energy transmission sector cost reimbursement.

The data are available in separate tables, where data is presented for each TSO annually. ANEEL expects the chosen variables to be reliable and representative, with a strong correlation to energy transmission services reflective of the production system. The Data used by ANEEL for building the costs benchmarking proposal for the third cycle of tariff review (TN 160 and 164/2017) is available in a panel, as each TSO has a numerical value arranged in chronological order for inputs and outputs. The panel data refer to operational processes from 2013 to 2016 and is referred to as 97 DMUS (TN 160/2017). However, regarding the aforementioned holding information, not all holding considerations were available from the Brazilian regulator for the proposition of 3 CTR in 2017.

For a holding configuration as an example of TSO, ELETRONORTE is formed by Amazonia Eletronorte Transmissora de Energia S/A - AETE, Brasnorte Transmissora de Energia S/A – BRASNORTE, Centrais Elétricas do Norte do Brasil – ELETRONORTE, Integração Transmissora de Energia S/A – INTESA, Linha Verde Transmissora S/A – LVTE and Transmissora Matogrossence de Energia S/A – TME. This research will consider the same 8 TSO analyzed in the 2CTR and Concession Renewal in 2012 as CEEE, CEMIG, CHESF, COPEL, CTEEP, ELETRONORTE, ELETROSUL, FURNAS for a homogeneous analysis over cycles of tariff review. This conduce to 32 DMUs in a panel data where does not present any missing value. The same process is supported and used by TSOs on the contributions made for ANEEL's proposed model for 3CTR in 2017. In addition, holding data configuration is unavailable at TN 160/2017 and TN 164/2017, making impossible to allocate adequacy the proposed quality variable - PV at this research.

Panel data has two dimensions, spatial and temporal. Spatial is composed of the cross section, in which data were collected for one or several units of samples in same period of time. The temporal approach allows to monitor units in a time dimension, in which, the data of TSOs are analyzed over the years (GUJARATI and PORTER, 2011). To better use the panel data technique, panel must be balanced, where will have the same number of information for all DMUs and for all variables from year to year allowing the application static tests if necessary (BARNUM; GLEASON, 2008; GROWITSCH; JAMASB; WETZEL, 2012; KUOSMANEN, 2012; KUOSMANEN; KORTELAINEN, 2012; SAASTAMOINEN; BJORNDAL; BJORNDAL, 2016). The disposed data for the 3CTR does not present any missing value, conducting to a balance panel data analyzes.

3.2.1 Modeling variables description

Forsund and Kittelsen (1998) highlighted the importance of selecting variables assertively in order to avoid inconsistent performance score results. According to Bogetoft and Otto (2012) and Jamasb and Pollitt (2001) recommendation, the minimum number of DMUs required for a consistent DEA measurement is to be greater than or equal to three times the sum of input and output variables. Accordingly, ANEEL uses 7 variables - input: OPEX adjusted by the wage of each region; outputs: network length (km) with tension level lower than 230kV, network length (km) with tension level higher or equal to 230kV, number of equipment modules, power capacity, number of modular units, and a quality variable. This research will use the same data for inputs. As for outputs, only the variable used for measuring quality will be changed.

The latest proposed for 3CTR, ANEEL suggested a different quality proxy for transmission service from 2CTR and 2012 Concession Renewal, based on DEC. It was proposed quality proxy constructed by the sum of interruptions by each power capacity level - IPC. To reduce volatility over service outages annually, the model had received an average mean of IPC during period of analyzes from 2013 to 2016. Also, ANEEL had made a mistake on inserting quality negative effect as positive on TN 160/2017, where later had corrected to negative impact at TN 164/2017. If the mistake purse, quality would be inserted and interpreted as a positive effect, where a maximization of quality interruptions at transmission service would be desirable, contradicting the variable purpose and concerns for performance evaluation. In addition, ANEEL assumes same operational cost for system outage in different transmission power capacity, where in a year, 6 minutes or 0,1 hours at 6000MW in Itaipu is equal to 10 hours of

60MVA Cteep, leading to a 600 MVA/H power interruption. These extend the operational cost, where is equivalent to assume that interruptions cost is the same for both TSO (AEA 2017).

In contrast, as a review of the literature shows, recent studies use a monetary value to capture the effects of service quality on cost efficiency. This monetary value is based on DEC and a monetary value for cost of outages. The proxy is composed by the sum of hours of interruption (DEC) multiplied by a cost of system unviability, used by Austria, Finland, Norway and Germany regulator (MESQUITA, 2017) and analyzed at Goerlich *et al* (2017), Altoé *et al* (2017), Silva (2015), Xavier *et al* (2015), Cambini *et al* (2013), Miguéis *et al* (2012) Growitsch *et al* (2009) and Yu *et al* (2009 a,b). This research study proposes the adoption of the Parcel Variable - PV as a proxy for the quality measurement into the benchmarking performance analysis. Parcel Variable is a monetary value established as a penalty for the lack of availability of system facilities for energy transmission service. In accordance with the literature, quality measurements must be adopted as part of optimization procedures, inside DEA model (ALTOÉ *et al.*, 2017; AZADEH; MOVAGHAR, 2010; CAMBINI; CROCE; FUMAGALLI, 2014; COELLI, TIM J *et al.*, 2013; JAMASB; OREA; POLLITT, 2012; TER-MARTIROSYAN; KWOKA, 2010; XAVIER *et al.*, 2015), where all DMUs will receive the same homogeneous treatment at linear programing weighting process (BOGETOFT and OTTO, 2012; CHARNES *et al.*, 2013). Based on literature, this study will insert quality inside DEA measurement procedures.

The literature shows that monetary value has been used to analyze operational performance of transmission and distribution (ALTOÉ *et al.*, 2017; CAMBINI *et al* 2014; GROWITSCH *et al.*, 2010; MIGUÉIS *et al.*, 2012; YU *et al.*, 2009b). Interruption of the transmission system has a negative impact on customer perception of service quality. This perception is based on service being unavailable during a power outage. The proxy needs to be flexible enough to accept a negative effect for a monetary value as punishment for TSOs as well as a positive effect if TSOs perform inside the boundaries permitted for interruptions. Thus, the maximization of the quality service will be always desirable (AJODHIA *et al.*, 2004; AZADEH *et al.*, 2010; CADENA et al., 2009; GROWITSCH *et al.*, 2012; KORHONEN and SYRJÄNEN, 2003; SILVA, 2015; TANURE *et al.*, 2006; TER-MARTIROSYAN and KWOKA, 2010). This positive effect can be a way to incentivize TSOs for quality improvements, in alignment with the recommendation of Joskow (2014) and Langset *et al.* (2001). At the time of this research study, none of the TSOs performed inside the permitted boundaries for interruptions, which means the Parcel Variable for quality would be used with a negative effect for all DMUs.

In addition, this research won´t use and analyze DEA procedures for adjusting scores on second stage or any normalization as happened over CTR. Addicted to not been focus of this research, literature review points out that second stage after DEA measurement might not be precise. This lead to low precision at efficiency score, with possibility to present bias at estimation and low power of explanation (BARNUM and GLEASON, 2008; BARNUM and GLEASON; HEMILY, 2008; COELLI *et al.*, 2005; GROSSKOPF, 1996).

3.3 DEA model

For DEA application, this research had used the same modeling procedures for inputs and outputs variables as the Brazilian regulator used to purpose 2017 3CTR. By this assumption, DEA modeling assumes an input orientation, where inputs will be minimized. Also, the non-decreasing returns of scale – NDRS was used. In addition to main modeling sets, the same weight restrictions will be used as ANEEL purpose for 3CTR and is presented at ANNEX 3.

Agrell and Bogetoft (2016), Haney and Pollitt (2009) and Jamasb and Pollitt (2000) had verify different quantitative methodologies and variables for measuring performance index at electric energy sector, where regulators from Brazil, Colombia, Finland, France, Germany, the Netherlands, Italy, Norway, Spain, England, the United States and Iran were analyzed. Still not been defined which methodology is better, but DEA has an overall acceptance over regulators. Related to the analyzed variables, that seek to best represent the productivity at Brazilian transmission service, for input will be used OPEX. As in Brazil, countries like Belgium, Estonia, Iceland, Ecuador, Australia also use OPEX as inputs. There are other countries that apply TOTEX at Finland, England, Holland, Norway, Ireland, Netherlands, Portugal, Peru and Guatemala (HANEY and POLLITT, 2009, 2013). Giannakis *et al* (2005) presented OPEX variable for operational and maintenance costs as a reflection of controllable costs by TSOs and it can be manageable, an interpretation aligned to ANEEL. Related to the analyzed variables, that seek to best represent the productivity at Brazilian transmission service, for input will be used OPEX in this research study. As in Brazil, countries like Belgium, Estonia, Iceland, Ecuador, Australia also use OPEX as inputs (HANEY and POLLITT, 2009, 2013).

For outputs, this study will seek for Network Length into two separate variables as did the Brazilian regulator, network length(km) with tension level lower 230kV, network length(km) with tension level higher and equal than 230kV. By this segregation, is possible to analyze effects at operational costs in each layer separately and his contribution for efficiency.

For the quality variable, some concerns remain on modeling sets. In the literature, quality can be interpreted as an undesirable variable when it is based on DEC. Under normal DEA assumptions, quality is treated as an output and maximization is desirable. This can lead to an error in which maximization produces an undesirable outcome in which higher levels of system outages is incentivized. In order to properly respond, quality must instead be considered as an uncontrolled variable that must be minimized if is based on DEC, where must be inserted at inputs on DEA. Although, some techniques for transformation also can be found as multiplying uncontrolled variables at output by "-1X+k" where *k* is a positive vector to be add (SEIFORD; ZHU, 2002) or use the inverse of undesirable output "1/(1-X)" (CHENG; ZERVOPOULOS; QIAN, 2013). However, an undesirable based on DEC and uncontrolled affect variable can be used at input when it does not require any transformation. Thus, the quality variable in this research, will be used as input, where a decrease in energy outages is desirable in terms of quality improvements as been used in the literature (GOERLICH and RUEHRNOESSL, 2017; ALTOÉ *et al.*, 2017; AROCENA, 2008; CAMBINI *et al.*, 2014; COELLI *et al.*, 2008; COELLI *et al.*, 2013; GIANNAKIS *et al.*, 2005; GROWITSCH *et al.*, 2010; MIGUÉIS *et al.*, 2012; TER-MARTIROSYAN and KWOKA, 2010; XAVIER *et al.*, 2015; YU *et al.*, 2009a, b, 2007).

To analyze what ANEEL has done, MODEL 1 will have all the assumptions of the 3CTR in the 2017 proposed model. To make MODEL 1 comparable, a reduction of 97 DMUs to 32 DMUs will be done because of the unavailability of holding information for PV. It is important to remember that MODEL 1 will receive the ANEEL proxy of quality as the sum of interruptions in each power capacity level - IPC. Also, the quality variable is inserted as an output with a negative sign and will treat as a non-controlled variable.

MODEL 2 will treat quality as an undesirable variable, where the financial value of the Parcel Variable - PV will be used as an input, in which will treat as a non-controlled variable. This is the same quality proxy used in the literature by DEC, with an affect that must be minimized.

By this assumption, the quality proxy PV can receive weights. In terms of score contribution, is possible to analyze the PV effect independently from other variables.

MODEL 3 will be the research-proposed model in accordance with the literature. The quality proxy will be measured by PV added to the OPEX(OPEX_adjusted). This implementation technique represents a direct impact on the operational cost.

To analyze the efficiency score produced by MODEL 1, MODEL 2 and MODEL 3 in a statistical interpretation, this research will use the methodology proposed by Banker *et* al (1984), the F test. This test measures the statistical average mean variance between samples. This test should indicate the best statistical model by the smallest deviation in the estimative assuming normal distribution. Also, Wilcoxon signed rank test will be used to test non-parametric relation between average (CHERCHYE *et al.*, 2008). In both model, we assume Hypotheses 0 - H0 will stand for an equal average mean between the analyzed models. H1 will show different average means between the models. Results from DEA MODEL 1, MODEL 2 and MODEL 3 will be shown in the next section. The model adopted in this research are summarizes in TABLE 3. Next section, will be discussed the results found with their technical and theoretical implications.

TABLE 3 – DEA research models

	Input	Output
MODEL_1_DEA_NDRS	- Opex ($)	- Network Length ≤ 230kV - Network Length > 230kV - Number of Module (un) - Number of Equipments (un) - Power Capacity of Transformation (MVA) - Interruption Power Capacity (MVAxH)
MODEL_2_DEA_NDRS	- Opex ($) - Parcel Variable ($)	- Network Length ≤ 230kV - Network Length > 230kV - Number of Module (un) - Number of Equipments (un) - Power Capacity of Transformation (MVA)
MODEL_3_DEA_NDRS	- Opex_Ajusted ($)	- Network Length ≤ 230kV - Network Length > 230kV - Number of Module (un) - Number of Equipments (un) - Power capacity of Transformation (MVA)

Opex_Ajusted ($) = Opex + Parcel Variable ($)

4 DATA ANALYSIS AND RESULTS

4.1. Data Analysis

Despite of DEA non-requirement on statistical assumptions, some previous analysis of the data base is necessary to comprehend and support the research results. TABLE 4 shows a statistical analysis of the data used at the 3CTR in 2017 during the public hearing no. 041/2017, excluding holdings and biddings companies. These data are available at ANEEL´s website (http://www.aneel.gov.br/audiencias-publicas) and at ANEXX 4.

TABLE 4 – Data statistics description

Statistics	OPEX	PV	OPEX+PV	Net Lenght < 230kV	Net Lenght ≥ 230kV	Power Capacity	Equipments	Modules	Interruption Power Capacity
Maximun	1.354.347,01	20.213,95	1.367.085,90	6.484	17.683	133.082	964	2.262	- 766.558
Minimum	126.327,16	- 157,03	127.317,36	-	1.828	9.637	117	362	- 14.195.769
Average Mean	553.102,24	6.501,41	559.603,65	1.356	8.371	45.805	508	1.128	- 5.746.816
Standard Error	377.004,01	5.905,36	381.374,39	1.951	4.991	36.445	301	630	4.550.110
3° Percentil	876.554,70	10.849,75	879.590,80	1.032	9.992	58.465	833	1.388	- 1.082.260

For the input OPEX, we can observe that FURNAS_2013 has the highest value being nine times higher than the lower cost (COPEL-GT_2014). When we exclude a cross-sectional analysis, from 2013/2016, the highest average costs in order by TSO are FURNAS, CHESF, ELETRONORTE, ELETROSUL, CTEE, CEEE, CEMIG and COPEL. This shows the previous state of TSO operational costs, size and heterogeneity in order to provide energy transmission services. This also can be observed by the high values of Standard Error in OPEX and over other variables in TABLE 4.

For quality, the highest Parcel Variable - PV comes from FURNAS 2015. This implies that FURNAS had been subtracted from Annual Revenue Permitted (RAP) for low quality service, an amount of R$ 20 MM from cost reimbursement. On the other hand, the negative number of R$ 157 TH was a quality award from ELETRONORTE for excellent operation in 2016. However, ELETRONORTE_2015 has the highest impact of PV in terms of RAP with -3.71%, reflecting14MM of outage cost. The ELETRONORTE_2016 reward was not sufficient to cover the monetary loss in 2015, and the lowest impact from PV comes from ELETROSUL_2016 with -0,22%, representing 1,2MM as can be seen in TABLE 5. For adjusted OPEX, OPEX+PV, the minimum value stands for COPEL 2014 and the highest for FURNAS_2013.

For output variables, attention to CEMIG 2013 is needed because it did not present any length for lower segments of 230kV power capacity. When we look for Interruption of Power Capacity - IPC ELETRONORTE_2013 presented the highest average levels for 2013/2016 in terms of MVAxH and COPEL_2014 the lowest.

TABLE 5 – ANEEL quality ratio (PV/RAP)

TSOs	2013	2014	2015	2016	AVERAGE
CEMIG	-2,19	-1,74	-2,54	-0,75	-1,81
ELETRONORTE	-2,48	-2,93	-3,71	0,03	-2,27
CTEEP	-0,63	-1,24	-0,82	-2,00	-1,17
CEEE	-1,12	-1,28	-1,59	-0,24	-1,06
CHESF	-2,65	-2,38	-2,38	-0,67	-2,02
COPEL	-0,69	-0,78	-1,03	-0,36	-0,72
ELETROSUL	-0,73	-0,70	-1,20	-0,22	-0,71
FURNAS	-1,96	-2,73	-2,44	-1,15	-2,07

4.2. Results and implications

For DEA efficiency measurements, TABLE 6 shows the results from MODEL 1, MODEL 2 and MODEL 3. ANEEL´s model (MODEL 1) shows 5 TSOs at the frontier, with 100% of efficiency score over the period of 2013 to 2016. The efficient DMUs are CTEEP_2015, CEMIG-GT_2016, COPEL-GT_2014, CTEEP_2014, CEEE-GT_2016. MODEL 2, with OPEX separated from PV, shows 9 TSOs at the frontier, with 100% of efficiency over the period of 2013 to 2016. The efficient DMUs are CTEEP_2013, COPEL-GT_2013, COPEL-GT_2014, CTEEP_2014, CTEEP_2015, COPEL-GT_2016, CEEE-GT_2016, CEMIG-GT_2016 and ELETRONORTE_2016. In MODEL 3, with an adjusted OPEX, only 3 DMUs are at the frontier: CTEEP_2015, CEMIG-GT_2016, COPEL-GT_2014. Only CTEEP_2015, CEMIG-GT_2016, COPEL-GT_2014 are 100% efficient in all three models. CTEEP_2014, CEEE-GT_2016 are 100% efficient in MODEL 1 and MODEL 2.

When we compare efficiency scores between MODEL 1 and MODEL 2, ELETRONORTE_2016 (60.9%), COPEL-GT_2013 (18.6%) and COPEL-GT_2016 (12.5%) had the highest score improvements between models, which can be seen in TABLE 6. Conversely, the efficiency scores of ELETROSUL_2015 (-16.9%), CEEE-GT_2015 (-14.3%), ELETROSUL_2014 (-11.6%) and CEEE-GT_2014 (-10.8%) were reduced from MODEL 1 to MODEL 2 when quality was considered as a separate variable in the inputs.

TABLE 6 – DEA Scores and Statistics (%)

BRAZILIAN TSOs (DMUs)	MODEL 1	MODEL 2	MODEL 3	Δ M1/M2	Δ M1/M3	Δ M2/M3
CTEEP_2015	**100,00**	**100,00**	**100,00**	0,00	0,00	0,00
CEMIG-GT_2016	**100,00**	**100,00**	**100,00**	0,00	0,00	0,00
COPEL-GT_2014	**100,00**	**100,00**	**100,00**	0,00	0,00	0,00
CTEEP_2014	**100,00**	**100,00**	99,86	0,00	-0,14	-0,14
CTEEP_2013	93,64	**100,00**	94,37	6,36	0,73	-5,63
COPEL-GT_2015	96,98	91,78	91,36	-5,20	-5,62	-0,42
CTEEP_2016	93,84	92,38	90,52	-1,46	-3,32	-1,86
CEMIG-GT_2015	86,08	86,08	85,77	0,00	-0,31	-0,31
CEEE-GT_2016	**100,00**	**100,00**	83,35	0,00	-16,65	-16,65
COPEL-GT_2013	81,33	**100,00**	81,58	18,67	0,25	-18,42
CEMIG-GT_2014	79,66	81,36	79,78	1,70	0,12	-1,58
COPEL-GT_2016	87,50	**100,00**	78,81	12,50	-8,69	-21,19
CEMIG-GT_2013	74,89	74,89	74,80	0,00	-0,09	-0,09
CEEE-GT_2014	81,35	70,50	66,40	-10,85	-14,95	-4,10
FURNAS_2016	68,18	66,08	65,74	-2,10	-2,44	-0,34
CEEE-GT_2015	77,67	63,30	63,27	-14,37	-14,40	-0,03
FURNAS_2014	64,90	62,65	62,25	-2,25	-2,65	-0,40
FURNAS_2015	63,09	60,87	60,44	-2,22	-2,65	-0,43
CEEE-GT_2013	65,69	63,54	53,69	-2,15	-12,00	-9,85
FURNAS_2013	54,37	52,68	52,52	-1,69	-1,85	-0,16
ELETROSUL_2014	67,44	55,84	50,57	-11,60	-16,87	-5,27
CHESF_2014	58,00	50,06	49,85	-7,94	-8,15	-0,21
ELETROSUL_2016	64,32	64,37	47,21	0,05	-17,11	-17,16
ELETRONORTE_2015	47,38	47,38	47,00	0,00	-0,38	-0,38
ELETROSUL_2015	63,84	46,94	46,84	-16,90	-17,00	-0,10
ELETRONORTE_2014	46,48	46,59	46,51	0,11	0,03	-0,08
CHESF_2013	52,64	45,81	45,69	-6,83	-6,95	-0,12
CHESF_2016	53,43	56,23	44,72	2,80	-8,71	-11,51
CHESF_2015	52,09	43,73	43,65	-8,36	-8,44	-0,08
ELETRONORTE_2013	43,07	45,84	43,29	2,77	0,22	-2,55
ELETRONORTE_2016	39,09	**100,00**	39,63	60,91	0,54	-60,37
ELETROSUL_2013	51,73	46,46	38,78	-5,27	-12,95	-7,68
Average Mean	72,15	72,36	66,51	0,21	-5,64	-5,85
Standard Error	19,46	21,76	21,01	2,29	1,55	-0,75

Variance analyzes

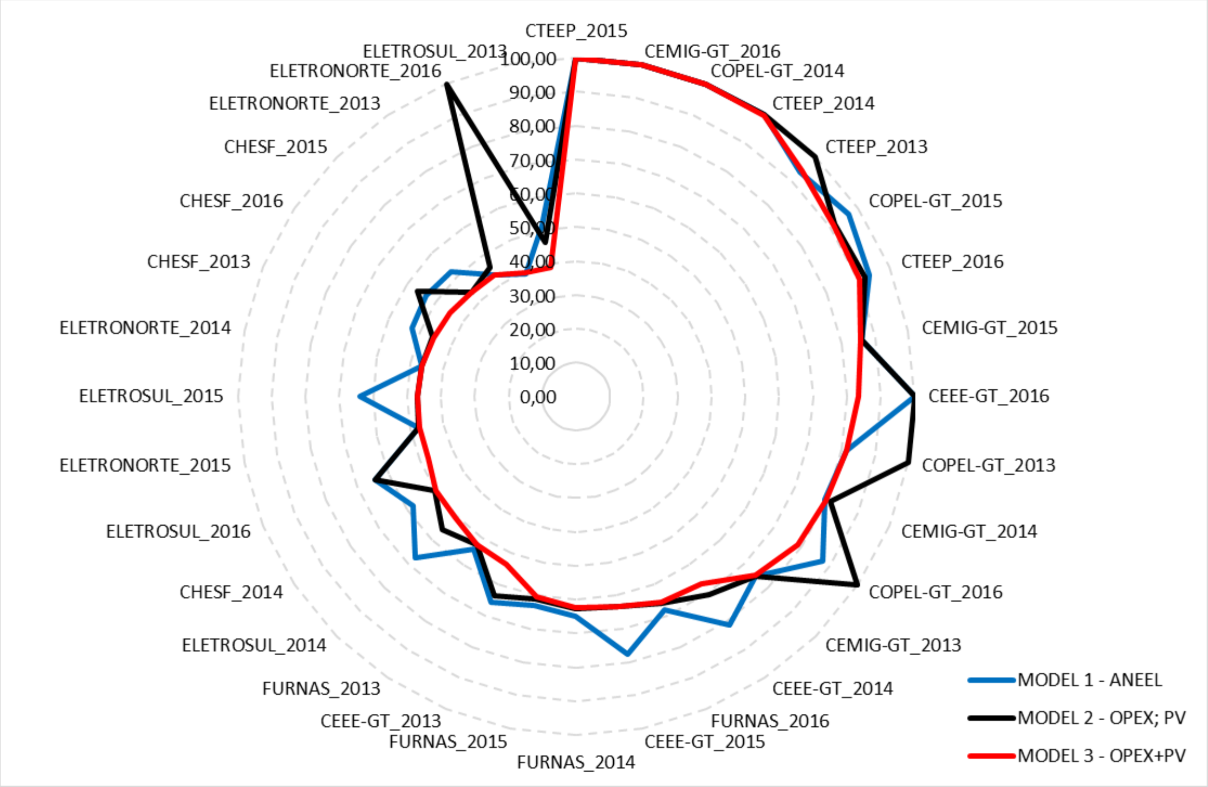
MODEL`S	Test - F	ρ - value
MODEL 1 | MODEL 2	0,8002	0,5388
MODEL 1 | MODEL 3	0,8581	0,6727
MODEL 2 | MODEL 3	1,0722	0,8473

Wilcoxon Test

Test - W	ρ - value
515,0	0,9731
608,5	0,1970
613,5	0,1736

When comparing MODEL 1 to MODEL 3, ELETROSUL_2016 (-17.1%), ELETROSUL_2015 (-17.0%), ELETROSUL_2014 (-16.8%), CEEE-GT_2016 (-16.8%), CEEE-GT_2014 (-14.9%) and CEEE-GT_2015 (-14,4%) had large efficiency score reductions. Other TSOs had efficiency score improvements, including CTEEP_2013 (0.73%), ELETRONORTE_2016 (0.54%), COPEL-GT_2013 (0.25%), ELETRONORTE_2013 (0.22%) and CEMIG-GT_2014 (0.12%). GRAPH 1 shows the differences among the models.

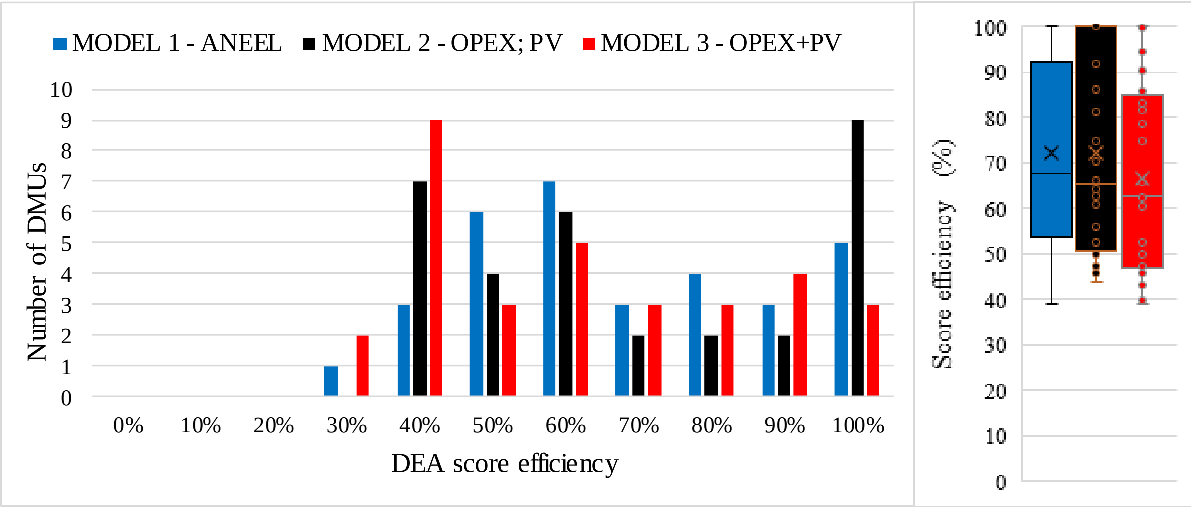
GRAPH 1 – Difference on efficiency score



When quality was added to OPEX in MODEL 3, DMUs had a significant impact on efficiency scores. Scores decreased from MODEL 2 to MODEL 3 for ELETRONORTE_2016 (60.3%), COPEL-GT_2016 (21.1%), COPEL-GT_2013 (18.4%), ELETROSUL_2016 (17.1%), CEEE-GT_2016 (16.6%) and CHESF_2016 (11.5%). Other TSOs such as CTEEP_2014 and CEEE-GT_2016 left the frontier in MODEL 3. Even for ELETRONORTE_2016 in MODEL 3, which had a quality award of 117 TH added to OPEX in 2016, it was not sufficient or high enough to place the DMU on the frontier. Costs increased 217 TH. Technically, this can be seen in DEA weights, where in MODEL 2 the quality variable did not contribute to explaining the efficiency score of ELETRONORTE_2016, which quality did not contribute to explain the score efficiency. In addition, none of the TSOs had score improvements in MODEL 3 compared to MODEL 2.

GRAPH 2 shows the median score, with most concentration around MODEL 1 (67.8), MODEL 2 (65.2) and MODEL 3 (62.7), which has less impact from extreme scores that influence the average mean on MODEL 1 (72.1), MODEL 2 (72.3), and MODEL 3 (66.5). The analysis of frequency shows that MODEL 2 (OPEX and PV separately) has more TSOs at the frontier compared to MODEL 1 - ANEEL and MODEL 3 (adjusted OPEX). MODEL 2 shows scores concentrated between 50% and 70%, allowing an average mean lower than MODEL 1 and higher than MODEL 3. Also, MODEL 3 present most scores between 40% and 50% which brings the average mean down.

GRAPH 2 – Score efficiency histogram and average mean



Analyzing only the efficiency scores from 2016, in MODEL 1, CEEE-GT_2016, CEMIG-GT_2016, COPEL-GT_2014, CTEEP_2014, CTEEP_2015 are at the frontier and benchmarks for themselves. In MODEL 1 most other TSOs have CEMIG-GT_2016 and COPEL-GT_2014 as benchmarks. In MODEL 2, CTEEP_2013, COPEL-GT_2013, COPEL-GT_2014, CTEEP_2014, CTEEP_2015, COPEL-GT_2016, CEEE-GT_2016, CEMIG-GT_2016 and ELETRONORTE_2016 are benchmarks for themselves. In MODEL 3, only CEMIG-GT_2016, COPEL-GT_2014 and CTEEP_2015 are benchmarks for themselves. In MODEL 3, attention to CEMIG-GT_2016 is needed, which references most TSOs, except for COPEL-GT_2014, CTEEP_2015. Lambdas can be seen in ANNEX 5.

Analyzing the DEA weights attribution, it revels the capacity of a variable to contribute to the score efficiency to each DMU. A non-contribution to compose the score efficiency or a zero weight to a quality variable, implies on a non-relevance to explain the score efficiency of a DMU. At MODEL 1 which uses a quality proxy as a negative output, shows 13 zero weights on the quality variable. This implies that 13 TSOs did not use an Interruption at Power Capacity proxy to contribute to the explanation of their efficiency score. The zeros can be verified for two of the five TSOs at the frontier, CEMIG-GT_2016 and CTEEP_2014. TSOs at the frontier represent most of the score contribution (87%) on the Equipment variable. CEMIG-GT_2013, CEMIG-GT_2014, CEMIG-GT_2015, ELETRONORTE_2013, ELETRONORTE_2014, ELETRONORTE_2015, ELETRONORTE_2016, FURNAS_2013, FURNAS_2014, FURNAS_2015, FURNAS_2016 were not at the frontier and also received zero weights. In MODEL 1, COPEL-GT_2015 and COPEL-GT_2016 had the highest weights on the ANEEL quality proxy with 0.26%. Other TSOs did not show relevance – see ANNEX 5.

MODEL 2 resulted in 14 zero weights for the quality variable. CTEEP_2014 and CTEEP_2015 are TSOs at the frontier showing zero weights for Parcel Variable (PV). CEEE-GT_2015, CEMIG-GT_2013, CEMIG-GT_2015, CHESF_2013, CHESF_2014, CHESF_2015, COPEL-GT_2015, CTEEP_2016, ELETRONORTE_2015, ELETROSUL_2015, FURNAS_2014, are FURNAS_2015 are the other TSOs with zero weights. Compared to MODEL 1, where PV is a proxy, in MODEL 2, COPEL-GT_2013, COPEL-GT_2016, and ELETRONORTE_2016 are TSOs at the frontier using quality to contribute to the score efficiency in 0.28%, 0.20% and 0.05%. Looking at TSOs with zero weights for quality, more than 70% of the efficiency score is explained by the Equipment variable (CHESF_2013, CHESF_2014, CHESF_2015, CTEEP_2014, CTEEP_2015, CTEEP_2016, ELETRONORTE_2015), while the others also use the Modules variable – see ANNEX 5.

In MODEL 3, where the Parcel Variable (PV) is added to OPEX, DEA did not measure any zero weights for any TSOs. This occurs because the model did not consider quality as a variable, in which, the affect of quality was added to the operational cost. MODEL 3 shows that the Equipment and Module variables contributed 40% to 60% to the composition of the efficiency scores for 20 of the 32 TSOs. It is important to highlight that MODEL 3 allocates more weight to the TSOs Net Length ≤ 230kV, Net Length > 230kV variable than MODEL 1 and MODEL

2. In all models, the variable that carried the least amount of weight was Power Capacity – see ANNEX 5.

F-tests and Wilcoxon-Test on efficiency scores should both support the same hypotheses for H0, where the average mean between MODEL 1 and MODEL 2, MODEL 1 and MODEL 3 and MODEL 2 and MODEL 3 remain statically equal. Results can be seen at TABLE 6. The analyzes support for both test that, H0 shows with 95% assurance that there is no statistical difference between average means in MODEL 1, MODEL 2 and MODEL 3. The average mean for MODEL 2 (72.3%) is higher than MODEL 1 (72.1%) and higher than MODEL 3 (66.5%) but not statistically significant. However, an analysis of the Standard Error from MODEL 1 (19.4%), MODEL 3 (21.0%) and MODEL 2 (21.7%) revels less deviation from the average mean. Less deviation suggests that MODEL 1, MODEL 3 and MODEL 2 measure highly homogeneous efficiency scores.

Research results show that quality is important for performance measurement and can impact efficiency analysis (CAMBINI *et al.*, 2014; COELLI *et al.*, 2008; GIANNAKIS *et al.,* 2005; GROWITSCH *et al.*, 2010; YU *et al.,* 2009a, b). The same authors agree that quality should be added to performance analysis to analyze efficiency of the energy transmission segment. In accordance with results found in Growitsch et al (2009) and Korhonen and Syrjanen (2003) quality introduced into performance analysis can decrease efficiency scores as seen in MODEL 3 compared to MODEL 1 and MODEL 2. However, we cannot affirm that quality variables will always decrease scores as seen by comparing MODEL 1 and MODEL 2 with different proxy and modeling assumptions. Improvements in service quality, less transmission outages measured by Parcel Variable (PV) had a positive impact and contribution in MODEL 2 for ELETRONORTE_2016 reaching the frontier. MODEL 3 compared to MODEL 1, with the adjusted OPEX by PV also presented improvements in the efficiency score for CTEEP_2013, COPEL-GT_2013 and CEMIG-GT_2014. Inserting a monetary value for quality proxy on efficiency analyses is flexible enough to permit efficiency score increased and decreases.

In addition to the MODEL 2 and MODEL 3 comparison, MODEL 3 had presented lower scores than MODEL 2. This effect was expected as MODEL 3 reduced the number of variables used to represent the productivity at Brazilian transmission segment. When a model presented less or some missing variable, the linear programming will weight other variables in ways of continuing the optimization process. In this case, the quality impact sparely was transferred to the operational cost. Checking the weights, MODEL 3 had presented a more homogeneous distribution on weight at other variables as Number of Modules and Network Length, besides Number of Equipment's. The variables selection is known as discrimination recover problem and can be further seen at DEA research approaches (ADLER and GOLANY, 2002; ADLER et al., 2010; PODINOVSKI and THANASSOULIS, 2007).

When we look to score efficiency variation between models, ELETRONORTE and CEEE demonstrate to be very sensitive to modeling specification at MODEL 2 to MODEL 3. Not only at weights, where number of equipment's contributes in more than 80% and 60% respectively to the score, it might be other variables or circumstance that would explain the score. Some study´s have adopted DEA 2 stage adjustments by analyzing the impact of environmental variables. At this process, TSOs has the score efficiency adjusted by environmental conditions that are operationally inserted as rains, geography conditions, number of lighting and others that are beyond ANEEL adopted variables. This have been analyzed and proposed by TSOs and for AEA 2017 for ANEEL 2017 CTR.

Adopting a quality variable for inputs comprised of a monetary value was analyzed in the literature (GOERLICH *et al.* ALTOÉ *et al.*, 2017; CAMBINI *et al.,* 2014; GROWITSCH *et al* (2010 a,b); MIGUÉIS *et al.*, 2012) and implemented in performance analyses of the energy regulatory processes in Austria, Finland, Norway and Germany (MESQUITA, 2017). This research study used the monetary value of Parcel Variable (PV), which represents a cost or an award for quality of electric transmission. The PV is already measured by ONS and used by ANEEL for adjustment in the Annual Revenue Permitted (RAP). However, Interruption of Power Capacity has been proposed by ANEEL for 3CTR in 2017 as proxy for service quality. This study recommends that ANEEL adopt a monetary value, the Parcel Variable (PV), as a proxy for service quality in accordance with the literature review and other regulators.

ANEEL approach also has its hazard and critics on MODEL 1. One of them, is at the metric, where ANEEL assumes same operational cost for system outage in different transmission power capacity, where in a year, 6 minutes or 0,1 hours at 6000MW in Itaipu (Furnas) is equal to 10 hours of 60MVA ant Cteep, leading to a 600 MVA/H power interruption, in which the operational expense is different as we see at Table 4. Second, ANEEL in TN 160/2017 implemented quality as an output, assuming that quality service from transmission outages was desirable. This was later corrected at TN 164/2017. At last, almost half of the TSOs do not have quality variable to contribute to the efficiency score, presenting zero weights for the quality variable. MODEL 3 first present consistence to quality based on DEC assumptions, where the monetary value is measured based on each TSO cost.

Secondly, MODEL 3 treat homogeneous quality to all DMUs by considering inside DEA, under the same optimization process. Not only that, with the implementation of this recommendation at MODEL 3, the Brazilian efficiency model will treat TSOs as homogeneous, by considering quality inside DEA measurement procedures. This technique is different from what has been done in the Concessions Renewal of 2012. Goerlich *et al.,* (2017) assure that quality must be implemented inside DEA procedures, on inputs by adjusting OPEX. This research also reinforces quality assumptions at DEA, where is recommended that ANEEL adopt quality inside DEA procedures, on inputs, by adjusting OPEX. These procedures are different from what has been done in the Concessions Renewal of 2012 and what has been proposed in 3CTR in 2017.

Third, MODEL 3 adjustment at OPEX by PV reduces the number of variables used to evaluate the score efficiency, where less variables, reduce DMUs score efficiency. This occurs because DEA measurement allocate weights in another variable, which may not contribute in the same proportion as the additional variable to the score efficiency. In addition, MODEL 3 does not permit that inefficient DMU reach the frontier, as seen in MODEL 2 where ELETROSUL_2016 had 100% score efficiency with low quality variable weight score contribution of 0,05%.

The adoption of MODEL 3 for regulation has the same average mean segment efficiency score statically, besides of different values. The procedures adopted al models treated equally TSOs when quality is introduced inside models where for the regulator the impacts are at the financial values for government policy. This take over on the score efficiency, where lower scores efficiency reflect on less of cost reimbursement when MODEL 3 is compared to MODEL 1 and MODEL 2. Based on TN 164/2017 data for operational cost, government should save R$ 2 Billion of cost reimbursement with the adoption of MODEL 3, as can be seen at TABLE 7. These recommendations and new tools should be added not only to the 3CTR of 2017 but also to future cycles of tariff review based on benchmarking for efficiency analysis of energy transmission service.

TABLE 7 – Operational cost reimbursement based on 2016

TSOs 2016	OPEX 2016	OPEXxMODEL_1	OPEXxMODEL_2	OPEXxMODEL_3
CEMIG-GT_2016	178.318,31	178.318,31	178.318,31	178.318,31
CTEEP_2016	527.085,92	494.617,43	486.921,97	439.326,11
CEEE-GT_2016	244.399,81	244.399,81	244.399,81	203.707,24
FURNAS_2016	1.340.563,19	913.995,98	885.844,16	881.286,24
COPEL-GT_2016	179.207,78	156.806,81	179.207,78	141.233,65
CHESF_2016	1.122.126,78	599.552,34	630.971,89	501.815,10
ELETROSUL_2016	528.205,86	339.742,01	340.006,11	249.365,99
ELETRONORTE_2016	929.786,97	363.453,73	929.786,97	368.474,58
TOTAL	5.049.694,62	3.290.886,41	3.875.457,00	2.963.527,22
SAVINGS	-	1.758.808,21	1.174.237,62	2.086.167,40

5 CONCLUSION

This research uses an academic and technical structure to clarify the incorporation of service quality into a frontier-based benchmarking model for the electric transmission segment. This research has contributed to the literature with a survey on service quality concerns of the electrical energy sector, with a review of quality proxies and modeling applications into frontier-based benchmarking. Results showed that quality measurement as a monetary value is effective when is used as an input by adjusting operational cost.

The Brazilian transmission regulatory model and the performance process adopted in 2007, 2009, 2012 and the latest proposed model in 2017 were presented, and it was shown that these are not supported by the literature or worldwide energy regulator best practices regarding the insertion of quality measures into the benchmark models. This research compared different models of frontier-based benchmarking methods for quality variable incorporation into Brazilian TSOs. As proposed, an overview of the concerns for quality variables were analyzed in the literature and relevant issues identified, such as worldwide adoption, proxy composition, and impact. Also, the research measured Brazilian TSOs efficiency regarding literature recommendations and worldwide regulator practices. In addition, an interpretation of the results in the context of Brazilian TSOs was made.

The Brazilian proposed model for tariff review in 2017 made by ANEEL should adopt a monetary value as the Parcel Variable - PV for a proxy of quality. The Parcel Variable stands for costs from transmission services outages. This has never been used during the cycle of tariff review from 2007, 2009, 2012 and is not included the proposed in 2017. In addition, on modeling techniques, quality must be inserted as an input which adjusts costs for Transmission Operational Services (TSOs).

Regarding the limits of this analysis, further research should investigate quality as used in other benchmarks of frontier processes. These might include using SFA and StoNED to check if the results are also consistent with theory development. Thus, GDEA – Generalized DEA approach could be also verified, in which might contribute for a unique sector score efficiency. Not only, a further study should analyze the possibility of adjusting scores at second stage, considering environmental variables. This adjustments will consider operational conditionals equally between TSOs. Finally, other researchers could compare quality in international performance analysis. This might help TSOs to share best practices on operational performance, specifically in cost reduction without diminishing services quality levels.

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ANNEX 1 – Quality benchmark models review literature

N°	Author	Title
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

N°	Author	Sector	Country	Method	Orientation	Variables	
						Input/Dependent	Output/Independent
1	Korhonen et al (2003)	Distribution	- Finland	- DEA	- Input	**Model 1** - Opex	**Model 1** - Energy Supplied - Total time interruption weighted (MIN)*
2	Ajodhia et al (2004)	Distribution	- Germany	- DEA - COLS	- Input	**Model 1,2** - Totex	**Model 1** - Network length - Number of customers **Model 2** - Network length - Number of customers - Total time interruption (min) *
3	Giannakis et al (2005)	Distribution	- Europe	- DEA	- Input	**Model 1** - Opex **Model 2** - Totex **Model 3** - Number Interruptions (un)* - Total time lost (MIN)* **Model 4** - Totex - Number Interruptions (un)* - Total time lost (MIN)*	**Model 1,2,3,4** - Energy supplied - Number of customerss - Network length
4	Tanure et al (2006)	Distribution	- Brazil	- DEA	- Output	**Model 1** - Opex - Network length - Installed Transformer Capacity (MVA) **Model 2** - Network length - Installed Transformer Capacity (MVA) **Model 3** - Opex - Installed Transformer Capacity (MVA) **Model 4** - Opex - Network length	**Model 1,2,3,4** - Number Interruptions (un)* - Total time lost (MIN)*

N°	Author	Sector	Country	Method	Orientation	Variables	
						Input/Dependent	Output/Independent
5	Yu et al (2007)	Distribution	- United Kingdom	- DEA	- Input	**Model 1** - Opex **Model 2** - Totex **Model 3** - Totex - Total time lost (min)* **Model 4** -Opex - Total time lost (min)* - Network Energy Loss (min)* **Model 5** -Totex - Total time lost (min)* - Network Energy Loss (min)*	**Model 1,2,3,4,5** - Energy supplied - Number of customers - Network length
6	Arocena (2008)	Generation and Distribution	- Spain	- DEA	- Input	**Model 1** - Totex - Total time lost in installed capacity (MIN)* **Model 2** - Totex - Total time lost in installed capacity (MIN)*	**Model 1,2** - Total hydroelectric power production - Total thermal power production - Low voltage line - High voltage line - Number of customers
7	Coelli et al (2008)	Distribution	- France	- DEA - SFA (Translog)	- Input	**Model 1** - Opex - Capital Replacement Value **Model 2** - Opex - Capital Replacement Value - Total Minutes of Interruptions (min)* **Model 3** - Opex - Capital Replacement Value - Total Number Interruptions (un)*	**Model 1,2,3** - Energy supplied - Number of customers - Network length
8	Cadena et al (2009)	Transmission	- Colombia	- DEA - SFA (Cobb-Douglas)	- Input	**Model 1** - Network Length - Non-electrical assets - Opex **Model 2** - Electrical assets - Non-electrical assets - Opex	**Model 1** - Power Capacity - Quality (un) * **Model 2** - Power Capacity - Quality (un) *

N°	Author	Sector	Country	Method	Orientation	Variables	
						Input/Dependent	Output/Independent
9	Yu et al (2009)	Distribution	- United Kingdom	- DEA	- Input	**Model 1** - Opex **Model 2** - Opex - Duration of Interruption (Hours) * - Energy Losses (physical)* **Model 3** - Totex - Duration of Interruption (Hours) * - Energy Losses (physical)* **Model 4** - Opex - Duration of Interruption ($) * - Energy Losses ($)* **Model 5,6** - Totex - Duration of Interruption ($) * - Energy Losses ($)*	**Model 1,2,3,4,5** - Energy supplied - Number of customers - Network length Model 6 - Energy supplied - Number of customers
10	Yu et al (2009)	Distribution	- United Kingdom	- DEA	- Input	**Model 1** - Opex **Model 2** - Totex **Model 3** - Totex - Total time lost ($)* **Model 4** -Opex - Total time lost ($)* - Network Energy Loss ($)* **Model 5** -Totex - Total time lost ($)* - Network Energy Loss ($)*	**Model 1,2,3,4,5** - Energy supplied - Number of customers - Network length
11	Growitsch et al (2009)	Distribution	- Norway	- DEA	- Input	**Model 1** - Totex - Energy not supplied ($)* **Model 2** - Totex + Energy not supplied ($) *	**Model 1,2** - Energy supplied - Number of customers

N°	Author	Sector	Country	Method	Orientation	Variables	
						Input/Dependent	Output/Independent
12	Growitsch et al (2010)	Distribution	- Norway	- SFA (Translog)		**Model 1,2,3,4** - Totex Adjusted	**Model 1,2,3,4** - Number of customers - Energy supplied
13	Martirosyan et al (2010)	Distribution	- United State	- Probit regression		**Model 1** - SAIDI * **Model 2** - SAIFI * **Model 3** - Opex **Model 4** - Totex	**Model 1,2,3,4** - Income per capita on territory - length of line per customers - Ratio of underground line by total line - Self-electricity generation - Total damage of weather - Regulatory Regime dummies - Quality standards dummy * - Utility specific dummy - Time specific dummy
14	Azadeh et al (2010)	Transmission	- Iran	- DEA	- Input	**Model 1** - Percent transmission loss - Number of employees - Number of substation	**Model 1** - length of line interrupted * - Average of Interruptions (hour)* - Average of Transformation Interruptions (hour)*
15	Jamasb et al (2012)	Distribution	- United Kingdom	- SFA (Translog)		**Model 1,2** - Totex	**Model 1** - Energy supplied - Network density - Network Energy Loss - Total time lost Outdated ($)* **Model 2** - Energy supplied - Network density - Network Energy Loss - Total time lost ($)*

N°	Author	Sector	Country	Method	Orientation	Variables	
						Input/Dependent	Output/Independent
16	Miguéis et al (2012)	Distribution	- Norway	- DEA	- Input	**Model 1** - Totex + Cost of Energy not supplied ($)* **Model 2** - Totex - Cost of Energy not supplied ($)*	**Model 1,2** - Energy supplied - Number of customers - Network length - Number of transformers
17	Coelli et al (2013)	Distribution	- France	- SFA (Translog)		**Model 1** - Capex - Opex - Number of Interruption (un)*	**Model 1** - Energy Supplied - Number of customers - Service area in square kilometers
18	Cambini et al (2013)	Distribution	- Italy	- DEA	- Input	**Model 1** - Opex + Capital Replacement Value **Model 2** - Opex + Penalties($) + Rewards ($)* **Model 3** - Opex + Energy not supplied ($)*	**Model 1,2,3** - Energy supplied - Number of customers
19	Xavier et al (2015)	Distribution	- Brazil	- DEA	- Input	**Model 1** - Network length - Transformer Capacity - Number of employees **Model 2** - Network length - Transformer Capacity - Number of employees - Quality measure* **Model 3** - Network length - Transformer Capacity - Number of employees - Quality measure*	**Model 1,2,3** - Energy supplied - Number of customers

N°	Author	Sector	Country	Method	Orientation	Variables	
						Input/Dependent	Output/Independent
20	Silva (2015)	Distribution	- Brazil	- SFA (Translog)		**Model 1** - Opex	**Model 1** - Capex - Third party cost - Material Expenses - Insurance - Payroll - Tax costs - Compensation for losses to customers * - Energy Supplied
21	Altoe et al (2017)	Distribution	- Brazil	- DEA	- Input	**Model 1** - Opex Adjusted	**Model 1** - Energy supplied - Number of customers - Network length
22	Goerlich et al (2017)	Distribution	- Austria	- DEA	- Input	**Model 1** - Totex **Model 2** - Sotex **Model 3** - Totex **Model 4** - Sotex **Model 5** - Totex - Outage Costs **Model 6** - Totex - Outage Costs **Model 7** - Outage Costs	**Model 1,2,3,4,5,6,7** - Network level 4-7 - Network level 6-7 - Transformed area weighted connection density for the high voltage level - Transformed area weighted connection density for the medium voltage level - Transformed area weighted connection density for the low voltage level
23	Zaja et al (2017)	Distribution	- Croatia	- DEA	- Input	**Model 1** - Opex	**Model 1** - Total electricity sales - Number of customers - Network Lenght - Peak Load

N°	Variables	Quality Relevance	Quality Metrics
	Environmental Factors		
1	Model 1 - Geographical dispersion of customers - Number of customerss	- Beside quality on an output indicator (as small values are preferred) technically are inserted as an input. But, the interest is the pure cost efficiency, then quality needs to be an output. - Without quality variable the model drecrease the score efficiency	
2	**Model 1,2** - Number of transformers - Energy Supplied	- The methodology that is used change the score efficiency with quality variables - Quality should be taken over to efficiency analysis	
3		- DEA with quality variables rise the score efficiency in TOTEX, but the Total Factor productivity reduces. - DEA Models with quality variable doesn´t show high relation to DEA without - Efficient firms doesn´t exhibit high service quality - DEA Model with quality variables is better	$\text{Number Interruption} = \frac{N^{\circ}\text{ of customer interruptions}}{100\text{ connected customers}}$ $\text{Total customer time lost} = \frac{\text{Average customer minutes lost}}{\text{connected customers}}$
4			$Y^{adj} = (Y_{max} + r) - Y_i$ Y adj = Adjusted quality index Y max = Maximum value of quality index Yi = Value to be adjusted r = minimum value of Y adj
5		- Quality can reduce the efficiency - Low correlation between models with cost and cost+qualtiy as expect the trade-off	
6		- Diversification in power generation and distribution is advantageous when qualitiy of supply is seek to be maximized. - When quality variables are ignored vertical unbundling raise costs.	$\text{Total customer time lost} = \frac{\sum(Installed\ Capacity\ interrupted\ * Hour)}{Installed\ Capacity\ interrupted}$
7		- Quality has no significant effect on technical efficiency scores.	$SAIFI = \frac{Total\ N^{\circ}\ of\ customer\ interruptions}{Total\ N^{\circ}\ of\ customers\ served}$ Total Interruptions = SAIFI * Total N° of customerss SAIFI (System Average Interruption Frequency)

N°	Variables	Quality Relevance	Quality Metrics
	Environmental Factors		
8	**Model 1** - Length of lines exposed to salinity - Substation equipments exposed to salinity - Electrical assets exposed to salinity - Infrastructure Complexity **Model 2** - Electrical assets exposed to salinity - Infrastructure Complexity	- Quality is discretionary	$Quality = \frac{\sum Number\ of\ available\ Lines\ * Length}{\sum Length}$
9	**Tobit regression** **Model 1,2,3,4,5,6** - Weather index I - Weather index II	- Weather factors can affect quality service of network utilities, as an exogenous factor. - Model 5 and 6 are significant to the analysis	
10		- Efficient firms doesn´t exhibit high service quality - DEA Models with quality variable doesn´t show high relation to DEA without	$Number\ Interruption = \frac{N°\ of\ customer\ interruptions}{100\ connected\ customers}$ $Total\ customer\ time\ lost = \frac{Average\ customer\ minutes\ lost}{connected\ customers}$
11		-Socially desired service quality does not have any improvement to cost efficiency	
12	**Model 2 correcting inputs** - Weather condition - Geographic condition **'Model 3 as Z variable** - Weather condition - Geographic condition **'Model 4 as Fixed effects** - Weather condition - Geographic condition		Totex Adjusted = Totex - Quality Quality = interrupetion supply (hours) * customers willingness-to-pay
13		- Incentive regulation has a negative impact on quality (especially in the duration of outages) compare strictly to quality standards, where it increase under incentive regulation. - Frequency of outages does not have a significant impact on it regulation set - Incentive regulation and quality standards are endogenous and are to be imposed when the utility has a poor performance - Incentive regulation affects quality through its impact on composition and size of operations and maintenance expenses. - Quality should be used at performance models	

N°	Variables	Quality Relevance	Quality Metrics
	Environmental Factors		
14		- Transformed undesirable outputs in desirable by DEA process Adler & Boaz (2001) - It could have reductions on costs, by reducing the number of employees	$Average\ of\ line\ Interruption = \frac{Total\ hours\ of\ line\ interruptions}{Total\ Lenght\ interrupted}$ $Average\ Transformation\ = \frac{Total\ hours\ of\ transformation\ interrupted}{Total\ number\ transformation\ interrupted}$
15	**Model 1,2** - Minimum air temperature - Number of days bellow zero - Number of days with heavy hail - Number of days with heard thunder	- Regulatory incentives to reduce service interruptions have not been effective - Incentives to encourage utilities to reduce network energy losses have led to performance improvement -Observed improvements in quality represented about 20% of the potential customers welfare gains	$Number\ Interruption = \frac{N°\ of\ customer\ interruptions}{100\ connected\ customers}$ $Total\ customer\ time\ lost = \frac{Average\ customer\ minutes\ lost}{connected\ customers}$
16	**2° Stage by Tobit regression** **Model 1,2** - Size - Interface - Forest - Snow - Coast		
17	- Proportion of network underground - customerss density proportion - Ratio of net book value to gross book value assets - Ratio of high voltage capacity to total transformers	- It´s seen that quality improvements reflect at positive at the convex costs, as the score efficiency approximate to 100%.	$SAIFI = \frac{Total\ N°\ of\ customer\ interruptions}{Total\ N°\ of\ customers\ served}$ Total Interruptions = SAIFI * Total N° of customerss SAIFI (System Average Interruption Frequency)
18	**2° Stage Regression** - Network density - Load Composition	- Efficient firms doesn´t exhibit high service quality	$\mathrm{R} = R1\frac{Residencial\ Energy}{8{,}76} + R2\ \frac{Non-Residencial\ Energy}{8{,}76}$ $Energy\ not\ supplied\ (\$) = SAIDI *\ R$ $SAIDI = \frac{Average\ customer\ minutes\ lost}{Connected\ customers}$ SAIDI (System Average Interruption Duration) R1 (Willingness To Pay Parameters for Residencial Users) R2 (Willingness To Pay Parameters for Non-Residencial Users)

N°	Variables	Quality Relevance	Quality Metrics
	Environmental Factors		
19	2° Stage Tobit Regression Model 3 - Number of lightning - customers density - Ownership	- Quality and environmental variable are better represented by homogeneity at DMUs - Is necessary to integrate quality of supply (number of interruption) to benchmarking models	$SAIDI = \frac{Average\ customer\ minutes\ lost}{Connected\ customers}$ SAIDI (System Average Interruption Duration)
20	**Model 1** - Energy Technical Losses (\$) * - Duration of interruptions (Hours) * - Energy not distributed (km)* - Frequency of Interruptions (un)* - Market share	- Quality variables as DEC can affect negatively the efficiency - DEC contradict it expectation by longer interruption greater the inefficiency	
21		- Quality has significant effect on technical efficiency highing the scores.	- Quality Measure (\$) = λ * θ $\theta = \frac{R * 15 * \delta}{\gamma} \qquad R = \left(\frac{\lambda}{Total\ Connected\ Customer}\right)$ - Not Techinical Loss (\$) = (Real Losses - Regulatory Losses Limit)* β Opex Adjusted = Opex + Quality Measure (\$) + Not Technical Loss (\$) β = Average Cost kWh Parcel A δ = Average Cost kWh Parcel B ϒ = Hours in a year θ= Average Cost per hour λ= (Duration of Interruption - Duration Interruption Limit by Regulation)
22		- Quality can decrease scores - Quality must be Financial - Quality must be add to Operational Cost	
23	**2° Stage Regression** - Density of customers - Density of energy consumption - Labor Prices - Quality Services - Geographical and weather factors	- Even with quality service decreasing, scores efficiency got higher	

ANNEX 2 – ANEEL Transmission Models

Tariff Review	Year	Cycle	Data	Technical Note	Methodology	Method	Orientation	Variables	
								Inputs	Outputs
1°	2007	2005/2008	2003/2005	TN 182/2007	DEA	1° Stage	NDRS	**TOTEX** - Operations and Maintenance Cost - Remuneration of Investments in Assets	**Transmission Network** - Network total lenght (km) " **Number of Module** - Sum of Modules: EL, CT, IB " **Equipment Modules** - Number of Equipaments " - Power Capacity (MVA)
						Adjust Score		**Adjust for all companies to be at 80% and 100% of efficiency**	$corrected\ score = \frac{(\theta - \text{Lowest}) * 20\%}{\text{Highest} - \text{Lowest}} + 80\%$
2°	2010	2009/2012	2002/2008	TN 274/2009	DEA	1° Stage	NDRS	**OPEX** - Operations and Maintenance Cost	**Transmission Network** - Network total lenght (km) " **Number of Module** - Sum of Modules: EL, CT, IB " **Equipment Modules** - Number of Equipaments " - Power Capacity (MVA)
						2° Stage		**Tobit Regression**	**Environmental Variables** - Salary average by region - Dispersion line area - Area covered **Quality Service **** - Duration and Frequency of Interruption **Tranformation Capacity** - Power Capacity (MVA)

" Aggregate Information

* Wheight Restrictions

** Different Metric

Tariff Review	Year	Cycle	Data	Technical Note	Methodology	Method	Orientation	Variables	
								Inputs	Outputs
	2012	Concession Renewal	2007/2011	TN 383/2012	DEA	1° Stage	NDRS	**OPEX** - Operations and Maintenance Cost	**Transmission Network** - Network lenght (km) - 600 à 765 kV " * - Network lenght (km) - 440 à 525 kV " * - Network lenght (km) - 325 kV " * - Network lenght (km) - 230 kV " * - Network lenght (km) - 138 kV " * - Network lenght (km) - 69 à 88 kV " * **Number of Module** - Sum of Modules: EL, CT, IB " **Equipment Modules** - Number of Equipaments " - Power Capacity (MVA)
						Adjust Score			**Quality Service **** - Parcel Variable / Total Allowable Revenue
3°	2017	2013/2016	2013/2017	PROPOSITION TN 160/2017 and TN 164/2017	DEA	1° Stage	NDRS	**OPEX** - Operations and Maintenance Cost	**Transmission Network** - Network lenght Lower and Equal (km) - 230 kV " - Network lenght Higher (km) - 230 kV " * **Number of Module** - Sum of Modules: EL, CT, IB " **Equipment Modules** - Number of Equipaments " - Power Capacity (OCP + ROCP) " **Quality Service **** - Parcel Variable
						Adjust Score		**3° Percentil for normalization**	

" Aggregate Information
* Wheight Restrictions
** Different Metric

Source: Autor elaboration - ANEEL TN 182/2007; TN 274/2009; TN 383/2012; TN 164/2017

ANNEX 3 – Weight Restriction

2CTR - 383/2012

$1{,}05 \le \dfrac{600\text{ to }750\text{ kV}}{230\text{ kV}} \le 1{,}57$	600 to 750 kV ≥ 1,05 230 kV 600 to 750 kV ≤ 1,57 230 kV
$1{,}01 \le \dfrac{440\text{ to }525\text{ kV}}{230\text{ kV}} \le 1{,}51$	440 to 525 kV ≥ 1,01 230 kV 440 to 525 kV ≤ 1,51 230 kV
$0{,}98 \le \dfrac{345\text{ kV}}{230\text{ kV}} \le 1{,}38$	345 kV ≥ 0,98 230 kV 345 kV ≤ 1,38 230 kV
$0{,}68 \le \dfrac{138\text{ kV}}{230\text{ kV}} \le 1{,}02$	138 kV ≥ 0,68 230 kV 138 kV ≤ 1,02 230 kV
$0{,}59 \le \dfrac{69\text{ to }88\text{ kV}}{230\text{ kV}} \le 0{,}88$	69 to 88 kV ≥ 0,59 230 kV 69 to 88 kV ≤ 0,88 230 kV

3CTR - 160/2017

$2500 \le \dfrac{\text{Length} \ge 230}{\text{OPEX}} \le 8500$	Length ≥ 230 ≥ 2500 OPEX Length ≥ 230 ≤ 8500 OPEX
$0{,}20 \le \dfrac{\text{Length} \ge 230}{\text{Length} < 230} \le 0{,}75$	Length ≥ 230 ≥ 0,20 Length < 230 Length ≥ 230 ≤ 0,75 Length < 230
$400 \le \dfrac{\text{OPC+ROPC}}{\text{OPEX}} \le 4000$	OPC+ROPC ≥ 400 OPEX OPC+ROPC ≤ 4000 OPEX
$15000 \le \dfrac{\text{Modular Vot. N.}}{\text{OPEX}} \le 70000$	Modular Vot. N. ≥ 15000 OPEX Modular Vot. N. ≤ 70000 OPEX
$1 \le \dfrac{\text{Modular Vot. N.}}{\text{Modular Equip.}} \le 10$	Modular Vot. N. ≥ 1 Modular Equip. Modular Vot. N. ≤ 10 Modular Equip.

ANNEX 4 – 3CTR DEA DATA

DMU	OPEX	PV	OPEX+PV	Network Lenght < 230kV	Network Lenght ≥ 230kV	Power Capacity	Equipments	Modules	Interrupted Power Capacity (IPC)
CEEE-GT_2013	319538,65	1199353,13	320738,00	894,175	4576,84	9636,91	241	1066	-806699,8642
CEEE-GT_2014	263234,32	2412319,93	265646,64	903,375	4576,84	10350,54	257	1105	-806699,8642
CEEE-GT_2015	277589,36	3623719,16	281213,08	903,375	4590,57	10567,54	263	1117	-806699,8642
CEEE-GT_2016	222541,20	413825,03	222955,03	894,175	4773,15	10958,04	277	1178	-806699,8642
CEMIG-GT_2013	193817,36	3133400,34	196950,76	0	4832,98	19646,85	248	621	-8627416,951
CEMIG-GT_2014	182972,34	2474802,39	185447,14	94,84	4922,74	19926,85	244	632	-8627416,951
CEMIG-GT_2015	170398,93	3194573,42	173593,50	94,84	4927,86	20666,05	253	664	-8627416,951
CEMIG-GT_2016	147604,35	2213403,33	149817,75	94,84	4948,49	21706,65	262	684	-8627416,951
CHESF_2013	1049426,23	14375662,19	1063801,89	632,45	14788,9	54072,49	923	2019	-4864640,477
CHESF_2014	975198,19	12615471,18	987813,66	606,55	15116,96	55404,99	932	2033	-4864640,477
CHESF_2015	1139099,23	15948669,09	1155047,90	503,2	15276,81	58269,99	958	2083	-4864640,477
CHESF_2016	1122126,78	4829280,16	1126956,06	503,2	14752,11	59494,31	964	2140	-4864640,477
COPEL-GT_2013	154361,75	720481,17	155082,23	21,65	1829,25	11533,25	117	362	-766558,2495
COPEL-GT_2014	126327,16	990197,84	127317,36	21,65	1828,155	12298,25	131	381	-766558,2495
COPEL-GT_2015	138581,31	1810357,87	140391,67	21,65	1852,365	12898,25	137	399	-766558,2495
COPEL-GT_2016	163485,37	694034,78	164179,40	21,65	1969,135	13398,25	143	420	-766558,2495
CTEEP_2013	419897,96	3531337,34	423429,30	6350,68	6409,36	58278,98	808	2185	-5916838,823
CTEEP_2014	396040,31	7399406,46	403439,72	6465,085	6409,36	59021,98	814	2211	-5916838,823
CTEEP_2015	400224,04	5376742,05	405600,78	6484,435	6411,29	59670,48	821	2230	-5916838,823
CTEEP_2016	451688,14	16668159,30	468356,30	6291,285	8061,925	60413,58	832	2262	-5916838,823
ELETRONORTE_2013	620282,76	6249700,64	626532,46	582,51	7771,36	41296,2	508	722	-14195768,51
ELETRONORTE_2014	589378,41	8477293,24	597855,70	582,51	7884,36	42271,2	523	765	-14195768,51
ELETRONORTE_2015	605920,90	14132211,82	620053,11	582,51	8402,55	44334,2	542	806	-14195768,51
ELETRONORTE_2016	843673,54	-157027,72	843516,51	612,51	8405,7	54077,93	564	881	-14195768,51
ELETROSUL_2013	544366,10	3135703,38	547501,80	993,445	7873,59	29867,8	258	639	-1174113,453

ELETROSUL_2014	430496,66	3241804,21	433738,46	993,445	8245,49	30773,8	263	648	-1174113,453
ELETROSUL_2015	481340,63	6221970,60	487562,60	993,445	8201,44	32660,8	287	711	-1174113,453
ELETROSUL_2016	479654,37	1285385,44	480939,76	923,915	8072,635	32611,8	294	719	-1174113,453
FURNAS_2013	1354347,01	12738890,74	1367085,90	1391,75	17617,06	127757,99	836	1085	-9622491,178
FURNAS_2014	1140383,40	18618972,71	1159002,37	1391,75	17683,06	128417,99	841	1091	-9622491,178
FURNAS_2015	1182618,04	20213951,80	1202831,99	1391,75	17334,56	130402,32	851	1102	-9622491,178
FURNAS_2016	1112656,83	10261181,92	1122918,01	1145,75	17515,56	133082,32	855	1120	-9622491,178

ANNEX 5 – MODELS Lambdas and Weights

MODEL 1 - ANEEL

DMUs	Lambdas					Weights						
TSOs	CEEE-GT_2016	CEMIG-GT_2016	COPEL-GT_2014	CTEEP_2014	CTEEP_2015	OPEX	NET LENGHT <230kV	NET LENGHT ≥230kV	Power Capacity	Equipments	Modules	Interruption Power Capacity
CEEE-GT_2013	0,75228968	0,00126494	0,24644538	0	0	3,13E-06	2,00E-05	2,66E-05	1,25E-06	0,0002266	0,0002191	2,00E-08
CEEE-GT_2014	0,86238316	0,00070274	0,1369141	0	0	3,80E-06	2,42E-05	3,23E-05	1,52E-06	0,000275	0,0002659	2,00E-08
CEEE-GT_2015	0,90366821	0,00049192	0,09583987	0	0	3,60E-06	2,30E-05	3,06E-05	1,44E-06	0,0002608	0,0002522	2,00E-08
CEEE-GT_2016	1	0	0	0	0	4,49E-06	7,64E-06	3,82E-05	1,80E-06	0,0023795	0,000238	1,80E-07
CEMIG-GT_2013	0	0,95710394	0,04289606	0	0	5,16E-06	3,62E-06	1,81E-05	2,06E-06	7,74E-05	7,74E-05	0
CEMIG-GT_2014	0	0,99189034	0,00810966	0	0	5,47E-06	1,42E-05	1,89E-05	2,19E-06	8,20E-05	8,20E-05	0
CEMIG-GT_2015	0	0,99350283	0,00649717	0	0	5,87E-06	1,53E-05	2,03E-05	2,35E-06	8,80E-05	8,80E-05	0
CEMIG-GT_2016	0	1	0	0	0	6,77E-06	3,39E-06	1,69E-05	2,47E-05	0,0010162	0,0001016	0
CHESF_2013	1,05582776	0	0	0	0,67821762	9,50E-07	1,62E-06	8,10E-06	3,81E-06	0,0004662	4,66E-05	7,00E-08
CHESF_2014	1,09702218	0	0	0	0,67260119	1,03E-06	1,74E-06	8,72E-06	4,10E-06	0,0005017	5,02E-05	7,00E-08
CHESF_2015	1,21981324	0	0	0	0,6558599	8,80E-07	1,49E-06	7,46E-06	3,51E-06	0,0004295	4,30E-05	6,00E-08
CHESF_2016	1,26615696	0	0	0	0,64954141	8,90E-07	1,51E-06	7,57E-06	3,56E-06	0,000436	4,36E-05	6,00E-08
COPEL-GT_2013	0	0	1	0	0	6,48E-06	4,13E-05	5,51E-05	2,59E-06	9,72E-05	9,72E-05	1,00E-08
COPEL-GT_2014	0	0	1	0	0	7,92E-06	1,35E-05	6,73E-05	3,17E-06	0,0021563	0,0002156	5,00E-08
COPEL-GT_2015	0	0	1	0	0	7,22E-06	1,23E-05	6,13E-05	2,89E-05	0,0050512	0,0005051	1,49E-05
COPEL-GT_2016	0	0	1	0	0	6,12E-06	1,04E-05	5,20E-05	2,45E-05	0,0042817	0,0004282	1,26E-05
CTEEP_2013	0	0,00741077	0,00390027	0,98868896	0	2,38E-06	4,05E-06	2,02E-05	9,50E-07	0,0006487	6,49E-05	2,00E-08
CTEEP_2014	0	0	0	1	0	2,52E-06	4,73E-06	6,31E-06	1,01E-06	0,0008398	8,40E-05	0
CTEEP_2015	0	0	0	0	1,00000001	2,50E-06	4,68E-06	6,25E-06	1,00E-06	0,0010902	0,000109	5,00E-08
CTEEP_2016	0,05624623	0	0	0	0,99233141	2,21E-06	3,76E-06	1,88E-05	8,86E-06	0,0010832	0,0001083	1,60E-07
ELETRONORTE_2013	0	1,23817673	0	0,22555	0	1,61E-06	1,26E-06	6,29E-06	6,45E-06	0,0001916	2,42E-05	0
ELETRONORTE_2014	0	1,2265481	0	0,24772039	0	1,70E-06	1,32E-06	6,62E-06	6,79E-06	0,0002016	2,55E-05	0
ELETRONORTE_2015	0	1,36254569	0	0,22728873	0	1,65E-06	1,29E-06	6,44E-06	6,60E-06	0,0001961	2,48E-05	0
ELETRONORTE_2016	0	1,28256289	0	0,28005961	0	1,19E-06	9,20E-07	4,62E-06	4,74E-06	0,0001409	1,78E-05	0
ELETROSUL_2013	0,38179138	0	0,5420517	0	0,07615692	1,84E-06	1,17E-05	1,56E-05	7,35E-06	0,0005954	5,95E-05	1,00E-07
ELETROSUL_2014	0,40874667	0	0,5153065	0	0,07594682	2,32E-06	1,48E-05	1,97E-05	9,29E-06	0,0007529	7,53E-05	1,30E-07
ELETROSUL_2015	0,54717807	0	0,37795405	0	0,07486788	2,08E-06	1,32E-05	1,77E-05	8,31E-06	0,0006734	6,73E-05	1,10E-07
ELETROSUL_2016	0,58281388	0	0,34259599	0	0,07459013	2,08E-06	3,54E-06	1,77E-05	8,34E-06	0,0007124	7,12E-05	1,10E-07
FURNAS_2013	0	0,52740568	0	0,85727237	0	7,40E-07	1,26E-06	6,28E-06	2,95E-06	6,48E-05	1,11E-05	0
FURNAS_2014	0	0,52199971	0	0,86515488	0	8,80E-07	1,49E-06	7,45E-06	3,51E-06	7,69E-05	1,32E-05	0
FURNAS_2015	0	0,51118778	0	0,88091991	0	8,50E-07	1,44E-06	7,19E-06	3,38E-06	7,42E-05	1,27E-05	0
FURNAS_2016	0	0,506863	0	0,88722591	0	9,00E-07	1,53E-06	7,64E-06	3,59E-06	7,88E-05	1,35E-05	0

MODEL 2 - OPEX+PV ; Network Lenght ≤ 230kV ; Network Lenght > 230kV ; Power Capacity ; Equipments ; Modules

DMUs	Lambdas			Weights					
TSOs	CEMIG-GT_2016	COPEL-GT_2014	CTEEP_2015	OPEX+PV	Network Lenght ≤ 230kV	Network Lenght > 230kV	Power Capacity	Equipments	Modules
CEEE-GT_2013	1	0	0	0,00000312	0,00001988	0,0000265	0,00000125	0,00021825	0,00021825
CEEE-GT_2014	1	0	0	0,00000376	0,000024	0,000032	0,00000151	0,00026351	0,00026351
CEEE-GT_2015	0,99821109	0	0,00178891	0,00000356	0,00002267	0,00003023	0,00000142	0,00050389	0,00024892
CEEE-GT_2016	0,97316637	0	0,02683363	0,00000449	0,00002859	0,00003812	0,00000179	0,00063555	0,00031396
CEMIG-GT_2013	0,95710394	0,04289606	0	0,00000508	0,00000396	0,0000198	0,00000203	0,00007616	0,00007616
CEMIG-GT_2014	0,99189034	0,00810966	0	0,00000539	0,00001557	0,00002076	0,00000216	0,00008089	0,00008089
CEMIG-GT_2015	0,99350283	0,00649717	0	0,00000576	0,00001664	0,00002218	0,0000023	0,00008641	0,00008641
CEMIG-GT_2016	1	0	0	0,00000667	0,00000334	0,00001669	0,00002495	0,00100122	0,00010012
CHESF_2013	2,61466451	0	0,25001422	0,00000094	0,00000151	0,00000756	0,00000038	0,00028791	0,00002879
CHESF_2014	2,71201119	0	0,22916811	0,00000101	0,00000163	0,00000814	0,0000004	0,00031006	0,00003101
CHESF_2015	2,67652771	0	0,27009123	0,00000087	0,00000139	0,00000696	0,00000035	0,00026517	0,00002652
CHESF_2016	2,43480229	0	0,3577982	0,00000089	0,00000143	0,00000713	0,00000035	0,00027178	0,00002718
COPEL-GT_2013	0,00034929	0,99965071	0	0,00000645	0,00000503	0,00002515	0,00000258	0,00009672	0,00009672
COPEL-GT_2014	0	1	0	0,00000785	0,00000393	1,964E-05	0,00000681	0,00011782	0,00011782
COPEL-GT_2015	0,0637728	0,9362272	0	0,00000712	0,00000356	0,00001781	0,00000617	0,00010684	0,00010684
COPEL-GT_2016	0,11751152	0,88248848	0	0,00000609	0,00000305	0,00001523	0,00000244	0,00015297	0,00015297
CTEEP_2013	0,02452354	0	0,97547646	0,00000236	0,00001506	0,00002007	0,00000094	0,0006203	0,00006203
CTEEP_2014	0,01252236	0	0,98747764	0,00000248	0,0000158	0,00002107	0,00000099	0,00035123	0,00017351
CTEEP_2015	0	0	1	0,00000247	0,00000462	0,00000616	0,00000099	0,00083492	0,00008349
CTEEP_2016	0,14182397	0	0,968139	0,00000214	0,0000037	0,00001815	0,00000085	0,00041585	0,00014946
ELETRONORTE_2013	1,24356645	0	0,22190693	0,0000016	0,00000129	0,00000645	0,00000638	0,00019889	0,00002394
ELETRONORTE_2014	1,2324676	0	0,24371923	0,00000167	0,00000135	0,00000676	0,00000669	0,00020843	0,00002509
ELETRONORTE_2015	1,36797696	0	0,22361759	0,00000161	0,0000013	0,00000652	0,00000645	0,00020097	0,00002419
ELETRONORTE_2016	1,28925517	0	0,27553611	0,00000119	0,00000096	0,00000479	0,00000474	0,00014773	0,00001778
ELETROSUL_2013	1	0	0	0,00000183	0,00001164	0,00001553	0,00000731	0,0000274	0,0000274
ELETROSUL_2014	1,00381679	0	0	0,00000231	0,0000147	0,0000196	0,00000922	0,00008856	0,00003458
ELETROSUL_2015	1,09541985	0	0	0,00000205	0,00001308	0,00001743	0,0000082	0,00007879	0,00003077
ELETROSUL_2016	1,1221374	0	0	0,00000208	0,00001326	0,00001767	0,00000832	0,00007987	0,00003119
FURNAS_2013	3,19083969	0	0	0,00000073	0,00000466	0,00000622	0,00000293	0,0000281	0,00001097
FURNAS_2014	3,20992366	0	0	0,00000086	0,0000055	0,00000733	0,00000345	0,00003314	0,00001294
FURNAS_2015	3,2480916	0	0	0,00000083	0,0000053	0,00000707	0,00000333	0,00003194	0,00001247
FURNAS_2016	3,26335878	0	0	0,00000089	0,00000568	0,00000757	0,00000356	0,00003421	0,00001336

MODEL 3 - OPEX+PV; Net Lenght ≤ 230kV; Net Lenght > 230kV; Power Capacity; Equipments; Modules

DMUs	Score	Lambdas			Weights					
TSOs		CEMIG-GT_2016	COPEL-GT_2014	CTEEP_2015	OPEX + PV	Net Lenght ≤ 230kV	Net Lenght > 230kV	Power Capacity	Equipments	Modules
CEEE-GT_2013	53,69	1	0	0	3,12E-06	1,99E-05	2,65E-05	1,25E-06	0,00021825	0,00021825
CEEE-GT_2014	66,4	1	0	0	3,76E-06	2,40E-05	3,20E-05	1,51E-06	0,00026351	0,00026351
CEEE-GT_2015	63,27	0,99821109	0	0,00178891	3,56E-06	2,27E-05	3,02E-05	1,42E-06	0,00050389	0,00024892
CTEEP_2016	83,35	0,97316637	0	0,02683363	4,49E-06	2,86E-05	3,81E-05	1,79E-06	0,00063555	0,00031396
CEMIG-GT_2013	74,8	0,95710394	0,04289606	0	5,08E-06	3,96E-06	1,98E-05	2,03E-06	7,62E-05	7,62E-05
CEMIG-GT_2014	79,78	0,99189034	0,00810966	0	5,39E-06	1,56E-05	2,08E-05	2,16E-06	8,09E-05	8,09E-05
CEMIG-GT_2015	85,77	0,99350283	0,00649717	0	5,76E-06	1,66E-05	2,22E-05	2,30E-06	8,64E-05	8,64E-05
CEMIG-GT_2016	100	1	0	0	6,67E-06	3,34E-06	1,67E-05	2,50E-05	0,00100122	0,00010012
CHESF_2013	45,69	2,61466451	0	0,25001422	9,40E-07	1,51E-06	7,56E-06	3,80E-07	0,00028791	2,88E-05
CHESF_2014	49,85	2,71201119	0	0,22916811	1,01E-06	1,63E-06	8,14E-06	4,00E-07	0,00031006	3,10E-05
CHESF_2015	43,65	2,67652771	0	0,27009123	8,70E-07	1,39E-06	6,96E-06	3,50E-07	0,00026517	2,65E-05
CHESF_2016	44,72	2,43480229	0	0,3577982	8,90E-07	1,43E-06	7,13E-06	3,50E-07	0,00027178	2,72E-05
COPEL-GT_2013	81,58	0,00034929	0,99965071	0	6,45E-06	5,03E-06	2,52E-05	2,58E-06	9,67E-05	9,67E-05
COPEL-GT_2014	100	0	1	0	7,85E-06	3,93E-06	1,96E-05	6,81E-06	0,00011782	0,00011782
COPEL-GT_2015	91,36	0,0637728	0,9362272	0	7,12E-06	3,56E-06	1,78E-05	6,17E-06	0,00010684	0,00010684
COPEL-GT_2016	78,81	0,11751152	0,88248848	0	6,09E-06	3,05E-06	1,52E-05	2,44E-06	0,00015297	0,00015297
CTEEP_2013	94,37	0,02452354	0	0,97547646	2,36E-06	1,51E-05	2,01E-05	9,40E-07	0,0006203	6,20E-05
CTEEP_2014	99,86	0,01252236	0	0,98747764	2,48E-06	1,58E-05	2,11E-05	9,90E-07	0,00035123	0,00017351
CTEEP_2015	100	0	0	1	2,47E-06	4,62E-06	6,16E-06	9,90E-07	0,00083492	8,35E-05
CTEEP_2016	90,52	0,14182397	0	0,968139	2,14E-06	3,70E-06	1,82E-05	8,50E-07	0,00041585	0,00014946
ELETRONORTE_2013	43,29	1,24356645	0	0,22190693	1,60E-06	1,29E-06	6,45E-06	6,38E-06	0,00019889	2,39E-05
ELETRONORTE_2014	46,51	1,2324676	0	0,24371923	1,67E-06	1,35E-06	6,76E-06	6,69E-06	0,00020843	2,51E-05
ELETRONORTE_2015	47	1,36797696	0	0,22361759	1,61E-06	1,30E-06	6,52E-06	6,45E-06	0,00020097	2,42E-05
ELETRONORTE_2016	39,63	1,28925517	0	0,27553611	1,19E-06	9,60E-07	4,79E-06	4,74E-06	0,00014773	1,78E-05
ELETROSUL_2013	38,78	1	0	0	1,83E-06	1,16E-05	1,55E-05	7,31E-06	2,74E-05	2,74E-05
ELETROSUL_2014	50,57	1,00381679	0	0	2,31E-06	1,47E-05	1,96E-05	9,22E-06	8,86E-05	3,46E-05
ELETROSUL_2015	46,84	1,09541985	0	0	2,05E-06	1,31E-05	1,74E-05	8,20E-06	7,88E-05	3,08E-05
ELETROSUL_2016	47,21	1,1221374	0	0	2,08E-06	1,33E-05	1,77E-05	8,32E-06	7,99E-05	3,12E-05
FURNAS_2013	52,52	3,19083969	0	0	7,30E-07	4,66E-06	6,22E-06	2,93E-06	2,81E-05	1,10E-05
FURNAS_2014	62,25	3,20992366	0	0	8,60E-07	5,50E-06	7,33E-06	3,45E-06	3,31E-05	1,29E-05
FURNAS_2015	60,44	3,2480916	0	0	8,30E-07	5,30E-06	7,07E-06	3,33E-06	3,19E-05	1,25E-05
FURNAS_2016	65,74	3,26335878	0	0	8,90E-07	5,68E-06	7,57E-06	3,56E-06	3,42E-05	1,34E-05